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Concepts and Applications for the Fourth Industrial Revolution

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ISBN 978-981-13-3740-6 ISBN 978-981-13-3741-3 (eBook)
https://doi.org/10.1007/978-981-13-3741-3

Library of Congress Control Number: 2018967947

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

In recent years, drones are approaching us as the realistic technology utilized in the ordinary life of the general public from the level of science fiction. As a photographer and remote sensing practitioner, I began to intensively occupy myself with drone by the revolutionary prospect of being able to take aerial photograph at any time or any place. Over time, a great deal of enthusiasm for this technology let me publish several technical articles about drones. I am currently working as an Editor-in-Chief of *Spatial Information Research* (Springer Nature) and share my interest about the drone by maintaining strong links with the international editorial boards, authors, and reviewer communities.

Emergence of CPS (Cyber-Physical System) such as a self-driving car naturally raises the question for learning goals fundamentally different from the Third Industrial Revolution era. I have taught CPS, known as a core technology of the Fourth Industrial Revolution, by utilizing drones as a learning tool in the university. This course is offered as a distant and online course for undergraduate students to introduce the larger picture of the Fourth Industrial Revolution. The CPS is associated with a wide range of technologies and disciplines from sensor-related disciplines to mechanical technology that manufactures actuators. Since most of the textbooks published on CPS focused on the technical aspects, there was a limitation to use them as teaching materials for liberal arts courses. Students can be a good driver, even if they do not know the detailed structure of the vehicle hardware, such as the engine, the accelerator, and the cooling system. Students can efficiently utilize computers for applications such as word processing, graphics, presentation materials, and Internet search without knowing the detailed technical aspects of hardware such as CPU, memory, and graphics card. The same principle can be applied to learning the CPS.

I have been liable for the fact that the core concept of the CPS cannot widely spread to the general public because there is no reference book to explain the CPS with a focus on the application side. In this sense, I would like to publish my lecture notes as a book. The book is structured in such a way that the reader can progress from simple facts to more complex concepts. The basic theory of CPS and drone in Chaps. 1 and 2 was introduced and supplemented by other important features such as smartphone drone. The book introduces the “cyber system” as a separate chapter to explore their technological significance as a representative product of the Third Industrial Revolution (Information Era). Chapter 3 is intended to serve as an aid in understanding the cyber system performing interconnections with the physical system that goes specifically into the ground remote controller, communication theory, receivers, battery, etc. To understand new and fascinating potentials of CPS requires an appreciation of the way how these systems function. Chapter 4 attempts to overview the core components of physical systems in relation to spatial information science such as mapping theory, remote sensing, and location information. The future of the self-driving car depends on high-definition 3D real-time map. Spatial information is the core technology for operating CPS since all data around a self-driving car is spatial information. The physical system is equipped with location sensors and imaging sensors as two distinct attributes. If students are familiar with the fundamental technical background of the physical system, learning and using imaging and navigation capability of drone becomes possible. The artificial intelligence needs to be moved around in various places to replace the natural intelligence. Location information for various places must be provided beforehand so that destinations can be set for the movement of artificial intelligence. It is known that about 90% of the information utilized by natural intelligence is based on the location. Further, it is said that the imagery data obtained by human eye accounts for 90% of total information acquired from various human sensory organs such as ear, nose and tongue. As the animals evolve from lower level (e.g. insects) to higher grade (e.g human), the utilization of visual data becomes higher. Likewise, as the substitution of natural intelligence by artificial intelligence advances, the dependence on imagery data increases. As a result, location and imagery information are the most important parts of the information utilized by artificial intelligence. Therefore, Chaps. 5 and 6 are devoted to introducing location sensors and imaging sensors. Chapter 5 introduces location sensors to provide a background for navigation technology, progressing from manual navigation to indoor localization. Chapter 6 describes a foundation theory on imaging sensors and selection criteria of the remote sensor such as spatial resolution. This chapter emphasizes low-height drone photography (LHDP), based on lightweight and inexpensive smaller sensors. Chapter 7 introduces a practical valuation of bidirectional bridging intensity from currently available drone CPS. From the very beginning, the cyber-physical infrastructure of the current road has not been built for the self-driving car. The cyber-physical infrastructure of the road is not connected, and the cars, street signs, and traffic lights do not communicate with each other. In this regard, I emphasize that the drone taxi will be more economical than the self-driving car in the future.

Finally, a future prospect of drone CPS is presented in Chap. 8. The main conclusion of this book is that drone is a game-changer toward anywhere CPS economy that can be called the Fourth Industrial Revolution in the sky. There are a number of products that people have consumed a lot of money based on traditional life value standards. However, there is a high possibility that these products will be undervalued based on totally different value standards. The hierarchy of human needs defined by Abraham Maslow will be rapidly changed from the lower needs (e.g. food, social security and working) to the higher needs (e.g. enjoying leisure). More exactly, human driving cars were deemed necessary in the non-CPS era before the fourth industrial societies. The current human driving cars can become very cheap or even disappear when unmanned flying cars are released. As the artificial intelligence (AI) society progresses, it will be evident that the drones are emerging as a necessity. Increasingly, people will prioritize the purchase of the products they need to enjoy reduced working hours and expanded leisure time as the society of the Fourth Industrial Revolution advances. There is a high probability that products that people do not consider currently as a necessity are emerging as a new necessity. Considering the primitive instincts of humans wanting to fly in the sky, drone is a representative product having these characteristics. It is very likely that the self-flying car will become a new necessity as a flying companion like the current smartphone. Furthermore, it is anticipated that recent advances in AI technology will open up a new potential for practical swarm flight as distributed/collaborative physical systems beyond the current stand-alone application based on single drone.

Last but not least, I wish to deliver my thanks to my family. My special note is to my wife who as the source of inspiration was always by my side during my entire life, sharing the sadness and injecting the spirit for the accomplishment of the work, and who has never stopped her prayer for the success. I must also thank my two daughters for their endurance of my negligence through many years. I particularly would like to thank my graduate students, Mr. Youngseok Hwang, Mr. Jung-Joo Lee, and Mr. Seong-Il Park, who readily offered the unreserved help and valuable suggestion during my long writing work. I consider myself fortunate to have been able to work with them in my research lab, Spatial Information Research Institute of Kyungpook National University of South Korea. Finally, I would like to appreciate my God, Jesus Christ, who made my spiritual mind fresh during the whole period of this work.

Daegu, Korea (Republic of) Jung-Sup Um
October 2018

Contents

Chapter 1
Introduction to the Fourth Industrial Revolution

Abstract Due to the relative newness of CPS concept, there are many weaknesses perceived in previous CPS books. For the moment, in terms of cost, the drone CPS is the only available system offering the advantage of 3D autonomous dynamic flying in the nearby classroom condition. Drone could become the primary ways for our young people to experience cyber-physical world. It helps illustrate for students to find a combined cyber and physical components in the single drone. Much CPS theory can be explained by typical drone flying procedures in which communication between sensors, actuators and controllers occurs through a shared communication network. Once basics for CPS with drone are delivered to the class, class can be extended to share a variety of examples with students so that they can explore the range of possibilities. The aim of this book is to help for teachers' communities find a combined cyber and physical components in the single drone.

1.1 Introduction

As the paradigm shifts from the information society to the super intelligent society, the relationship between the real world and the virtual world has completely changed. As social infrastructure such as car, road, building and factory etc., which is the foundation of society, is interconnected and intelligent, the phenomenon breaking up the boundary between cyber world and real world is observed in various fields (smart home, smart building, smart farm, smart factory, smart grid, smart transportation, etc.). It is expected that new value added services are being created through cyber-physical bridging. The society as a whole will be transformed into a system capable of collaborating with AI (artificial intelligence). Roads will also be rebuilt to provide a structure suitable for artificial intelligence. The building structure will be changed so that artificial intelligence can be introduced into various operations (e.g. energy saving, vital sign[1] checkup for residents, indoor air

[1] Vital signs (often shortened to just vitals) are a group of the 4–6 most important signs that indicate the status of the body's vital (life-sustaining) functions: body temperature, pulse rate, respiration rate (rate of breathing).

J.-S. Um, *Drones as Cyber-Physical Systems*,
https://doi.org/10.1007/978-981-13-3741-3_1

condition monitoring). Of course, the factory will also be changed to optimize the production process using artificial intelligence.

As a result, the CPS (Cyber-Physical Systems) society is expected to introduce completely new and innovative applications and service providers, and bring a new paradigm shift in business and market models through new data value chains [1]. These new widespread developments of CPS such as self-driving cars[2] naturally raise the question of whether the focus of learning goals for the new pedagogies are fundamentally different from the learning goals of the third industrial revolution era. In terms of cost, the drone is the only available system offering the advantage of autonomous 3D dynamic cyber-physical bridging in the nearby ground target. In particular, drones are fairly easy to handle, comparatively inexpensive and the system satisfies most of the sensing requirements for the typical CPS concept [2]. Giving drone example to conceptualize CPS will help students picture their work along that one narrow line. Drone would be great for helping students achieve a certain level of competence for CPS by using relevant examples from the easily accessible equipment instead of struggling with a various CPS task and understanding a great, theoretical piece of work, and focusing various partial components of CPS.

1.2 Concepts of the Fourth Industrial Revolution

The use of the word "revolution" in combination with "industry" has now become a part of our cultural heritage. Our industrial achievements are so monumental and numerous that their impact can hardly be overestimated. We are living every day using various appliances and instruments produced in the course of the Industrial Revolution such as the washing machine and vacuum cleaner, the trains and cars to transport us wherever we wish [3]. The term 'industrial revolution' refers to the change of the technological economic and social systems in industry [4].

World Economic Forum (WEF) conference in January 2016 has made it clear to the global business leaders, heads of state, public intellectuals, and NGO's on the dawn of the new industrial revolution[3] [5]. So to speak, 2016 was the year of publicizing the start of industry 4.0 to replace industry 3.0 that emerged about four decades ago [6]. Further, 2016 was the year to retire the term "information revolution". The fourth industrial revolution (also referred as industrial revolution 4.0 or, in Germany in particular, Industry 4.0) is currently the subject of debate in the economic literature as academics are trying to make reasonable projections for the future [7].

[2] An autonomous car is expressed in various terms, but California, the U.S. officially used the term "self-driving car" in the law. So, this book uses the term a self-driving car. An autonomous car (also known as a driverless car, auto, self-driving car, robotic car) is a vehicle that is capable of sensing its environment and navigating without human input.

[3] Schwab, K. 2016. The Fourth Industrial Revolution. Geneva: World Economic Forum.

Many scholars have been offering their own thoughts, interpretations and prescriptions of what exactly the world should expect and react. Some argues that the fourth industrial revolution and future innovations in general do not imply such a growth potential what we have experienced in the past, for example computer [8]. On the contrary, other theorists claim that innovation and growth by technology such as artificial intelligence will be ever stronger than the past industrial revolution, and it is reasonable to call it a new industrial revolution [9]. The definition of the fourth industrial revolution is still chaotic in many ways. Nonetheless, self-driving cars are starting to run on the road, and various household appliances equipped with artificial intelligence such as refrigerator, TV and smartphone are rapidly increasing. As artificial intelligence exceeds people (such as game competition between human versus artificial intelligence), the signs of change are realized.

It is not easy to understand what the Fourth industrial revolution means clearly because it is just the beginning stage. In this regard, it is also more difficult to develop a specific response strategy. There is a lack of textbooks introducing real-world device or technology accessible easily that can provide an evidence in understanding the fourth industrial revolution. In the middle of the eighteenth century, the first movement in terms of industry started in England. Following the USA and European countries like Germany, the society began to change agricultural society into an industrial one [4]. Engine and electricity were the prototypical technologies of the first and second industrial revolution (Table 1.1).

The expedition of discovering science and technology for better life quality had always been an intellectual passion of man. The First Industrial Revolution that began in 1784 has improved life quality of mankind greatly through the introduction of the steam engines and mechanized production processes [10]. The Industrial Revolution caused the situation of replacing manual workers with machinery. Before the First Industrial Revolution, people had to work with farm animals as well as with man power. This advancement transformed most of work from agricultural lands into factories. Therefore, bigger factories and many manufacturing enterprises were built particular in the industry of knitting [4].

Close to a century later, electric power and mass-production processes were introduced and this period was then known as the Second Industrial Revolution. Suddenly, consumer goods that were previously accessible by the wealthy or an elite minority could be produced inexpensively enough to make them affordable to the general public. The Third Industrial Revolution has made progress in automating production through information technology. The fourth industrial revolution is a process of transforming production system by integrating the cyber world repre-

Table 1.1 Summary of industrial revolution from first to fourth

First	Second	Third	Fourth
Steam power, water power	Electricity	Computer and automation	CPS: blurring the physical and digital divide such as AI
	Mass production		

Table 1.2 Comparison of third versus fourth industrial revolution

	Third	Fourth
Trend of society	Information society	AI society: smart factory, smart city, smart grid
Means of production	Automatic, robot controlled production/mass products	Autonomic, decentralized production/ individualized product
Core product	Computer, internet	Drone, self-driving car
Core technology	Computer, internet	AI, IOT, big-data, AR/VR, and 3D printing
Communication	Web services (browsers): connected documents	Internet of Things & Services
	Web 1.0: connected companies	Linking the virtual (on-line) to the physical world (off-line)
	Web 2.0: connected people machine to machine	O2O (Online to Offline)

sented by the information technology and the real world which was the subject of the first and second industrial revolution. This fourth industrial revolution is linking the physical world (production process) to the cyber world (the internet and computer). The "Internet of Things" is a central element, providing a comprehensive synergy of the industry (physical, off-line) with the cyber services (on-line). The marriage between these two provides numerous new opportunities for production process, with profound implications for whole society and the economy.

Disruptive technologies are those which are unexpected but which have the power to change industries (not always for the good of the established players). Steam engines and electric power are good examples of the disruptive technologies in the first and second industrial revolution. Traditional businesses and services in the energy-based first and second industrial revolution (electric power) were disrupted by integration of digital and telecommunications technologies to re-create automated services in the third industrial revolution (Table 1.2). In the fourth industrial revolution, the global economy will face unprecedented changes with the advent of disruptive technologies such as artificial intelligence (AI), the internet of things (IoT[4]), big data, advanced robotics, augmented/virtual reality (AR/VR), and 3D printing. These new technologies are expected to bring fundamental changes in production, distribution and consumption, while transforming current modes of trade and investment among countries.

There are three reasons why today's transformations represent not merely a prolongation of the Third Industrial Revolution but rather the arrival of a Fourth and distinct one: velocity, scope, and systems impact. The speed of current breakthroughs has no historical precedent. When compared with previous industrial revolutions, the Fourth is evolving at an exponential rather than a linear pace [5]. Moreover, it is disrupting almost every industry in every country. Already, artificial

[4] IoT (Internet of Thing) basically means that all objects are connected to the Internet.

intelligence is all around us, from self-driving cars and drones to virtual assistants[5] and translation software [11]. AI implementation has advanced to new areas and is driving the overall efficiency improvement of the entire factory. For example, in the previous third industrial revolution era, machines and robots simply carried out the instructions as they were input into the machines. These machines and robots had no cognitive capabilities. They responded simply and precisely to the instructions given. Now, in the fourth industrial revolution, these machines are given "eyes" and the ability to communicate. This is the technical core of the fourth industrial revolution. Both machines and robots must have an equal level of cognitive intelligence and the ability to communicate with each other. Readers should be aware of this; it is the difference between the third and the fourth industrial revolution.

1.3 CPS Based Disruptive Technology (M2M → IoT → CPS)

Traditionally, systems, processes and people within the cyber world and the real world were totally isolated objects, and no inter-connectivity was considered. The Internet of Things has brought greater inter-dependence. That does not mean that Cyber-Physical System suddenly appeared 1 day. The Cyber-Physical System (CPS) is a term describing a broad range of multi-disciplinary, next generation engineered systems that integrate embedded computing technologies (cyber parts) into the physical world via sensors and actuators in a feedback loop [12]. CPS (Fig. 1.1) is a space where the real world and virtual space converge and where things are

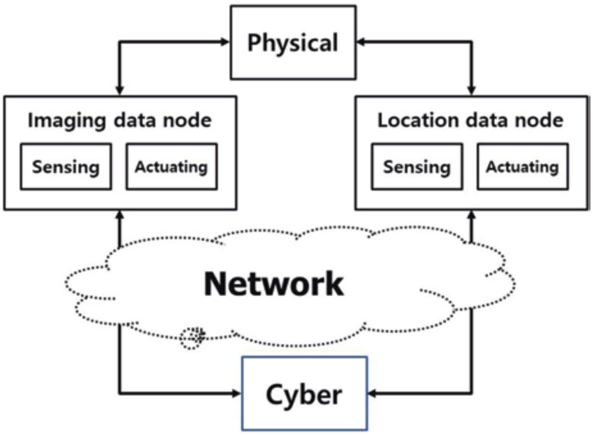

Fig. 1.1 Schematic representation of the CPS concept

[5]A virtual assistant is a software agent that can perform tasks or services for an individual. The capabilities and usage of virtual assistants are expanding rapidly, with new products entering the market and a strong emphasis on voice user interfaces such as Apple's Siri, Google Assistant, Amazon Alexa and Microsoft Cortana.

Table 1.3 Overview of cyber-physical system

Physical systems	+ cyber systems =	Cyber-physical systems
Eighteenth to nineteenth century	Late twentieth century	2020
Energy	Computer, NI (Natural Intelligence)	AI (Artificial Intelligence), Autonomization
Mechanization (1st), Electrification (2nd)	Automatization	Linking off-line and on-line
Off-line	On-line	Linking analogue and digital
Analogue things (atom)	Digital data (bit)	Linking analogue things (atom) and digital data (bit)
First Industrial Revolution: Mechanical production powered by water & steam engines	Third Industrial Revolution automated production by IT technology	Towards pervasive computing
Second Industrial Revolution: Mass production powered by electricity		Production and service process (including distribution and consumption) is connected.
Nineteenth to twentieth century, electricity & internal combustion	Late twentieth century, computer & internet, 100 years interval between first and third revolution	30 years interval between third and fourth revolution
Wired telephone[a]	Wireless internet	Internet of Things
		Linking the virtual to the physical world

[a]In 1866, a telegraph cable was successfully laid across the Atlantic. Communication became easier during the Industrial Revolution with such inventions as the telegraph

intelligently networked [13]. CPS also known as "smart" systems is interacting networks of physical and computational components. CPS provides the foundation of critical infrastructures such as electric power generation and delivery, personalized health care, emergency response, traffic flow management, etc. (Table 1.3). These systems form the basis of emerging and future smart services, and improve a quality of life in many existing areas as well as many other areas being envisioned.

Increasingly, CPS is everywhere in modern technology from smart buildings to automobiles. CPS containing artificial "brains" controlled by autonomous parts occurs in various aspects of our daily life that include unmanned aerial vehicles, smart grid, smart farm, smart transportation, medical monitoring and robotics systems. They are just a few examples of technologies that will have a major impact on how we will lead our lives. The machine-to-machine (M2M) technology used for the communication between devices (i.e., sensors) installed in facilities and factories progressively advanced into IoT (Internet of Thing). The IoT has technologically advanced into 'M2M → IoT → CPS' through an intelligent technology of the Internet. M2M means a connection between machine and machine (e.g. remote meter reading and bar code). IoT, which is an extended form of M2M, is represented by a smart healthcare device that monitors the health information of people through the connection between things and people [2].

New opportunities are becoming increasingly dependent on the further "Internetification" of the physical world: airplane engines, trains, buses, building, toothbrushes, lighting and solar panels etc. They assigned to an Internet connection with the digital world, and are also equipped with sensors to monitor dynamic situations and events of real life. The cluster associated with mobility technologies plays an important role in different levels, in particular in the infrastructures for intelligent cities [3]. These may occur in either simple or complex events and process chains. The leading paradigm is M2M: machine-to-machine communication, not only between machines in factories but also between all conceivable devices and systems [3]. Today, robots[6] are present in large numbers in industry. Thus industry without robots is now almost unimaginable. They do everything covered by the three Ds: dirty, dangerous and dull work. The robot continues to work without breaks, but it boasts perfect precision which is of major importance to the durability and quality of products: ranging from self-driving cars to drone. In this regard, robots are more capable than humans. The robots perform better than any tools that humans have invented in the past: from the car to the aircraft. This is where we observe a crucial difference from normal tools: production robots are a part of industrial automation. Mostly they can be found in cages or behind a fence on the workfloor. However, artificial intelligence (AI) robots will no longer be in a warehouse, but will adapt themselves to changing environments by self-learning, and will lead the production process by interacting with human colleagues [3].

In recent years, robots, which have traditionally been used for industrial purposes, have emerged as assistant device aiding the lives of ordinary people. In accordance with the vision of the Fourth Industrial Revolution, humans and intelligent machines will jointly perform production tasks in the future. Sensors and self-learning AI will be essential to this process. Introduction to AI unmanned vehicles on land (self-driving car) and in the air (drone) and under water demonstrates the typical performances of intelligent robots: mobility (legs, arms, neck, wrists), perception (sight, hearing, smell and touch), control via a digital central nervous system and a digital brain function. But there are also integrated AI drone under development outside the domain of industrial robots, which can operate collectively, in swarms. This justifies the future outlook that intelligent robots such as drone will soon become a genuine force in society and will cooperate with humans [3].

[6] The word robot has Czech origins: it was used in a science-fiction play in 1920, where it referred to human clones that were raised to work. In May 2014, Marieke Blom, chief economist of the ING Bank, stated that the term "robot" refers to every reduction of human labor, with all the corresponding digital technology and wireless networks [3].

1.4 Comparison among Physical vs Cyber vs CPS Space[7]

CPS forms a system of systems through a network connection by a number of sensors, actuators, and control devices. Through this CPS system, information about the real world is acquired and analyzed, and the processed results are applied to the physical world again through an actuator system. This paradigm differs from conventional simple control systems in that it is a bidirectional system that interacts closely with the real world. In the real world in which we live, there exist social infrastructure such as transportation systems, buildings, houses, electronics, electrical grids and the Internet, and robots in real space (Table 1.4). A system that encompasses such entities of the real world is called a physical system. The cyber world [14] refers collectively to a virtual computing space created by computers and internet that performs operation to control sensor nodes of physical system. The CPS performs the function of environmental monitoring through a variety of sensors that can detect changes occurring in the real world. The physical system recognizes, analyzes, and predicts the real world phenomenon based on the information obtained from sensors. The resulting control information is applied as the input of the real world system, which transforms the real world system to the desired direction, e.g. a self-driving car running toward the destination.

Various electronic appliances, household appliances, communication devices, automobiles, etc. used mainly in daily life are equipped with specialized computers. A special system built-in to serve as the brain of devices is called embedded systems (Table 1.5). Embedded systems such as smart phones, MP3 players, cameras, navi-

Table 1.4 Comparison among physical space vs cyber space vs CPS space

	Physical space	Cyber space	CPS space
Measurement units of fundamental component	Atoms	Bits	Atoms + bits
Spatial perception	Tangible space	Intangible space	Intellectually recognized space even without touching
Format of space	Reality	Virtual reality	Intellectually augmented reality
Fundamental component	Land + things	Computer + web	Real life + computer
Co-relationship between computer and space	Things embedded in space	Virtual things embedded in computer	Computer embedded in real things

[7] This chapter and Chap. 6 were revised from the paper initially published in Spatial Information Research (SpringerNature).

Um J-S (2017) Embracing cyber-physical system as cross-platform to enhance fusion-application value of spatial information. 25 (3):439–447.

Um J-S (2017) Valuing current drone CPS in terms of bi-directional bridging intensity: embracing the future of spatial information. 25 (4):585–591.

Table 1.5 Comparison of CPS versus embedded system

	CPS	Embedded
Component	Cyber system, physical system, network, sensor and actuator connected to real-life	Hardware, software belonging to cyber system, sensor and actuator connected to cyber space
Example products	Self-driving car	Air bag, hi-pass in expressway
Major application	Smart home, smart city, smart factory, smart grid	Application is restricted in the specific products
Connection to physical system	Yes, integrating with the physical world (offline resources) in real time	Do not consider connection to physical system. Consider single variable involved in the hardware.
Real-time processing	Yes, the physical system operates according to the real-time transition.	It operates according to the binary logic flow of single variable involved in the hardware.
Feedback among variables	Focused on dynamic causal relationship among variables characterized by interdependence, mutual interaction, information feedback, and circular causality	Do not consider causal relationship among variables
		Focused on static condition
		Narrow and uni-lateral approach for single hardware

gation systems, and fire detectors can be easily identified in our daily lives. These systems characterized by real-time processing, miniaturization and low-power consumption, operate independently to achieve specific goals without interaction with other systems. Electronic devices equipped with embedded systems can be seen as unidirectional and closed physical systems because they operate according to user requirements. These conventional embedded systems do not consider changes in the overall system when controlling the physical system according to the software operation.

In the case of CPS, the state of the system changes depending on the interactions with the environment, time, and humans. The embedded system performs only a simple linear task without comprehensively considering the consequences of these factors. It implements a simple unidirectional control from the cyber world to the physical world. With the progress of control and system theory, the embedded system began to evolve into a form in which the bidirectional bridging with humans could be activated. As a result, CPS has emerged as a new paradigm that encompasses physical entities in the real world, which is to extend the concept of embedded systems. In order to view cyber and physical systems comprehensively, it is necessary to understand the intrinsic differences between the two systems first. The physical system changes depending on time and space while existing embedded system operates depending on logic. As a self-driving car adjusts the driving route and speed according to time and traffic conditions by road, so the state of the CPS changes according to the fluctuation of time and space. On the other hand, in the case of the cyber system, the result of software operation changes according to the flow of logic, which requires mechanical calculation to operate the hardware involved. Since the operating principles of the two systems (CPS vs embedded system) are fundamentally different from each other, there is a need for synchronization medium for proper interaction between the two systems in the case of the cyber embedded system.

CPS has already begun to infiltrate our society and the visible change has begun to take place. In the U.S.,[8] seven key fields of application of CPS were proposed as follows: Smart Factory, Smart Traffic System, Smart Grid, Smart Healthcare System, Smart Home/Building System, Smart Defense System and Smart Disaster Response System [15]. For example, sensors attached to roads, buildings, and bridges provide basic information of 3D facility map. Thus, CPS is expected to dramatically improve efficiency and productivity in a variety of areas such as precision farming, building control, disaster response, energy, manufacturing and industry, and social infrastructure etc. It can be said that CPS platform is a platform on platform comprised of several small and tangible or intangible platforms. In particular, CPS technology is expected to provide a zero-defect intelligence system that can guarantee high reliability and safety to flexibly cope with unexpected crisis.

Just as the Internet has revolutionized interpersonal communication and interaction, CPS is expected to initiate radical changes and revolution in the interaction between the real life system and virtual worlds. For instance, drones as CPS create a new reality space with innovative applications and processes, since it dissolves the boundaries between real and virtual spaces. Many applications empowered by CPS are expected to generate added value in each sector of society and lead to the development of new business models in a cascading fashion. It is expected that future CPS will address key challenges facing in the social infrastructure such as smart city and will also play a crucial role in diverse industrial sectors such as automated production technology. In addition, CPS is expected to play a major role in reducing carbon dioxide emission through efficient system operation as well as improving business efficiency through reductions in cost, energy and time [1].

1.5 Digital Twin

The term digital twin can be described as a digital copy of any physical system equipped with sensors such as a real factory, building, city, machine, worker etc. It is an exact cyber copy of a physical system proposed as CPS architecture. It is one of the main concepts associated to the Industry 4.0 wave. A digital twin is an up-to-date mirroring or twinning of a physical object's properties and states, including

[8] The United States President's Council on Advisors on Science and Technology (PCAST 2007) report mentioned the importance of CPS and the urgency of its introduction to enhance the U.S. industrial competitiveness. The NITRD (Networking and Information Technology Research and Development Program) program stated that there is a need to set CPS as a top priority, and in 2009, it began supporting large-scale research through the National Science Foundation (NSF).

shape, position, gesture, status and motion etc. Every real product and production site is represented by a digital avatar and twin as digital counterpart of a physical individual product [16]. They can be independently expanded, automatically updated as well as being globally available in real time.

The concept of the Digital Twin (DT) dates back to the presentation at a Product Lifecycle Management (PLM) center of a University of Michigan (2002). It has recently been adopted in manufacturing contexts [17]. The DT was first born in NASA in their production and maintenance of spacecraft components. This technology made it possible for NASA engineers to check repairs for the Apollo 13 mission, helping to bring the crew back home safely. They define 'digital twin' as "an integrated, multiscale, probabilistic simulation of a vehicle or system to mirror the life of its corresponding flying twin, based on the best available physical models, sensor updates, fleet history, etc., [18]. In this industry, any changes on a space vehicle during a mission are frequently tested by simulating the built-in vehicle system. Such high-fidelity twin running in parallel with corresponding flying object immediately can identify a malfunction (or potential malfunction) arising in the real space vehicle. For example, an in-line digital twin allows an operator to train on a virtual machine as dedicated training simulator until they have the skills and confidence needed to operate the real machine. Using an in-line Digital Twin accelerates the learning process and minimizes the risk of damage to the machine [19].

Although this term more and more widely used in industry, it is difficult to find the theoretical definition in the scientific literature. Attempts to reproduce real-world spatial objects in cyber-system are not new. This was a central notion in the IT industry with the creation of computer-aided design representations of physical assets or profiles of individual customers [16]. Although virtually representing physical objects and processes is not new, digital twins are another evolution of the digitization of our living world. For decades, product, process and engineering have been improved by using 3D rendering of computer-aided design (CAD) models, asset models and process simulations to validate manufacturability and efficiency. The real world can be divided into a static environment and a dynamic environment. The existing 3D visualization statically represents the shape and size of the feature. The biggest difference is that digital twin is living and animated dynamic entities that physical objects and data in real life are connected in real time. A building or facility corresponding to a static environment can be visualized as a digital twin through 3D modeling. The dynamic environment is implemented in the virtual world associating the data collected from the sensors of the cyber-physical system.

Today digital twins are cloud-based virtual representations of physical assets. Thus, they have profited from the decreased cost of cloud computing and nanotechnology – particularly sensor technology. Increased 3D digital imagery of our living world has made it easier to feed digital twins with data from IOT sensors. Advanced big data analytics and AI had accelerated the latest iteration of digital twins and the interest today due to the ability to evaluate "what if" scenarios in real time. By connecting digital twins with physical assets using real-time data, physical products and processes are virtually reproduced into a digital environment. Further, AI deep-learning algorithms analyze these physical assets, thereby reducing downtime and maintenance costs.

Table 1.6 Comparison of classical 3D versus digital twin

	Classical 3D, DEM (Digital Elevation Model)	Digital twin
Motion	Static	Dynamic
Visualizing individual components	No, visualizing entire entities	Yes, visualizing sliced entities
1:1 scale to physical system	No	Yes
Utilizing real-time data	No	Yes
Real time update		
Machine readable mapping	No	Yes
Integrating hardware and software	Yes	Yes
Snapshot vs streaming	Snapshot	Streaming
Structured vs non-structured	Non-structured	Structured
Utilizing sensor	No	Yes
Utilizing IOT	No	Yes
Utilizing spatial information	Yes	Yes
Utilizing big data	Very low	Yes
Utilizing AI	Very low	Yes
Cloud, VR, AR	Very low	Yes
Utilizing 3d cubic data	Very low	Yes
Tangible data priority	Very low	Yes
Moving target application	Focused on static target such as house and mountain	Dynamically moving target such as drone, self-driving car and robot

It is well known that the traditional product design process takes professional knowledge and experience of the individual as the center (Table 1.6). Under the circumstance, the designers must carry out several tests to constantly verify the validity and usability of the proposed scheme at the designing stage. The traditional way of doing design depends on the experience of a specific expert. On the contrary, digital twin product design tends to increasingly set the customers as the center and enhance the participation of customers. Meanwhile, the digital twin design process becomes more and more virtualizing, networking, and visualizing since the modern big data-driven product design process and cloud manufacturing come into being [20].

For instance, human can have digital twins – avatars for their body that check health condition tracked by the smartphones or carried by their humans in the real world. The idea of digital twin is to be able to design shape, position, gesture, status and motion of the human organ. Human could be advised to observe the virtual version of their body systems when it comes to their classical medical checkup processes and practices. They can no longer diagnose symptoms and perform operation approach that has characterized many medical investigations. Instead, more digital

Table 1.7 Comparison of cyber-physical system versus digital twin

	Cyber-physical system	Digital twin (DT)
Relationship between cyber and physical system	Cyber-physical system fusion	Copy of physical system
Major application	Much wider than DT	System design
Integrating hardware and software	Yes	Yes
Utilizing sensor	Yes	Yes
Utilizing IOT	Yes	Yes
Utilizing real-time data	Yes	Yes
Utilizing spatial information	Yes	Yes
Utilizing big data	Yes	Yes
Utilizing AI	Yes	Yes
Utilizing cloud, virtual reality (VR), augmented reality (AR)	Yes	Yes
Utilizing 3d cubic data	Yes	Yes
Tangible data priority	Yes	Yes

twins – avatars approach that has exactly the same physical structure as the human patient, could identify the source of variance within the model. It provides indicators to the operator where the signal of health anomaly may lie, minimizing unnecessary medical operation, saving diagnostic costs.

Currently these avatars embody limited information about an individual, and this data is fragmented across multiple systems. At present, there is not a single entity that aggregates it all. But with the growing popularity and sophistication of digital assistants on your phone, in your car and in your home, personal or product avatars will likely become very important to various industrial sectors in the future. This proliferation of digital twins might not be as far in the future as one might imagine. As the digital-twin trend evolves, twins will communicate with one another to create digital factory or digital cities, digital person models of multiple linked digital twins. Understanding the links across these digital entities, tracking elements requiring interactions will be vital to support a secure Cyber physical systems [21].

Cyber physical systems and digital twin are the same context in which physical assets and cyberspace are linked to each other (Table 1.7). Virtualizing the real world in cyberspace is called the digital twin, while the system linking the real world and the virtual world is called the cyber physical system. In the cyber-physical system, the physical element (optimized by smart sensors and actuators) acts as the central object while cyber space plays a central role in digital twinning that easily access, monitor, and diagnose problems with digital modeling. People want a realistic experience in a virtual space, and enjoy the game or collect tangible life pattern information (such as vital sign: temperature, pulse, respiration) by fusing the real space and the virtual space. This human desire has created a digital twin by fusing with virtual and augmented reality technologies. The convergence of the real world and the virtual world will be accelerated by the rapid development of the IOT technology, virtual reality and augmented reality technology. The digital twin will let you deliver tangible content service satisfying the human's fundamental five senses in virtual space without visiting the real life space. Energy Zero Building will be designed in a digital twin space and simulated training will be provided to save people from a virtual drowning accident. Demand for digital twin will be increased rapidly because virtual reality can reduce trial and error in actual situation and minimize risk.

Data in digital twin informs how our infrastructure is built, managed and eventually decommissioned, and real-time data can inform how our infrastructure is operated on every second basis. Work records for digital twin are stored from the past to the present and these records can be used to predict the future outcomes. Together with other digital twins, entire systems can be modeled, creating an environment where industrial players can understand, at a more granular level, the complex interactions of machines, environments, and humans [22]. Data is now as much a critical component of our infrastructure as bricks and mortar. Data is part of infrastructure and needs maintenance in the same way that physical infrastructure needs maintenance. It must be updated, housed and made secure. Data must also be supported by physical infrastructure such as data centers, high speed broadband, and widespread high capacity mobile and broadband networks. Using AI and machine learning can help to extract maximum information from vast amounts of data about infrastructure assets and turn it into useful insights and predictions so that efficient and effective decisions can be made.

CPS technology herald tremendous social changes. Many countries are now manufacturing high-precision roadmaps [23–27] for self-driving cars. In the next few years, CPS unmanned vehicles such as autonomous mobile drones, self-driving car, unmanned tractors, unmanned fighter planes, unmanned submarines, and autonomous mobile robots are expected to be fully utilized. In this case, there should be not only a high-precision roadmap but a high-precision map of the entire country. Digital twin can perform a function of integrating and analyzing the big data of various resources obtained from CPS centered on a specific place. In the situation where all things are connected, spatial information such as high-precision map can emerge as a platform for increasing the added value of digital twin. For example, the position of a friend connected to me, the position of a terminal connected to a car sensor, and the position of a truck loaded with dangerous materials play a role in enabling the overall mechanism to work properly through continuous connections to all activities on CPS network.

1.6 Valuing Drones in Bi-directional Bridging

The cyber-physical system must be able to bridge the real world with the virtual world in feedback loop through the sensor network. The work process of the cyber-physical system is achieved by acquiring data about the real world, communicating it to the workers in the cyber world, and interacting with each other. The cyber to physical bridging is the sensing process, which involves using sensors to acquire spatial information[9] about physical phenomena [28]. Location in off-line physical world becomes an integral dimension of data, allowing information patterns and decisions to be viewed through the lens of place. To enable bi-directional bridging, communication network resources are required to tightly integrate the virtual reality and the physical world. Theoretically, a number of researchers and experts expressed the idea of combining the cyber and physical system [29]. In addition, several studies have analyzed the usefulness of combining the cyber and physical system [30].

The CPS hierarchy as spatial sensor-enabled devices could be broadly classified into three different categories according to sensed information to the physical world, depending on the extent of the ‘cyber-physical bridging. Once the ‘cyber-physical system has been classified as shown below, it could be a scientifically valid basis to explore intensity of cyber-physical bridging among them in a follow-on practical application. For instance, the quantitative evidence concerning the cyber/physical synergistic pattern for individual targets could be utilized as major tools to ensure intensity of the cyber/physical bridging that may be frequently encountered in real applications.

1. Very large, complex, and interconnected CPS: a smart electric power grid, smart farm and smart city
2. Intermediate CPS between small and closed CPS and very large, complex, and interconnected CPS: smart factory, smart hospital and smart building.
3. CPS focused on single, small and closed equipment: drone and self-driving car

CPS hierarchy as spatial sensor-enabled devices includes very large, complex, and interconnected CPS (LCIC), intermediate CPS, and drone observation (Table 1.8). Operating the CPS depends on how much detail of the spatial information can be collected as demanded by feedback loop decision. The LCIC data can provide an overall view of the major land categories involved in the study area such as smart city. The sensor network in LCIC can give us the general idea for geographic extent of the urban infrastructure such as road facility. Then we can collect more refined information showing safety operation in the intermediate CPS such as smart factory,

Table 1.8 Comparison of the drone vs area-wide CPS in terms of spatial distribution hierarchy

	Drone CPS	Area-wide CPS
Cost	Very cheap	Very expensive
Accessibility to the target	Everywhere	Restricted to specific application
Visibility of sensor	Visible in real-time basis	Not yet commonly available
Application examples	Various fields: e.g. photography, mapping, survey	Restricted to specific CPS such as smart city
Technology maturity	Transition state from prototyping to full-scale development	Still prototype

[9] Geographers often express their own perspective that 90% of all the data around us have location and spatial information.

and check intelligent equipment to a complex production process in order to improve efficiency and quality.

After that, analysts can study the problem in detail by drone observation. More detailed information for the problem should be obtained by near ground observation. So, multi-stage concept can fully be practiced in this CPS application. An effective integration LCIC and the drone CPS requires sensing of spatial information from the LCIC and the drone CPS and vice versa. Drones as sensor-enabled devices collect spatial data and monitor any physical world in real time while LCIC sensors and intelligent clouds of sensors communicate with each other through drone CPS as IOT. Thus, for a system to function as a LCIC cyber-physical system, drone CPS as its subsystems must be tightly integrated and coordinated. Multi-stage CPS hierarchy concept is particularly important as it enables consistent maintenance between LCIC and drone CPS.

Although CPS is a relatively new concept, the system components are well-known. Bi-directional bridging in CPS has been researched for the past few years, with a focus on area-wide targets (generally still yet for prototype application) [31–33]. Despite the advantages of typical CPS, severe cost, heavy hardware and operating conditions by the large number of networked sensors inhibited the utilization of CPS for area-wide target such as smart city. The operational transfer of the research output relies heavily on the initial understanding or assumption of client need, the sensor and ground target. Such a focus on area-wide CPS, using mainly prototype techniques created scientific research problems, without necessarily supporting the operational utilization of CPS. Much of the earlier research for bi-directional bridging in CPS was conducted to solve problems created by the use of prototype equipment, which industry may not have much interest for such research output. Such practices have resulted in the expenditure of time, labor and money on solving problems which were largely irrelevant in industry (and also, possibly, some research problems unsolvable with current technology). Much of the previous research has been written more or less for pure scientific concept itself and did not usually serve to assist industry's requirement for CPS in terms of cost, equipment and practicality.

Although off-the-shelf commercial drone have been used routinely as 'CPS products' by industry, much of the scientific paper has often been written without proper consideration of the practical implications of drone in relation to CPS. The evaluation for drone cyber/physical bridging intensity provides a good basis for general understanding concerning the potential of CPS (i.e. sensor requirements, the appropriate communication techniques and likely levels of technology development e.g. prototyping to full-scale development). Cyber-physical bridging involves investigations into the most appropriate use of sensors for spatial data capture and the use of these sensed spatial data for feedback control. This offers opportunities for adequate monitoring and feedback control of physical activities which is important for lifecycle management of the real life system [34].

1.7 Drones as a Tool to Ignite CPS Concept Learning

The most important factor that motivates teachers is the desire to ignite learning in others, to spark curiosity and creativity and to light up the potential of the human mind. When a new way of teaching tools is thought to spark learning, teachers naturally relocate towards these new pedagogies. It is essential to use evidential instrument to help students understand their own work more clearly in relation to learning goals. However so far, there has been little realistic and explicit picture to teach CPS technology as the new learning goals [35]. Much of the previous CPS books has been written more or less for pure scientific concept itself and did not usually serve to assist learner's requirement for CPS in terms of cost, example equipment and practicality. Although off-the-shelf drone have been used routinely as `CPS products' by many students, much of the textbook has often been written out without proper consideration of the practical implications of drone in relation to CPS. Depending on the extent of the 'teaching material', many books in the CPS discipline are broadly classified into three different categories according to approaches to assist students and related researchers.

1. Pure technical or theoretical book (e.g. communication network, sensor and actuator theory),
2. Intermediate book between pure theoretical book and application-based book, mostly focused on very large, complex, and interconnected CPS
3. Textbook focused on single CPS equipment example for small and closed CPS (e.g. drone, self-driving car)

Although the lines of demarcation among the three different type of book are not sharply defined, most of the CPS book published so far would belong to the first or second type of book. In the 'second type, typical theory for CPS is often introduced at the beginning and is followed by examples and presentation for the case applications. The books are not generally sharply focused on specific small and closed CPS product such as drone. The author felt that none of them really revealed valuable pedagogical tool for exploring the core concepts of the fourth Industrial Revolution that had led author to study the drone in the first place. On the other hand, this book is more or less directed to the third type of book. Drone was considered by the previous researches to hold considerable promise as CPS system. In the near future, drone as cyber-physical systems will rely less and less on human control and more and more on the intelligence embodied in the computational core. Self-driving cars, commercial intelligent drones and mobile robots share the same physical space as CPS, where deep learning routinely supports smarter decision-making by these systems. In particular, among them, drone CPS is fairly easy to handle, comparatively inexpensive and the system satisfies most of the learning requirements for typical CPS concept.

The idea of utilizing drone as CPS representative presents many challenges and advantages, especially in classroom condition where contact to real CPS equipment is a constraint and teaching for the real-life CPS system could be performed more efficiently and in less time. The users do not need access to the complex CPS systems such as smart city and smart building. In this regard, drone could be recognised as 'DIY CPS' or 'a modern do-it-yourself CPS testbed tool. There are numerous benefits for providing students with drone example to supplement CPS instruction. When the book shows students the single representative example of CPS, this narrows the students' learning loads for various CPS components such as sensors, actuators, big-data, deep learning, IOT etc. MEMS (Micro-Electro-Mechanical Systems)[10] mean a very tiny machine made using nanotechnology, particularly available in moving parts of drone since it requires very small and light equipment. It can inspire students to learn about particular CPS components for the first time by showing real MEMS parts of drone.

1.8 Conclusion

Stephen Hawking indicated that technology could weaken or empower human. We become stronger with the machine and weaker without it. We can move much faster in an automobile than by walking, but if we never drive car to get anywhere we would lose this ability [35]. The machine made man strong like this. Without machinery, countries around the world would not have been able to grow through trade as it is now. One of the single greatest areas of technological development in the near future will be in the area of drone technology. In this regard, drone deserves critical attention as a genre concerned about speculating crucial changes for the future.

Drones are widely spreading like toys from around our lives. In this regard, drones could be recognised as 'DIY CPS' or 'a modern do-it-yourself CPS testbed tool. The young people will be entering a world where they will need to create and demonstrate value in the cyber-physical world. Bi-directional bridging to the cyber-physical world enables and accelerates such value creation. In the near future, most 'cutting-edge' equipment will be based on an AI approach. With the advent of drone, the off-line system isolated from internet in the sky could become of only historical significance, since drone will permit the direct capture of the physical world from the sensor and real-time transmission of the area-wide spatial data to global network.

Because of this, drone can assist the teaching of fourth industrial revolution literacy and will be to make things simple for people who just want answers to problems and some fun with minimum trouble. The very act of carrying a drone as flying companion changes one's life in distinct ways [35]. The 'flying with your own

[10] MEMS (Micro-Electro-Mechanical Systems) is the technology of microscopic devices, particularly those with moving parts such as drone. MEMS can be defined as miniaturized mechanical and electro-mechanical elements (i.e., devices and structures) that are made using the techniques of microfabrication. The critical physical dimensions of MEMS devices can vary from well below one micron on the lower end of the dimensional spectrum, all the way to several millimeters.

drone' or flying companion movement in many schools and systems, would allow students to bring their own drone into schools and make them part of the learning experience.

Ultimately, the aim of this book is to help students creatively apply cutting-edge CPS concept to their own discipline problems. Current literature, techniques, theories, and methodologies will be reviewed and discussed. Commercial off-the-shelf drone is illustrated in the scope and coverage of the book that the student is currently facing and will be more readily accessible in the future. It is believed that drone as CPS will have great technical, economic and societal impacts in both the academic and industrial communities in the future. The drone CPS of tomorrow will far exceed those of today in terms of both performance and efficiency. The domain of drone CPS is opening up unprecedented opportunities for research and development in numerous disciplines [36]. This book is to evaluate how drone might realistically become operational in the context of the latest technology and of near-future technology development.

References

1. Kim S, Park S (2017) CPS (cyber physical system) based manufacturing system optimization. Procedia Comput Sci 122:518–524. https://doi.org/10.1016/j.procs.2017.11.401
2. Um J-S (2017) Valuing current drone CPS in terms of bi-directional bridging intensity: embracing the future of spatial information. Spat Inf Res 25(4):585–591. https://doi.org/10.1007/s41324-017-0126-2
3. Sogeti VINT (2014) The fourth industrial revolution: things to tighten the link between IT and OT. Sogeti VINT, Groningen
4. Dombrowski U, Wagner T (2014) Mental strain as field of action in the 4th industrial revolution. Procedia CIRP 17:100–105. https://doi.org/10.1016/j.procir.2014.01.077
5. Schwab K (2017) The fourth industrial revolution. Crown Business, Geneva
6. Ahmad IA (2016) Is it the dawn of industrial revolution 4.0 in Malaysia? myForesight. Malaysian Industry-Government Group for High Technology, Malaysia
7. Kuruczleki E, Pelle A, Laczi R, Fekete B (2016) The readiness of the European Union to embrace the fourth industrial revolution. Management (18544223) 11(4):327–347
8. Gordon RJ (2014) The demise of US economic growth: restatement, rebuttal, and reflections. National Bureau of Economic Research, Cambridge, MA
9. Brynjolfsson E, McAfee A (2014) The second machine age: work, progress, and prosperity in a time of brilliant technologies. WW Norton & Company, New York
10. Ishak H (2016) Industrial revolution 4.0 –tackling it by its horn. myForesight. Malaysian Industry-Government Group for High Technology, Malaysia
11. Schwaab K (2015) The fourth industrial revolution: what it means, how to respond. Foreign Aff 12:2015–2017
12. Ahmadi A, Cherifi C, Cheutet V, Ouzrout Y (2017) A review of CPS 5 components architecture for manufacturing based on standards. In: SKIMA, international conference on software, knowledge, intelligent management and applications, Colombo, Sri Lanka, Dec 6, 2017–Dec 8, 2017
13. Um J-S (2017) Embracing cyber-physical system as cross-platform to enhance fusion-application value of spatial information. Spat Inf Res 25(3):439–447. https://doi.org/10.1007/s41324-017-0112-8
14. Lee I, Sokolsky O (2010) Medical cyber physical systems. In: Design automation conference, 13–18 June 2010, pp 743–748

15. PCAST (2007) Leadership under challenge: information technology R&D in a competitive world. President's Council of Advisors on Science and Technology (PCAST), Washington, DC
16. Negri E, Fumagalli L, Macchi M (2017) A review of the roles of digital twin in CPS-based production systems. Procedia Manuf 11:939–948. https://doi.org/10.1016/j.promfg.2017.07.198
17. Grieves M, Vickers J (2017) Digital twin: mitigating unpredictable, undesirable emergent behavior in complex systems. In: Kahlen F-J, Flumerfelt S, Alves A (eds) Transdisciplinary perspectives on complex systems: new findings and approaches. Springer, Cham, pp 85–113. https://doi.org/10.1007/978-3-319-38756-7_4
18. Schleich B, Anwer N, Mathieu L, Wartzack S (2017) Shaping the digital twin for design and production engineering. CIRP Ann 66(1):141–144
19. Goossens P (2017) Industry 4.0 and the power of the digital twin. Maplesoft. Cybernet Systems Co
20. Tao F, Cheng J, Qi Q, Zhang M, Zhang H, Sui F (2018) Digital twin-driven product design, manufacturing and service with big data. Int J Adv Manuf Technol 94(9):3563–3576. https://doi.org/10.1007/s00170-017-0233-1
21. Cearley DW, Burke B, Searle S, Walker MJ, Claunch C (2017) The top 10 strategic technology trends for 2018. Gartner. http://brilliantdude.com/solves/content/GartnerTrends2018.pdf. Accessed 28 Sept 2018
22. Hauschild M (2017) Top 10 digital trends for power and utilities. The Manufacturer
23. Chen A, Ramanandan A, Farrell JA (2010) High-precision lane-level road map building for vehicle navigation. In: IEEE/ION position, location and navigation symposium, 4–6 May 2010, pp 1035–1042. https://doi.org/10.1109/PLANS.2010.5507331
24. Ahmed M, Karagiorgou S, Pfoser D, Wenk C (2015) A comparison and evaluation of map construction algorithms using vehicle tracking data. GeoInformatica 19(3):601–632. https://doi.org/10.1007/s10707-014-0222-6
25. Kim D, Chung T, Yi K (2015) Lane map building and localization for automated driving using 2D laser rangefinder. In: 2015 IEEE intelligent vehicles symposium (IV), June 28 2015–July 1 2015, pp 680–685. https://doi.org/10.1109/IVS.2015.7225763
26. Noh S, An K, Han W (2015) High-level data fusion based probabilistic situation assessment for highly automated driving. In: 2015 IEEE 18th international conference on intelligent transportation systems, 15–18 Sept. 2015, pp 1587–1594. https://doi.org/10.1109/ITSC.2015.259
27. Guo C, Meguro J, Kojima Y, Naito T (2015) A multimodal ADAS system for unmarked urban scenarios based on road context understanding. IEEE Trans Intell Transp Syst 16(4):1690–1704. https://doi.org/10.1109/TITS.2014.2368980
28. Akanmu A, Anumba C, Messner J (2014) Critical review of approaches to integrating virtual models and the physical construction. Int J Constr Manag 14(4):267–282. https://doi.org/10.1080/15623599.2014.972021
29. Pereira F, Gomes L (2016) Combining data-flows and petri nets for cyber-physical systems specification. Int Fed Inf Process Publ IFIP 2016(470):65–76
30. Wang L, Haghighi A (2016) Combined strength of holons, agents and function blocks in cyber-physical systems. J Manuf Syst 40:25–34
31. Carhart N, Rosenberg G (2016) A framework for characterising infrastructure interdependencies. Int J Complexity Appl Sci Technol 1(1):35–60. https://doi.org/10.1504/ijcast.2016.081294
32. Sun X, Ansari N, Wang R (2016) Optimizing resource utilization of a data center. IEEE Commun Surv Tutorials 18(4):2822–2846. https://doi.org/10.1109/COMST.2016.2558203
33. Huang J, Kirsch CM, Sengupta R (2015) Cloud computing in space. INFORMS J Comput 27(4):704–717. https://doi.org/10.1287/ijoc.2015.0652
34. Akanmu A, Anumba C, Messner J (2013) Scenarios for cyber-physical systems integration in construction. J Inf Technol Constr 18:240–260
35. Lombardo T (2005) Science and the technological vision of the future. Center for Future Consciousness, Glendale
36. Xia F, Kong X, Xu Z (2011) Cyber-physical control over wireless sensor and actuator networks with packet loss. In: Wireless networking based control. Springer, New York, pp 85–102

Chapter 2
Drone Flight Ready

Abstract Man wanted to fly all the time in the sky, an unknown world. Until Wright Brothers invented the plane, this dream was not realized. The human desire to fly in the sky is now popularized, and now everyone is looking at the world with a bird's eye because of the drones. The first advantage of the drones is that they can easily access to any place such as dangerous targets or inaccessible targets, because no people are aboard. Drones do not require expensive equipment to be installed for human safety. The drones have allowed us to experience new horizons that we have never seen before, and they are helping us to do things that are impossible or difficult. Just as smartphones have brought a "mobile revolution" throughout the industry, drone is expected to open a "new world" not only in the information technology (IT) industry but also in various industries. Drones have many uses and advantages, but there are also risk factors such as abuse of terrorism, safety accidents, hacking, and privacy invasion etc. Experts expect that the drones will soon become a necessity for people, such as cars, computers and smartphones. This chapter introduces the basic concepts to be learned in advance in order to fly such drone in the sky, such as drone regulation, drone purchase theory, drone classification, drone flight simulator, and practical flight.

2.1 Introduction

There are many names and acronyms for unmanned aircraft, most commonly referred to as "drones." Other commonly used names include: Remotely Piloted Aircraft System (RPAS), Unmanned Aerial Vehicle (UAV), Model Airplane and Model Aircraft. The key characteristic of a drone is that the aircraft portion of the system is unmanned, although all drones are piloted either by a person or computer. Since the Nikola Tesla who surprised audiences with a small unmanned boat, drone designers have spent much time and effort in advancing that the first crude flying device into the modern drone of today. Drones take a wide variety of forms, ranging from small indoor toys to large and sophisticated equipment such as commercial airliners. For the purposes of this book, we will use the term drone to refer to all

J.-S. Um, *Drones as Cyber-Physical Systems*,
https://doi.org/10.1007/978-981-13-3741-3_2

types of unmanned aircraft likely to be operated by people for hobbies and education. The most sophisticated drones, such as those used for international military operations, are not expected to be used by readers of this book.

2.2 Definition of Drone

The Meriam-Webb Dictionary describes drones as "an unmanned aircraft or ship guided by remote control or onboard computers". Drones are characterized by their remote and automatic nature. Drones are generally abbreviated as Unmanned Aerial Vehicle (UAV), emphasizing that there is no man on board and there is a remote pilot on the ground. It is unclear why the UAV was called a drone. The typical aircraft, such as airplanes, helicopters, balloons and gliders, requires a pilot or a crew controlling the aircraft in the sky. Unmanned aircraft does not need a human pilot to operate the aircraft in the sky. These drones are either fully automatic (i.e. controlled by computer onboard) or controlled remotely from the ground. There are various expressions of drones in English,[1] and the official names are not unified. Due to the wide variety of design and performance of unmanned aerial vehicles, legal definition is not easy. The drone covers the meanings of various types of aircraft such as UAV, RPA (Remotely Piloted Aircraft), RPV (Remotely Piloted Vehicle), UAS (Unmanned Aircraft Systems) which are divided according to each purpose.

Unmanned Aerial Vehicle, which is the original language of unmanned aircraft, literally means an aircraft flying without human control. Actually, since the external pilot operates and monitors the flight from outside the aircraft, there is an opinion that the correct English name should be Uninhabited Aerial Vehicle. Therefore, the definition of drone, which is used in a similar way, means that pilots do not fly directly on the aircraft. It is operated by remote control from the ground (such as autonomous or semiautomatic flight according to preprogrammed routes, or equipped with artificial intelligence). Unmanned aircraft is also referred to as the Remotely Piloted Aircraft (RPA).[2] This means that the RPA is always under control

[1] US FAA (United States Federal Aviation Administration) definition: An unmanned aircraft system (UAS), sometimes called a drone, is an aircraft without a human pilot onboard – instead, the UAS is controlled from an operator on the ground [1].

UK CAA (Civil Aviation Authority): Popularly known as drones, but also referred to as remotely piloted aircraft systems (RPAS) or unmanned aerial vehicles (UAV), drones come in a variety of shapes and sizes, ranging from small handheld types up to large aircraft, potentially a similar size to airliners [2].

[2] The Global Air Traffic Management Operational Concept (Doc 9854) states "An unmanned aerial vehicle is a pilotless aircraft, in the sense of Article 8 of the Convention on International Civil Aviation, which is flown without a pilot-in-command on-board and is either remotely and fully controlled from another place (ground, another aircraft, space) or programmed and fully autonomous." This understanding of UAVs was endorsed by the 35th Session of the ICAO (International Civil Aviation Organization) Assembly [3].

of a pilot on the ground. A Remotely Unmanned Aircraft (RUA) relatively embrace a broad choice of devices since it includes aircraft flying without man's control e.g. meteorological balloons. Piloted Aircraft means relatively narrower concepts than unmanned aircraft since it could indicate complicated devices piloted from remote locations by licensed or trained aviation professionals. Unmanned Aerial vehicles (UAVs) cannot perform their duties on their own, and are operated by ground control equipment, communication equipment, etc. In this regard, it refers to the entire system of aircraft supporting its own mission. Therefore, they are collectively referred to as the Unmanned Aircraft System (UAS)[3] "flown by a pilot via a ground control system, or autonomously through an on-board computer, communication links and any additional equipment."

Ballistic or semi-ballistic vehicles, cruise missiles, and artillery projectiles are not considered drone. Unlike missiles that are destroyed like targets once they are launched, basically drone should be recovered [4]. At this time, it is necessary to be able to recover the airplane after flight,[4] so that it can be repeatedly put into the mission. The biggest difference between the manned and the unmanned flight is that the visual flight rule (VFR). Visual flight is a way to fly to the destination in which a pilot visually refers to terrain features and maps. VFR established as a common method for manned aircraft operations cannot be applied to drone since the pilot does not board. The instrument used here is GPS (Global Positioning System), INS (Inertial Navigation System), a speedometer, an altimeter, a compass (compass), vision sensor and multispectral sensor etc. It is possible to fly its predefined flight setting (e.g altitude, speed and direction) or automatic flight path point if the manned aircraft is equipped with the Flight Management System (FMS) or the autopilot. However, in the case of unmanned aircraft, it is essential that camera, video and flight information transmitting devices are provided for the pilots' remote control capability. It is difficult for remote pilots to steer the unmanned airplane safely due to communication delays or interruptions as well as constraints of situation recognition. In this regard, automatic control devices are essential to perform basic stabilization and autonomous flight.

The biggest issue is the distinction between unmanned aerial vehicles and model aircraft. Due to the advancement of technology, the performance of the radio control model aircraft has increased and the boundary with the unmanned aerial vehicle has become blurred. There is a misunderstanding in distinguishing an unmanned aircraft from a radio-controlled model aircraft simply by weight and size. Generally, radio controlled model aircraft is based on passive navigation, visual line of sight flight,

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[3] The term unmanned aircraft system (UAS) was adopted by the United States Department of Defense (DoD) and the United States Federal Aviation Administration in 2005 according to their Unmanned Aircraft System Roadmap 2005–2030 [5]. The International Civil Aviation Organization (ICAO) and the British Civil Aviation Authority adopted this term, also used in the European Union's Single-European-Sky (SES) Air-Traffic-Management (A™) Research (SESAR Joint Undertaking) roadmap for 2020 [6].

[4] U.S. Department of Defense (DoD) UAV Roadmap 2002–2027 states that UAV does not carry a human operator, can be recoverable, be piloted remotely, uses aerodynamic forces to provide vehicle lift and can fly autonomously [4].

recreational flight, or non-autonomous flight. Schwab [5] defines the drones as "flying robots". It is not the unmanned aerial vehicle which is controlled simply by remote control but the aircraft which can perform the specific mission by itself. The cluster drones systems being tested by Intel composed of more than 100 drones performs various tasks in the air [6]. Instead of controlling each drone as a controller, it is a cyber-physical system that acquires big data in the physical space and performs its mission in cyberspace. The current professional drones that are on their way to fulfilling their duties look more like "flying robots" than radio controlled vehicles.

Drones do not have pilots but can have passengers. Even if the person rides inside the drone, it belongs to the drone unless passengers are a pilot. The terms, unmanned vehicles need to be interpreted as similar concepts as the self-driving car that transports passengers without drivers. From this point of view, autonomous flight taxis are also drones. The drones are used as the concept of autonomous flying robots [5] by differentiating them from single-purpose mobile devices in limited spaces such as industrial robots and robot cleaners. UAV is an aircraft capable of flight beyond the visual line of sight under remote or autonomous control. A UAV is operated beyond the visual line of sight for sport or hobby and does transport passengers or crew [7]. According to this definition, hobbyist model aircraft operated within the visual line of sight is not included in unmanned aircraft, and unmanned transport aircraft carrying human beings are included in unmanned aircraft.

2.3 History of Drone

As the proverb says, 'war accelerates human development', the drones have initially been developed for military purposes as a real weapon to attack enemies in early 1900s, and the technology has spread to the private sector. Although the drones have expanded to civilian realm very recently, the history of the drones is older than we thought. Humans had a concept of unmanned aerial target hitting long before the Wright brothers succeeded to fly in 1903. It was rather a concept of missile to bomb and strike a target which does not require people to ride. The fundamental idea was that the aircraft carrying the weapon is flying remotely and hitting the enemy [8]. In the early 1900s, a Croatian Electrician and scientist, Nikola Tesla, proposed the idea of combining a radar (RAdio Detection And Ranging) with wireless communication to develop a remote-controlled unmanned airplane that could reduce the life-threat of a pilot. Tesla, more famous for his autographed car, was a genius scientist who founded the basic theory of unmanned aerials in the early 1900s. Following this idea, in 1918, at the end of the first world war, US Government developed the first drones, the Kettering Bug (pilotless aircraft). "Kettering Bug" is a kind of air torpedoes that fall on a target after flying a given time (about 80 km). But the accuracy rate was so low, it couldn't be put into real battlefield operation. Nevertheless, the unmanned airplane continued to develop.

Unmanned aerial vehicles were developed with the rapid development of aviation power through the First and Second World War. There was a great development in the military UAV, and the United States and Israel centered on a variety of targets such as surveillance and reconnaissance. Unmanned aerial vehicles, used as anti-aircraft gun training targets or flying bombs during the First World War, were widely developed from the end of the 1980s for the purpose of reconnaissance and bombing guidance due to the advancement of sensors and flight control computer. US Global Hawk (RQ-4 Global Hawk) and Predator (MQ-1 Predator), contributed to victory of the coalition forces in the battlefields of Gulf War, Afghanistan and Iraq. Gulf War of the Middle East, which occurred in 1991, was the turning point that convinced the utility of the unmanned aircraft for military purposes. The Gulf War was also a test site for a variety of state-of-the-art drones developed by the United States, because unmanned aircraft at the time were assured the outstanding possibility of being a weapon of war. It was in the second Gulf war that they really came into the reconnaissance and information gathering duties for enemy bases by sending live television pictures to their handlers [8].

Many military experts expect the unmanned system to rise to the core of future military power. In recent years, unmanned aerial vehicles have been developed in various countries around the world, recognizing the value and necessity of unmanned aerial vehicles. In particular, high performance unmanned aerial vehicles have been developed, especially in the United States and Israel, including stealth,[5] tactical surveillance, vertical landing/take-off, and supersonic.[6] Unmanned aerial vehicles (UAVs), which have been developed for military purposes, have been expanded to the private sector in recent years. The following Table 2.1 provides a more detailed description of the history of drones by year.

The miniaturized shooting drone, which we now commonly imagine, was first revealed at the International CES (Consumer Electronics Show) 2010 in Las Vegas. Parrot AR Drone was a remote controlled flying quad-copter built by the French company Parrot. The AR Drone was able to manipulate with a mobile phone using the iPhone app store, and was able to shoot it. However, at that time, drone shooting was considered as the idea playing with toys, because uneasy operation and due to shaking photographs. Since then, according to the rapid improvement of drones shooting technology such as a video transmission/reception device and a gimbal to compensate for the shake at the time of shooting, the era of shooting drone is currently emerging. In addition to this, as the software technology for drone driving has been advanced, the drones were blown to the desired position, and stable aerial photographing became possible. Professional shooting drones are expanding their use in a variety of fields, such as broadcasting, while having more loading capacity and increased battery power. Indeed, the evidence shows that the drone market for hobby and aerial photography is exploding [12].

[5] Stealth means movement that is quiet and careful in order not to be seen or heard, or secret action. Stealth aircraft are designed to avoid detection using a variety of technologies that reduce reflection/emission of radar, infrared [9] visible light, radio-frequency (RF) spectrum, and audio, collectively known as stealth technology [10].

[6] Vehicles that fly at supersonic speeds are flying faster than the speed of sound.

Table 2.1 Detailed description of the development history of drones by year

Year	Description
1898	At an exhibition at Madison Square Garden, New York, USA, inventor Nikola Tesla surprised audiences with a small unmanned boat that changes direction by his verbal command. He's actually using radio frequencies to switch motors on and off [11].
1915	The reconnaissance aircraft of British Army Air Corps collected more than 1500 pieces of photographs to detect the railroad situation of German camps. Since then, the military-purpose reconnaissance system using the unmanned airplane achieved a remarkable speed of technological progress.
1918	During the first world war, the US government developed the first unmanned airplane, "Kettering Bug" based on Tesla's theory. Kettering Bug was a kind of aerial torpedo falling toward a target after a pre-determined time (about 80 km). However, the success rate was low, so it was not put into the real battlefield.
1940	Actor and hobbyist Reginald Denny sold 15,000 radio-controlled target drones to the U.S. military to train anti-aircraft gunners during World War II [11].
1950	US defense company Ryan developed 'Ryan Firebee', a military surveillance UAV put into the Vietnam war.
1995	The MQ-1 Predator of the US Defense Industries was developed in 1995 and put into service several times, including the Libya air raids. In the decade following 9/11, Terror Attacks, Military UAVs are switched from reconnaissance to combat.
2010	The Parrot AR Drone, a smartphone-controlled quad-copter for consumers, was introduced at the Consumer Electronics Show in Las Vegas [11].
2016	There are several autonomous drone taxis (flying car) to go on general sale in the near future; Aeromobile 4.0, Terrafugia TF-X, EHang184 and Volocopter VC200 etc.

Currently, the drones are mainly used for photo/video recording and surveillance functions. The drones delivering goods are currently in the test phase. In the long term, they are expected to evolve into AI drones with their own data collection function. The main function of unmanned aircraft was to collect imagery information for ground surveillance focusing on reconnaissance at the beginning of development. Currently, various types of unmanned aerial vehicles have been developed to various missions. Thanks to advances of various scientific technologies, unmanned aerial vehicles are becoming more sophisticated for new purposes. It is also being developed to perform not only the function of the manned aircraft, but also the tasks impossible by manned aircraft efficiently. It is the fastest growing sector in the aerospace industry, and it is also a field where the future is more promising than today. In the not too distant future, it is anticipated that the commercial manned airliner or the manned aircraft for cargo transportation will be replaced by drones.

2.4 Advantages over Manned Aircraft

Unmanned Aerial Vehicle (UAV) has many advantages over manned aircraft (Table 2.2). Manned aircrafts have to load many devices for the safety of the pilot or the passenger on board. On the contrary, unmanned aircraft can carry out long-term mission by reducing such load and stabilizer. Especially, if solar heat is used as

Table 2.2 Comparison of unmanned versus manned movable body

category	Unmanned vehicle	Manned vehicle
Areas where the mission can be performed	Can be operated in any target difficult to access due to pilot's life threat	Hazardous areas are inaccessible
Time to stay in the air	Can be held for a long time from above the target area.	Usually limited to 8 h or less due to pilots' cumulative fatigue
Operational time bands	Day, night, anytime	Limitations exist due to the pilot (not 24 h)
Data collection capability	Various sensors can be installed at the same time (e.g. simultaneous acquisition of various data: location and imagery data)	The types of information collected are limited to one or two (It is difficult to install many kinds of information gathering equipment)
Data transmission capability	Real-time target tracking and information gathering with built-in information sending/receiving function	The ability to communicate in real time is relatively poor
CPS support	Direct contact with real-world objects in cyberspace	Relatively poor
Economic efficiency	Very cheap among information gathering methods	Several hundred times compared to unmanned movable body

energy, they can secure semi-permanent running time and reduce operating cost. The concept of using unmanned aircraft for 3D (Dangerous, Dirty, Dull) mission has been discussed for a long time.

The Dangerous Mission It is possible to acquire information about the unknown world that humans have not approached in the past. Unmanned aerial vehicles are suitable for carrying out dangerous missions because there is no fear of injuring the pilot and the passengers when the aircraft falls. Implementing risky missions was the reason developing drone for military reconnaissance missions and remote attacks in the early days. Civilian drones are also suitable for reconnaissance flights over dangerous areas causing a pilot loss. It is the best tool to carry out missions too far away from the operating point.

The Dirty For example, in 1986, a nuclear power plant accident occurred in Chernobyl, Soviet Union. Helicopter pilots who were on reconnaissance missions without any protective equipment were all killed due to radiation exposure beyond their lethal dose. On the other hand, there are cases where unmanned airplanes were carried out reconnaissance missions for nuclear reactors showing radioactive leaks by the 2011 earthquake in Japan and successfully acquired high-quality aerial photographs.

The Dull Humans cannot work over a certain period of time because of fatigue. However, the drone can work 24 h a day without feeling fatigue at all if fuel is supplied. Unmanned aircraft does not need to consider the pilot's fatigue, risk and survivability, etc. because they are not on board. It can carry out its mission continuously to the extent of the fuel range and aircraft hardware durability. The human neuromuscular system has delay time (1/800 sec) to sense objects and a delay time (1/5 sec) to actuate the actual muscles again. However, unmanned aircraft, unlike human cognitive systems, react much faster without feeling fatigue (sensing and actuating within a few milliseconds). Especially, in the case of UAVs that use renewable energy sources such as solar power, it can replace the low-orbit satellites (e.g. communication relay satellite) by allowing continuous flight for several days or longer.

The cost of training pilots is much cheaper than manned aircraft since there is no fear of pilot loss due to the aircraft crash. An astronomical amount of money is spent to train fighter pilots. If an accident causes a pilot to die, astronomical investment costs will disappear with loss of life. The manned aircraft has state-of-the-art safety equipment to protect the life of the pilot. Because it is heavy equipment, it contributes greatly to fuel consumption. The use of drones reduces the cost of installing safety equipment to protect pilots. Aircraft accidents are likely to damage not only the aircraft but also the pilots and passengers on board, and sometimes even the ground crew. Air accidents are most likely to cause a very strong negative impact for national credibility. It is possible to minimize the victims in case of accidents, by replacing various missions with unmanned aerial vehicles (e.g. relatively simple cargo transportation).

2.5 Types of Drone

There is no universally standardized method of classifying general-purpose drones. The classification of drone varies from one country to another. In the past, many of the methods classifying drone tend to follow the military standard since unmanned aircrafts started from the military. It was usual to classify drone according to altitude. These days, as the unmanned aerial vehicle technology has been developed, there are many ways to classify drones by considering the complex structure of drones such as drones' wings, maximum take-off weight (MTOW), flying distance, altitude, and flight time etc.

2.5.1 Fixed Wings and Rotary Wings

The drones are largely divided into fixed wings and rotary wings (helicopter) according to wing design (Table 2.3). A fixed wing refers to a drone with a wing fixed to its body, while a rotary wing refers to a drone with a wing rotating structure (Fig. 2.1). Fixed wing craft have the same basic design as manned airplanes like a miniature airplane generating lift from the flow of air over wings. The fixed-wing drones are capable of high-speed flight, high flight altitude and long-distance flight, but they require a runway at take-off and have a disadvantage of consuming a lot of fuel. Fixed wings have the advantage that it is possible to monitor and shoot in a

Table 2.3 Comparison of fixed wings versus rotary wings

	Fixed wings	Rotary wings
Fixed form of wing	A wing fixed to its body	Wing rotating like a helicopter
Vertical take-off/ landing	Require a runway at take-off	Yes
Hovering flight	No	Yes
Flight speed	Military drone can fly at 1000 km/h, while civilian 80 km/h	Slower than the fixed wing
Flight height	High flight altitude	Low flight altitude
Flight distance	Long-distance flight	Flight range is narrow
The stability of the vehicle	It is basically stable compared with the rotary wing, suitable for aerial photogrammetry surveying	As the wings continue to move, it is unstable and noisy shaking from side to side or up and down in flight,
Data collection scope	Can take pictures for a wide range of ground target	Capable of capturing a specific target intensively (multiple altitude, vertical, horizontal, oblique direction)
Examples	Military aircrafts that require fast mission from a long distance, such as from miniature drone called MAV (A micro aerial vehicle), to large aircraft with wingspan of tens of meters (GLOBAL HAWK, HELIOS[a])	Low-priced drones are mostly rotary wings; DJI and 3D robotics etc

[a]The Helios Prototype was the aircraft developed as part of an evolutionary series of solar- and fuel-cell-system-powered unmanned aerial vehicles. AeroVironment, Inc. developed the vehicles under NASA's Environmental Research Aircraft and Sensor Technology(ERAST) program. They were built to develop the technologies that would allow long-term, high-altitude aircraft to serve as atmospheric satellites, to perform atmospheric research tasks as well as serve as communications platforms [4, 13]

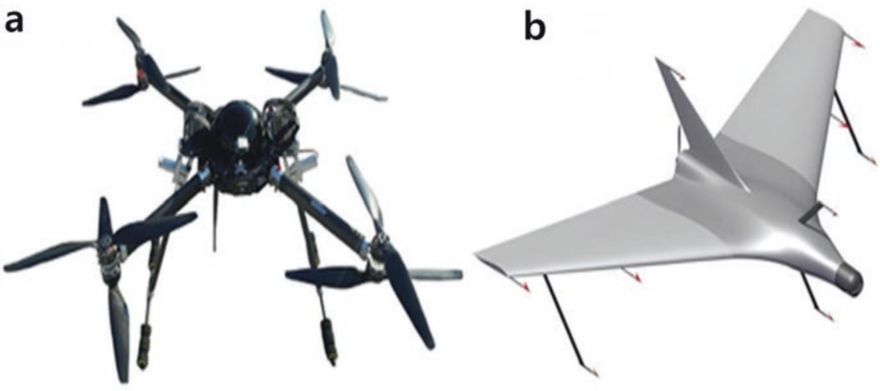


Fig. 2.1 Rotary wing and fixed wing, (**a**) rotary wing (**b**) fixed wing

wide area, but it is impossible to fly vertically and only horizontal flight is possible. When landing, the aircraft must land at a defined safe decelerating speed, so runway is required.

On the contrary, in the case of the rotary wing drones, since the wing is not fixed, there is an advantage that it is possible to fly vertically and hover without a separate takeoff and landing facility. They can generate lift by directing air downward using rotors, just like a helicopter. The rotary wing drone is now common, usually containing four, six, or even eight small rotors. It has the advantage of hovering flight and vertical takeoff and landing. The drawbacks of the rotary drones are that it is slower than the fixed wing, has a lower flying height, and has shorter flight time. Rotary drones are more disadvantageous than the fixed wing, shaking from side to side or up and down in flight, speed, and range, but they are the most suitable form of aircraft when vertical takeoff/landing and hovering are required. Since the rotary wing drone is basically unstable compared to the fixed wing drone, the speed and position of the drone body must be precisely measured by a high-priced and precise navigation sensor in order to automatically control the propeller.

There is a limit to utilizing rotary wings in the mission where maneuverability is important due to their inherent performance limitation (flying height/low speed). Hybrid drones have the advantages of speedy flight by fixed wing and vertical take-off/landing capability of rotary wings. The long distance flying in hybrid drones is operated by a fixed wing function. It has a separate propulsion motor for flight. Propellers used in rotorary wing drones operate only during takeoff and landing, and the rear large propeller is responsible for most of the flight.

2.5.2 Nano Drone

Unmanned aircrafts can be significantly reduced in size because there are no persons on board and flight method can be designed to be completely different from manned aircraft. Insect-similar miniaturized drones [14] can break the existing framework of drone flying the sky with a propeller. The robotic insect can crawl on the wall or even ride the ceiling. Insect-similar miniaturized drones utilize insect flight methods, which are very unique and have superior flight performance than any other human-made flight. Insects like dragonflies are able to fly forward and stay in a three-dimensional space, and exhibit excellent stability even in a sudden blast of air. This is a completely different way of flying than a human developed airplane. Unlike conventional airplanes, low-speed flight is possible, noise is low and it can be disguised as an insect. It is possible to apply to both civilian and military forces. If we attach a cleaning dust to insect-similar drones on the wall, it becomes a cleaning drone. It can be used for various purposes such as reconnaissance and life-saving in war and disaster. Nano drones are quite small and can fit in your palm, while mini drones are about the size of your hand. They may be little, but offer lots of fun indoors and out. The wireless-nano-drones are palm-sized, portable drones that can be used for 5–10 min at an altitude of about 30 m. It is possible to connect to a mobile device through a WiFi and share images in real time. Models such as Dragonfly, Hummingbird, Black hornet and Roachbot belong to the category of nano-drone. Nano-drones are expected to be actively used in security and surveillance field in the future.

2.5.3 Military vs Civilian

Drone can be classified as military or civilian depending on the operator. Drones used as war weapons belong to military drones (Table 2.4). Recently, drones used for hobby and photography can be treated as civilian drones. Although technology developed within the military environment, it often could be introduced into the civilian drone, but it has completely different characteristics with a wide range of uses. Military drones are divided into target drone, reconnaissance drone or surveillance drone, cargo, bomber, offensive, and transport and multi-role drone depending on the application. The drones have been used for disposable targets and unmanned bombs toward a timely exercise since the 1960s. The target drones include Ryan Firebee, which was produced in the 1950s while Global Hawk (RQ-4), was introduced in 1998 for surveillance of nuclear weapons activities. As reconnaissance

Table 2.4 Comparison of civilian versus military drone

Category	Civilian	Military
Price	From US$ 10	Tens of billions of US dollars
Industry characteristics	Similar to home electric device, departing from smartphone	Similar to manned aircraft industry
Weight	From 50 g	There are Nano drones, but usually more than 150 kg.
Flight speed/hours of operation	Flying speed is slow/several tens of minutes	Can fly at high speed (Mach)[a]/over 24 h
Flight height/distance	Low/narrow flight range	High and long distance flights are common.
Communication method	Wifi, Bluetooth, LTE	Satellite communication
Power source	Battery	Jet engine
Data collection capabilities	Similar to sensors mounted on smart phones	Equipped with advanced sensors for detecting enemies
Ability to transmit data at long distance	Long distance communication capability is relatively poor	Target tracking and gathering necessary information in real time from long distance
Flight control	Manual or pre-defined route flight	Intelligent automatic flight
Economic consideration	Economy is the most important variable.	The first priority is military purposes rather than economy.

[a]It is easy to assume the term Mach 1 is the speed of sound through Earth's atmosphere

and attackable drones, there are midrange Predator (MQ-1) and large-sized Reaper (MQ-9).

Military drones do not seriously care about the expenditure of budget and are developed with astronomical amounts of money to carry out the offensive missions in counter-terrorism. Military drones are equipped with state-of-the-art equipment such as remote detection device and satellite control device. It collects real time imagery for the place where it is hard to access or dangerous area. It is equipped with an attacking weapon and is used as a function of a fighter to attack an enemy instead of a ground army. In this way, the importance of military drone is increasing day by day. Thus US Air Force has given priority to training drone pilots in aviation manpower supply and demand program as the core of the air force.

The drones used as war weapons for a long period of time, have been recently introduced in real life, and the demand is increasing and the prices are going down. Then, the world finally comes up with the idea to utilize drone to improve the quality of human life. Recently a number of civilian drones have been released in the market, becoming a part of everyday life. The drones can now be cameras for broadcasting stations, and hang the camera to shoot peaceful scenes and entertain viewers [11]. The Table 2.4 provides a more detailed comparison between military versus civilian drones. In fact, many drones used by hobbyists today seamlessly incorporate a dazzling variety of technologies such as Wi-Fi communications, rechargeable batteries, small high-resolution digital cameras, GPS receiver chips, accelerometer chips, and other miniaturized electronics. Many off-the-shelf drones used by hobbyists are often equipped with better equipment than the UAVs used for military and intelligence missions, and provide imaging and sensing from a perspective not easily achievable by manned systems [15].

2.5.4 Various Classification Criteria

The flight altitude is closely related to the size of the drone (ie, the maximum takeoff weight, MTOW), and affects the flight distance and speed of cruise. In this regard, in the case of military drone, it is common to classify drones based on flight altitude. Recently, as the performance of commercial civilian drones has greatly improved, a variety of unmanned aerial vehicles such as solar drone have appeared. More sophisticated classification criteria have been suggested by reflecting the trend of such technological progress. The drones are classified into short range, medium range and long range depending on the flight radius, flight duration and flight altitude (Table 2.5). However, depending on the type and purpose of the drones, the time to stay in the sky varies from 10 min to 40 h. A battery-powered version, like a toy drone, has a flight time for about 10–30 min, but a military drone employing a jet engine has a longer endurance time up to 40 h. Because the solar-powered drones complete their mission over the years, endurance time in the future is expected to be semi-permanent.

Some drones are small enough to fit in the palm of your hand. Similarly, the weight of small drones can be less than 100 g whereas heavy drones can go up to

Table 2.5 Various classification criteria of drone

Flight altitude (m)	Low (5 m), medium (150 m), high, DJI Inspire 1: 4500 m
	Solar powered stratosphere drone
Maximum take-off weight, (MTOW, kg)	Nano, MAV (Micro Air Vehicle), DJI Inspire 1: 2935 g
Flight distance (km)	Short range, medium range and long range
Flight speed	With the DJI Inspire 1, the max speed is about 22 m/s[a]. The max ascent speed is 5 m/s and the max descent speed is 4 m/s [16]. Notice that this is significantly less than the total max speed of the Inspire flying horizontally.
	Subsonic: less than Mach 1, Transonic: up to Mach 1.3
Time to stay in the sky (hour)	Around 10 min to Semi-permanent depending on type, DJI Inspire 1: 18 min

[a]The most wind resistance the Inspire 1 can take, according to the specs, is about 10 m/s [16]

several hundreds of tons. In comparison to micro-drone such as toy grade drones, there are larger drones that are not often available in civilian application. These drones are called macho-drones, and are still in the developmental phase because of the regulatory requirements. Macho-drones are more likely to be configured as fixed-wing aircraft or conventional helicopters. They often have gasoline, diesel, or turbine engines and much larger payloads. They can perform essentially the same missions as manned airplanes and helicopters and extend them, because they are not constrained by the endurance of on-board crew members. They represent a scaled-down version of airplanes, helicopters, and military drones used in combat and for spy mission flight [17].

Drones use a variety of different types of power. The power source can be classified into battery type, solar type, and jet engine type. Battery type literally drives the drone by the battery power. The light-weight drone like toy drones adopts battery power a lot (e.g. Syma-X5C). The jet engine operates on the same principle as the engine of an automobile. The engine, the heart of a car, plays a vital role in generating moving power by utilizing energy such as gas and electricity. These engines offer high speed and great fuel efficiency over long distances. It is an engine that propels resulting power occurred when high-temperature, high-pressure gas is ejected at high speed. It is expensive, and it is mostly used for high-performance drones, like military drones (US Global Hawk).

2.6 Drone Industry Growth Background

The core technology components of the drones are sensors and wireless networks. Basically, the location sensor (GPS, acceleration sensor, gyro sensor, and magnetic sensor) is used for the flight, the camera as the imaging sensor is mounted. Wireless communication is used for the data link between the drone and the remote controller. The reason why the drones can be equipped with a small but smart sensor is due to the MEMS (Micro Electro Mechanical System) technology. MEMS refers to micrometer-sized systems manufactured by combining semiconductor and mechanical technologies to miniaturize various machines and electronic devices. The reason why the drones appeared in everyday life is due to the miniaturization of the sensors using MEMS technology and decreased price of the sensors. If the representative industrial technology of the twentieth century is a semiconductor, promising technology in the twenty-first century could be expected to be called MEMS.

The technology used for drones is not really new. MEMS technology has been used not only in factories but also in mechanical and electronic devices such as automobiles. It is usual to look at how thinner and lighter they are, and how much better the function is when new models of TVs, computers, smartphones, tablet PCs and many other electronic devices are released. This technology has moved to the drones (Table 2.6). MEMS technology let to lead to smart era forming our daily social network through smart phones. This technology made the era of drone as flying smartphone realistically possible. This is because the smartphone infrastructure has been completed as a central management system that can control things in everyday life. The smartphone is the machine where we can contact MEMS most frequently.

One of the biggest advantages of smartphones is equipped with the variety of sensors that operate and detect user behavior instantly. If you turn it horizontally, it will be horizontally. If you turn it vertically, it will be vertically. The same is true for games that move the smartphone from side to side to avoid obstacles or acquire items. Various sensors using MEMS are included in the smart phone. Among them, the location sensors (GPS, acceleration sensor, gyro sensor, magnetic sensor) are widely used because they can quickly detect the motion state of the smartphone which changes according to the operation of the smart phone. Drone at a laboratory-experiment level a few years ago are now becoming a necessity in broadcasting scenes. The reduced size and complexity of sensors improved reliability, automa-

Table 2.6 Comparison of drone vs smartphone in terms of sensors and network components

Drone	Sensor and network equipment	Smartphone
YES	Motors, Electric Speed Controllers (ESC), Propellers (actuator)	NO
YES	Flight control board, Flight controller (FC)	NO
YES	Body frame and wing frame	NO
YES	Transmitter (remote controller, wireless controller) and the receiver.	NO
YES	Cellular Network (communication)	YES
YES	WiFi/Bluetooth (communication)	YES
YES	GPS (location sensor)	YES
YES	Accelerometer (location)	YES
YES	Gyroscope (location)	YES
YES	Magnetometer/Compass (location)	YES
YES	Barometer (location)	YES
YES	Proximity sensor (location)	YES
YES	Camera (front and back, imaging sensor)	YES
YES	LiPo Battery (actuator)	YES

Fig. 2.2 A drone that can fly together with an iPhone or Android phone (Phone-drone)

tion and operator interface of the drone. Thus, the scope of drone operation such as disaster prevention/damage investigation, remote sensing, and weather observation has been expanded beyond imagination. Drone systems have now become an indispensable instrument of many field workers.

A drone attached to a smartphone equipped with various sensors is on the market. Phone Drone (Fig. 2.2) is a drone that can fly together with an iPhone or Android phone. It is a folding drone for smartphones introduced by an American company, xCraft. A GPS and a camera built into a smartphone is to be used as the brain and the eyes of drones by putting a smartphone such as an iPhone or Android into the main body. As you link your smartphone with WiFi, real-time operation is possible just like any other drones. You can also track other smartphones or set up autonomous flights by taking a GPS spot where you want to fly in advance. When fully charged, you can fly continuously for 20–25 min, and the maximum speed is 56 km. The wireless recognition range is the same as the Wi-Fi distance, and there is a function of returning to the take-off position automatically when the battery is almost exhausted.

2.7 Drone Abuse and Regulation

2.7.1 Drone Abuse Cases

As the drones spread to the public hobby and commercial purposes, they are becoming more and more common enough to worry about various moral and social problems. This is because there is no place where it is impossible for drone to access such as large scale sport events and concert halls where large crowds are gathering, large storage facility (gas or crude oil), and nuclear power plant, etc. The following Table 2.7 summarizes the abuse cases and dysfunctions of drone such as privacy

Table 2.7 Common and hot drone abuse cases

Drone nearly crashes into a passenger plane	In July 2014, a drone was approaching closely toward an Airbus A320 as it was taking off from London's Heathrow airport. The plane was at about 700 feet when the incident occurred. The UK Civil Aviation Authority (CAA) rated the incident as a "serious risk of collision," the top rating it can give.
Drone crashes near the White House.	On Monday, January 26, 2015, a drone landed on the White House lawn. The White House does have its own specific flight restrictions, but the drone wasn't easy to detect.
Invading privacy	A drone flew over the Studland nudist beach in Dorset, England.
	Privacy laws already penalize photographers who use high-powered lenses to invade private spaces. Flying this low over naked people is an intrusion into their privacy.
Terror	On April 25, 2005, A Japanese man flew a drone carrying radioactive sand into the rooftop of the Japanese prime minister's office.
Drone crashes into cultural heritages	On June 23, 2015, Korean tourists crashed a drone with a camera into the roof of Milan cathedral in Italy.

invasion, airliner collision, falling into public utility, threat of terrorism, destruction of cultural property and drug smuggling [18].

It is a shooting function of the drone that is often raised as a security and privacy problem. When a drone with a camera is shot in the air and ground targets around them are captured, it may cause security problems and threaten portrait rights. It may actually be a paparazzi tool to take pictures of. In fact, drone occurred over UK nudist beach made the concern real. The drones appeared in the air at Studland nude beach[7] in England. The drones are flying toward the other end of the beach, showing that they can abuse the flight and shooting functions by floating the drone in a space that cannot be photographed.

In addition to these illegal photographing problems, accidents caused by drones (e.g. inadequate control of pilots, drone crashes, and radio disturbances etc) can occur at any time and places. On January 26, 2015, a commercial small drone were taken down the White House building and crashed, and the Secret Service had an emergency investigation. Immediately after the fall of the drones, a warning was issued to the White House, and the buildings were sealed off. It is surprising that the White House, one of the most important buildings in the United States, was easily eroded by the drones. There are also a number of accidents involving civilian drones. Collisions with other aviation bodies can also be a big problem. There has been a surge in the dangerous approach of drones to airports. A civilian pilot who was landing at La Guardia airport in New York saw a black drone with wings about 4 m in length and reported to the FAA.[8] It happened at about 1600 m above Manhattan. In the Los Angeles International Airport at 2000 m altitude above sea level, there were

[7] This is by far the best nudist beach in England.

[8] The Federal Aviation Administration (FAA) of the United States is a national authority with powers to regulate all aspects of civil aviation. These include the air traffic management, the certification of personnel and aircraft.

two civil aircraft that have passed through a trashcan-sized drone. It is not only the military drone that raises the danger. The number of accidents caused by drones operated by law enforcement authorities and universities has also surged.

Drones can be used to steal confidential information from various data centers, research facilities, and government facilities through wireless networks. It is possible to inspect a military unit with a high-performance camera, or capture the appearance and operational performance of various weapons, which is being tested before launch. Drones can be a big threat if they are abused by terrorists, because drone loaded with radioactive materials can easily be transported to densely populated areas. Whenever drone meets guns, explosives, or biochemical, it can turn into a place of terrorism. There are cases of carrying mobile phones, cigarettes and drugs to drones to deliver to criminals. On April 22, 2015, a drone was discovered on the Japanese Prime Minister's residence. The distance between the drone and the prime minister was not so far, and radioactive material (Fukushima Prefecture sand) was contained in the drone. There is also an unusual case of abusing the drones that a teenager in the United States made a drone shooting with his own guns.

2.7.2 Drone Regulation

New technologies require new regulations suited to the situation. As drone expanded to general consumer sharply in internationally, countries are struggling to incorporate drones into their aviation regulatory frameworks. Drones, which can be used for diverse illegal intentions, have been introduced to the private sector widely, but the law has failed to cope with the rapid pace of technology diffusion. Applying manned flight regulations to govern small, unmanned drones will not result in regulations that fit the problems. Globally, aviation safety regulators are facing the same kinds of challenges: to maintain high levels of safety without unnecessarily impeding progress or unduly constraining commercial opportunities to use a technology capable of a multitude of beneficial humanitarian, economic and recreational applications [19]. Even for countries with existing drone legislation, laws are constantly being reevaluated; almost all the laws listed were written or amended within the past few years. Various regulatory standards are being implemented for each type of UAV in the world countries. The standard example of national drone regulation tends to have the following several elements as shown below;

1. flight restricted zones according to weight of drone, flight altitude and population density etc
2. pilot's license in the case of professional use
3. aircraft registration in the case of professional use
4. radio wave regulation
5. insurance in the case of professional use

When flying drones, you should only control the drone within the visible range of the human eye. Visual line of sight (VLOS) is often required for all users, restricting the horizontal and vertical distance of drone operation, as well as meteorological and lighting conditions for operation [20]. If the visible distance is shortened by fog or the like, the distance that you can steer is limited. The drones equipped with cameras are subject to the Privacy Act and require prior informed consent from those who may be concerned or approval of the relevant government agency. It is usual to be illegal to fly at night, one of the most common violations by the general public. It is forbidden to fly over heavily populated areas and to steer drone under the drunkenness state.

Even if the size of the drones is small, collision with the aircraft can lead to serious accidents, but also there is a risk of infringing the national defense security. Like birds, drones present significant risk to large, piloted aircraft. Even the smallest of drone can cause jet engine failure by being sucked into the turbine when operating at close proximity. Drone flight is prohibited in a control zone within a certain radius[9] from the center of the airport. Toy style small drones also must be approved by public authority to fly in flight restricted zones. Airspace is typically restricted around airports or other sites of national importance. It is permitted for private drones to fly only at the relatively low flight altitude (eg less than 150 m) within non-flight restricted area. In addition, drone flight over the certain security facility (e.g. military facilities, power stations, ports, and national research facilities) is not allowed due to national defense and security issues.

Other than aviation regulation, there are other things to consider when flying drones. It is a radio wave regulation enacted to safely manage the products that use the radio waves. Radio regulation specifies restrictions on the output range of the broadcasting and communication equipment, including drones, in order to prevent disturbances between devices and the indiscriminate use of radio waves as public goods. Accordingly, the allowable output is determined according to the frequency used in the drone, and the output capable of transmitting and receiving imagery is also restricted. At this moment most drones are using the license exempt frequencies, like the 868 MHz, 2.4 GHz and 5.8 GHz bands. The 2.4 GHz band is mostly used for control, while the 5.8 GHz is mostly used for video. The 433 MHz and 868 MHz bands are mostly used for telemetry, besides the 2.4 GHz. These frequencies are also used for a large number of applications on the ground, like Wi-Fi, home automation and parking sensors.

You do not need to obtain permission from the government authorities if you fly the drones with standard, off-the-shelf radio system in a line-of-sight perspective. That is because drone sold in most countries go through a certification process with the FCC.[10] The certification is to ensure that the drones do not cause radio interference

[9] Airspace is the portion of the atmosphere controlled by a country above its territory, including its territorial waters or, more generally, any specific three-dimensional portion of the atmosphere. It is not the same as aerospace, which is the general term for Earth's atmosphere and the outer space in its vicinity [4].

[10] The Federal Communications Commission (FCC) is an independent agency of the United States government to regulate interstate communications by radio, television, wire, satellite, and cable. The FCC regulates uses of radio frequency spectrum in the United States.

with other equipment. However, in practice there are only a handful of drones for profession that do not require a license. Most of them are Wi-Fi-based systems such as those seen on the Phantom and Inspire series. Wi-Fi video systems typically have limited range and measurable latency [21]. But the latency makes Wi-Fi systems inadequate for racing. The drones use the 2.4–5.8 GHz frequency band from the toy drones to the shooting drones. For instance, in South Korea, the output standard is set at 300 mW for the 2.4 GHz band and 10 mW for the 5.8 GHz band. The radius that can be operated within the allowable output range is about 300 m. In addition, the maximum output of the video transceiver is limited to 10 mW, so the actual operating distance is only about 30 m. However, the toy drone is usually able to communicate up to 20 ~ 100 m, while there are the drone for shooting that can be communicated up to 3 km of video transmission and reception with 500 ~ 3000 mW output. This system has many criticisms as excessive regulation in relation to drones because there is a gap between government regulation and reality.

2.7.3 Unrealistic Regulation

Regulators need to recognize that according to initial rules, the industry can keep moving forward, back or delay [22]. In this regard, for the same drone, a license is needed with a lot of restrictions for professional use. But when it is used recreationally, the drone can be used without license and with less restriction. For example, when a DJI Phantom 4 is used for leisure and pictures are taken, this is legal. When money is earned by selling these pictures, it is considered a professional flight and a license is required. Thus, there is evidence of a considerable increase in the unauthorized use of small, inexpensive drone by individuals and organizations, including companies [17].

Beyond-line-of-sight (BLOS) is a situation where the pilot is operating the aircraft without the ability to visually see it. Autonomous operation is almost always BLOS. Most drones can be considered robots. Most of them have autonomous safety features, usually including automatic take off, landing, hovering and automatic return to home. If the control link is interrupted, the drone keeps within a certain distance of the take-off position, below a certain altitude, and excludes it from airports and other controlled airspace. Most of them can autonomously fly according to flight plan defined in advance by entering waypoints, and modifiable in flight [17]. They are capable of flying autonomously based on their GPS. More capabilities are added like 'detect and avoid' by mapping the area around them, just like robots on the ground. Even though most drones can be considered to be robots, it is essential for a ground operator to have a robust radio connection to control the drone. It is required by law to always have visual contact with the drone and being able to control it manually. Radio connections are also needed to relay the information gathered by the payload.

Numerous reports conclude that US drone manufacturers and users are at a serious disadvantage because of their inability to test commercial drone applications in the US. Due to such regulations, US drone manufacturers and users have moved portions of their research and development to other countries [22]. The primary obstacle to using delivery drones in most nations is a requirement that drones stay within the pilot's VLOS (Visual Line of Sight). In the emerging delivery market, Amazon reports that it has shifted some of its air delivery research and development overseas instead of flying drones in the US national boundary [22]. Amazon has been testing abroad (e.g Canada) due to the US drones regulatory policy. The flight distance should not deviate from the view of the remote operator. However, Amazon claims that the drones can operate safely at distances of over 16 km, which are not visible in sight. Technology moves more quickly than the regulatory process. The Prime Air — a delivery system from Amazon is designed to safely get packages to customers in 30 min or less using drones [23]. Amazon vehicles will be built with multiple redundancies, as well as sophisticated "sense and avoid" technology and will gather data to continue improving the safety and reliability of delivery systems. Many companies including Amazon is working with regulators and policymakers in various countries in order to make drone technology a reality for the customers around the world [24].

2.8 Check Points for Drone Purchase

Drones for personal use are available in too many diverse models from a variety of manufacturers (Table 2.8). Depending on the size, the weight of the drone and the functionality of the system, price ranges from tens of dollars to millions of dollars. Even with the same model, there are price differences, depending on the specifications of installed hardware (such as camera or battery, etc). Before purchasing

Table 2.8 Off-the-shelf drone classification according to application level

Category	Weight/size	Camera performance/ steering thrill and excitement	Product characteristics and features
Professional drones for aerial photography	12-3 kg/large	Very good/low	Similar to smart home appliances (e.g. TV, notebook computer)
Racing/FPV drone	Weighting less than 5 kg/ small- intermediate	Low/best	
Drone adequate to intermediate level users	Weighting less than 5 kg/intermediate	Intermediate/ intermediate	
Toy grade drones for beginners	500 g or so/micro drone, mini drones	Low/low	Similar to toy

drones, it is important that you first determine the purpose of your purchase and know exactly what functions you need [25]. If you want to purchase a drone for flight training, you do not need to buy drones equipped with expensive hardware such as gimbals. Currently available drones can be divided into toy grade drones for beginners, intermediate drones, racing/FPV drones, and professional drones according to flight distance, flight time and additional functions (Table 2.8).

Generally large drones are expensive while small drones are inexpensive. Large drones will lift heavy equipment while small drones are not. During the drones purchase, everything such as size, weight and price are all trade-offs. It is difficult to give any specific recommendations on what to choose. First of all, start by finding an answer to the question “what do you want to do with your drone”? This will hopefully tell you what type of sensor or equipment you want to carry. Many of the commercial off-the-shelf drones will come with a camera and other sensors installed for the given specific mission [26]. Another aspect to consider is the redundancy required for your mission. Single battery will not give any redundancy in an event of a battery failure and the drone will crash. A dual battery drones such as Inspire 2 will continue to fly with one battery failures. Six or eight multi-rotors will also give a sufficient redundancy to perform a controlled emergency landing with four rotors [26].

The most important feature of the expensive drones is that the flight stability is overwhelmingly high. The big, expensive drones can fly safely simply due to big size and heavy weight. The disadvantage of the small drones is that the flight is not stable and is easily affected by the wind. Of course, drones that guarantee the stable flight with big size are costly. After all, if you are planning to fly a drone in the open air, it’s a good idea to pick a balanced model that’s not too big or too small. But the difference between low versus high price is due to the presence of sensors such as GPS. For instance, DJI Inspire 2 uses GPS (Global Positioning System, USA) and GLONASS (Global Orbiting Navigation Satellite System of Russia) to determine its position and automatically stabilize the flight. The high-performance gyroscope and accelerometer data are processed by high-performance processors. With various kinds of sensors, even beginners can easily fly the aircraft with stability. Products such as Inspire 2 also have the ability to return to their original starting position when batteries are low or communication with the transmitter is lost. This intelligent flight function makes a difference from low cost drones that only support simple manual flights.

In addition, there is a difference in the quality of the camera used for aerial photography. If you are planning to upload videos on a platform like YouTube, you should consider choosing a high-quality capable model. In addition, the intermediate drones are capable of FPV (first-person view) flight, which allows the user to experience a virtual reality as if they were flying while watching the camera images in real time using a video trans-receiver. Finally, you should also consider additional batteries. The flight time fluctuates depending on the battery model. If it is a high-end model, it will be 20–30 min, and if it is a low-end model, it will be less than 10 min. It is not realistic to fly again after charging for a few minutes if the battery is discharged. Therefore, it is better to purchase a spare battery when purchasing drones.

Table 2.9 Key features of the Syma X5C Quadcopter

Size	31 × 31 × 8 cm	**Weight**	340 g
Controlling distance	About 50 m	**Flying time**	9–12 min
Camera pixel	1280 × 720	**SD card**	2 GB
Aircraft battery	LI-poly 3.7 V 500 mAh	**Battery for controller**	4"AA" batteries
Charging time	About 100 min	**Channel/frequency**	4/2.4 GHZ

2.8.1 Toy Class Drone

Drones for beginners are characterized as toy grade by their low cost, their compact size, their simple function and robustness. Toy grade drones for beginners usually have a flight time of 5–10 min and can fly at distances of 30–300 m. Toy class drones are simple and light drones, weighting less than 1 kg, for recreational use and do not have GPS. Syma X5C weighs around 340 g and should be considered toys (Table 2.9). For beginners, it is advisable to purchase introductory drones that are cheap and light because of the high risk of monetary damages and safety accidents. It is a good idea to purchase a product that will allow you to practice the drones themselves, as there is no reason to buy heavy and expensive models just for flight exercise. Heavy drones are not suitable for beginners because they are vulnerable for safety accidents if they crash in the air or collide with other objects such as people. Expensive and heavy drones are very inadequate to flight exercise for beginner, compared to toy grade drones, since expensive parts can be easily broken due to unstable control.

2.8.2 Drone Adequate to Intermediate Level Users

Mid-range drones are drones weighing more than 1 kg and less than 4 kg for recreational or professional use and in most cases with GPS. This is a popular and rapidly increasing group of drones. Examples of popular Intermediate drones include DJI's Phantom series, DJI's Spark, Mavic, Cheerson's CX-20, XK's X380, and Parrot's Bebop. Mid-range drones (mostly multi-copter in configuration) cost from a few hundred to a few thousand dollars, and have limited endurance and range. Mostly powered by electric motors and batteries, they are capable of flying for around 15 min, at distances ranging up to 100 m or so from the operator, at about 100 m above the ground [17].

If you want to experience a professional drone, but the price is too high, you can choose a product that is one level lower than a professional one, or you can choose to exclude options from a professional or choose a previously released version of professional. The midrange drones have a large spectrum of prices, and the specifications of the models vary widely depending on the options you choose. Core function unavailable in the introductory drones is the auto-flight[11] and auto-shooting functions. Beginners get used to the drones to some extent want to fly away at high altitudes. In this case, the auto-return mode is very useful since drones out of sight can be returned to take-off point in a short time.

When you want to purchase a drone for this price range, you need some knowledge of drones in order to choose the right option at a reasonable price. You can choose a model with a long flying distance, a sensor-based automatic flight (such as automatic navigation/automatic takeoff/landing/hovering), or a model with an accessory extension (such as action cam/FPV goggles). The drone equipped with advanced sensor technology such as GPS, IMU, Lidar, and Gimbal are preferred by the users. It is a product that can shoot high-definition aerial images and feel like a real pilot while flying over rivers and forests. The mid-range drones can shoot high-quality images for targets located at hundreds of meters away since they can hold their own position in the air, even if users leave their hands on the remote controller. There is a variety of self-flying camera drone that combine camera and AI technology to follow targets (such as moving human and car) around and take photos and videos (e.g. DJI's Phantom series, DJI's Spark and Mavic). Self-camera drones automatically adjust the shooting angle, so targets can get caught in the center of the frame.

2.8.3 Racing/FPV Drone

If you feel that drone flight itself is more fun than drone shooting, it is good idea to consider a drone capable of first-person view (FPV). This drone will fly fast with the power (e.g. 90 km/h) due to the small aircraft size, and will be operated by the goggles. Racing/FPV drones are usually made in such a way that the user assembles the parts directly or modifies the existing drones, rather than being released as a finished product. If there is no delay and no video transmission for racing, it is evaluated as a good racing/FPV drone. It requires a great deal of practice before you can master a flight control for FPV drone. If you are interested in FPV racing, it would be helpful for you to save money and time by experiencing a quick taste of the cheap toy-class FPV model before buying a good FPV. Drones for racing/FPVs have a fairly high barrier to entry because they require considerable practice to master proficient steering.

[11] Auto-flight, autonomy and self-flying, or self-piloting are interchangeable terms. Automatic return is usually referred to as RTL (Return To Launch), Return To Home and Return To Base, such as RTH and RTB).

Table 2.10 Comparison of professional shooting drones versus toy-grade drones

Category	Syma X5	Inspire 2
Size	31 × 31 × 8 cm	43.8 × 45.1 × 30.1 cm
Weight	340 g	3.2 kg
Flying time/maximum flight altitude	7~8 min/100 m	27 min/5000 m
Controlling distance/ frequency	Around 50 m ~ 100 m/2.4 GHz	7 km/5.8 GHz/2.4 GHz
Aircraft battery	LI-poly 3.7 V, 500 mAh	LiPo 6S 22.8 V, 4280 mAh
	1.85 Wh	98 Wh dual battery
Gimbal	No	Yes
FPV	Not available	Available

2.8.4 Professional Drones for Aerial Photography

The professional shooting drone is equipped with a high performance motor and battery, and a high-resolution camera (Table 2.10). The shooting drone is equipped with various AI functions such as automatic takeoff/landing, GPS-based route planning, automatic navigation based on waypoint, etc., allowing the user to shoot aerial images at a low cost that cannot be compared with the toy grade drones. The shooting drone is capable of transmitting and receiving radio waves at distances of at least 1 km–8 km and it can fly for 20–25 min due to its high capacity battery. The professional drones are large in size and have a lot of motors, thus they are stable in the wind. The greater the number of motors, the less the drop accident caused by the motor failure. Thus the drones using more than 6 motors are often used for aerial photographing. The drone is equipped with a variety of additional functions such as avoiding obstacles during shooting. As the intermediate level drone specs have recently been upgraded, performance differences between mid-range and professional have narrowed considerably, and the performance of the professional grade drone is not surprisingly different from the intermediate grade. But the professional drones are bigger in size and far superior in AI function detail. DJI Inspirer 2 as a professional-looking model is more than 45 cm while the typical drone size in intermediate-range is 30–35 cm.

Professional drones are more than 3 kg and less than 25 kg and are mostly used by professionals. Professional drones present greater risk because of their weight and range. Table 2.10 compared the Syma X5C model with the Inspire 2 model, best known as the most introductory and professional drones. There is a big difference from size. Professional shooting drones weigh about 10 times more. The maximum flight time also shows a big difference. Batteries also vary greatly depending on the power difference. In the case of the operating frequency, the introductory toy drones are supported only in the 2.4 GHz range. The Inspire 2 supports up to 5GHz in the frequency range, which allows significantly longer transmission/reception distances than introductory drones. Also Inspire 2 supports FPV (First Person View) function that watches the images in real time through the goggles while flying the drone. General introductory toy drones do not support this feature. Such expensive drones are not easy to fly because of the large number of revolutions and the risk of injury. Therefore, a flight simulator is needed to practice steering skill, and the professional shooting drone usually includes this capability.

2.9 Drone Simulator and Primary Movements of Drone

2.9.1 Drone Simulator

From the theoretical point of view, simulation refers to an experiment to operate the target system in a time-sequential manner while modeling refers to a means of expressing the operating principle for the target system mathematically, physically, or logically (so to speak, an abstraction of reality). Furthermore, simulation is a thoroughly proven approach to conduct numerical experiments at a low cost in analyzing system behavior and design. As a fidelity simulation method, digital twin can be used not only during system design, but also during runtime to predict system behavior online. It is a powerful means of analyzing the result of a specific situation (what-if), from an aircraft system or a car to a social phenomenon. Simulation technology is being used in entire academic disciplines such as economy, defense, society, environment, etc. Simulation is being implemented by information technology, and the rapid development of this technology is increasing its utility day by day.

Simulation in drone manufacturing process is a process of verifying drone parts in a lab or a test bed that the system meets the performance standards before assembling software and hardware components into a real drone system. The manufacturing process of the drone has become meaningless without introducing the simulation concept since it is being matured in a refinement manner continuously enhancing the weak performance identified in the actual test evaluation. As drone technology becomes more sophisticated, complex, and integrated, the importance of simulation technology is expected to become more prominent. This simulation technique, which is used in the drone manufacturing process, is becoming an essential element in drone flight training. It is difficult to grasp the spatial cognitive ability for the drones moving in the air since beginners are unfamiliar with controller sticks. If you make a mistake the drone driving, it may cause damage to the user as well as the equipment. Increased flight training costs and the limited training space available are crucial factors in accommodating the flight training demands of suddenly increasing drone users. We have come to find the possibility of solving the problem by computer technology (data communication and virtual reality). Simulation has become a clear alternative to overcome this problem.

With the help of the simulator, you can master the flight skill without worrying about drone crashing. The 3D flight simulator is a game-based tool that allows practicing flight skills (Table 2.11). Controlling the unmanned aircraft in the house, the

Table 2.11 The three different types of simulator according user-interface

	Examples	Remote controller required
PC	RealFlight Simulator (Fig. 2.3)	Yes
Smartphone	Quadcopter Fx[a] (Fig. 2.4)	No
Simulator linked to with commercial off-the-shelf drone	DJI Drone Simulator (Fig. 2.5)	Yes

[a]It can be operated in the PC window environment by installing emulator (e.g. Bluestack) that enables one computer system to behave like smartphone operating environment

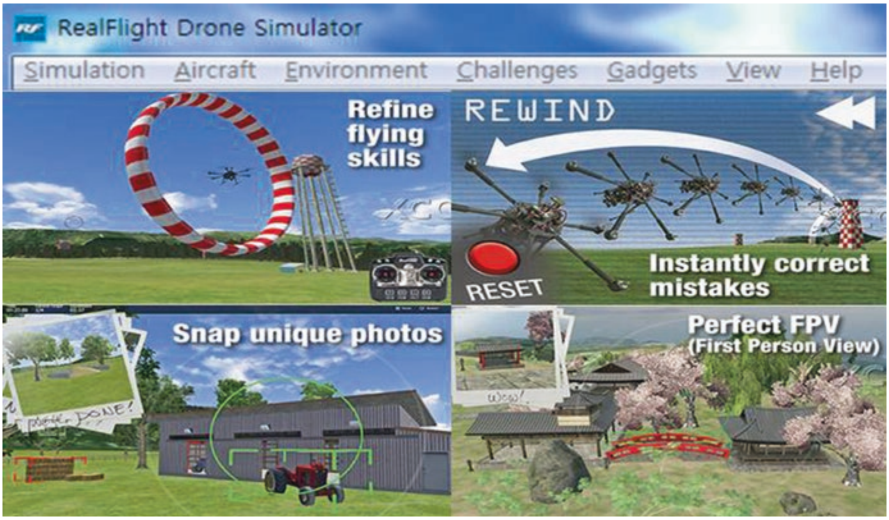


Fig. 2.3 Typical scenes of RealFlight drone simulator and its sub-menu
Simulation (Select Controller, Graphics, Mute/Unmute Audio, Settings, Capture Screenshot), Aircraft (Select Aircraft, Remember Aircraft Position, Clear Aircraft Position, Reset Position), Environment (Select Airport, Sun (Azimuth, Inclination), Wind (Direction, Increase, Turbulence), Reset to Default), Gadgets (Flight Modes, Viewpoint, Radio, Heads-Up Display, Binocular, Quick Load)

simulator allows you to practice flying on a computer under any weather condition, without damaging your drone. It can be especially useful if you live somewhere in a climate where it's not feasible to fly your drone over the winter. The flight simulator is a great instrument to work on your muscle memory and hand eye coordination. It offers self-level mode and acrobat mode. They are especially great for beginners, but can be useful for intermediate flyers, especially those challenging acrobatic trick, and practicing their video and photography skills [27]. Recently, professional drones are equipped with a function to tackle unexpected situations (e.g. avoiding various obstacles). Flying real drone to test these techniques can be quite risky and costly.

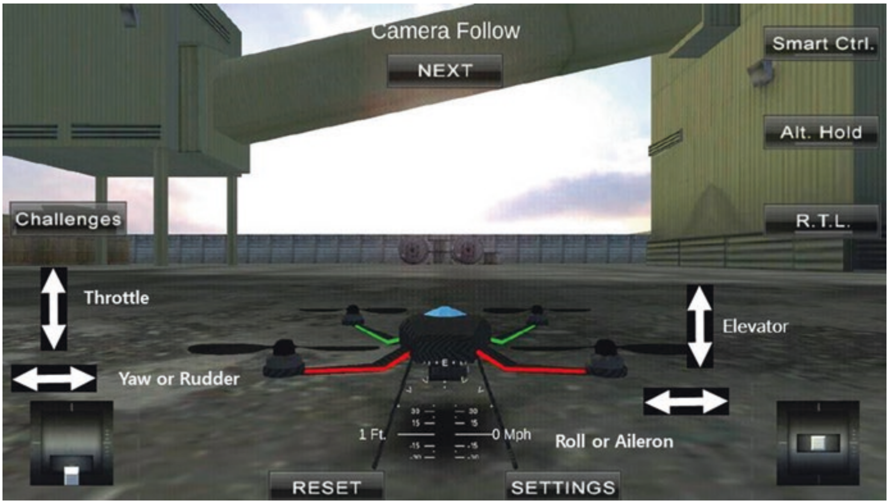


Fig. 2.4 Typical scene of Quadcopter FX Simulator

Fig. 2.5 DJI Inspire 1 simulator

The drone flight simulator software can help you practice aerial photography, FPV racing, video taking, and allows you to practice on many different drone models [27]. You can also change camera tilt angle, and field of view (FOV). You are able to change the physics in the simulator, such as gravity, drag and drone power etc. The simulator realistically simulates the real world by taking into account real physical characteristics such as balance and gravity, so that it feels like it is actually flying because you have to control takeoff, position movement and maneuvering between ground objects. The simulator software is able to create any scenario according to a drone pilot's training requirements, whether it's to recreate a movie scene, an outdoor wedding, a tower inspection, a structure fire or even a hostage situation [27]. The system is improving itself by repeating flight in the virtual world using the data that can actually be collected over the years. Various ground features have been created that are similar to the present world (buildings, dark walls, roadside trees, fog, wind, vehicles, etc). You can drive on the beach, in the city, in the mountains, at the airport, and even in space.

2.9.2 Three Primary Movements of Drone

To understand the principles of flight, you must first become familiar with the physical laws affecting aerodynamics. The procedure operating the drone is essentially the same as that performed by the pilot of the manned aircraft. Therefore, it is necessary to understand the three-axis motion of the aircraft in order to operate the drones. Yaws, pitches, and rolls are used as drone control terms. For the same three primary movements, the plane uses a different term. The yaw is expressed as rudder, pitch is the elevator, and roll is the aileron. Any vehicle (moving object) such as a ship, an automobile or an aircraft moves while performing three basic operations (roll, pitch, and yaw). The vehicle has three rotational axes (the center point of any rotational system) that are perpendicular (90°) to each other. These axes are referred to by their direction—longitudinal, vertical and lateral: roll, pitch, and yaw (Fig. 2.6).

Rolling: his head to the left and right, Wing up/down
Pitching: his head up and down, Nose up/down
Yaw: his head, clockwise or counterclockwise

Yaw is the side-to-side or lateral change in direction. Yaw is also known as azimuth or heading (nose left/right = heading/yaw/azimuth). Pitch is the upward or

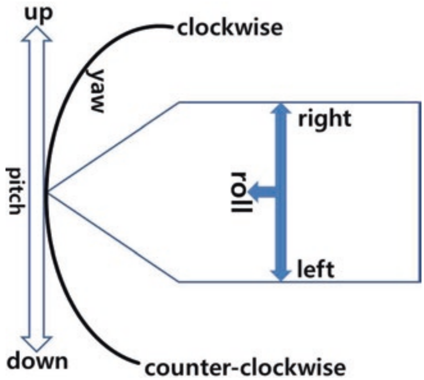


Fig. 2.6 Three-axis motion of the aircraft

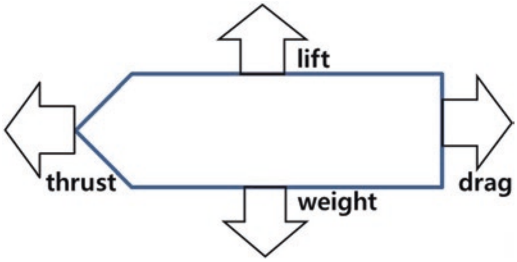


Fig. 2.7 Four forces affecting flight

downward tilt of the object for changes in altitude (y-axis rotation). And roll is the spinning or rotation of an object around a central axis (z-axis rotation). In essence, yaw causes the drone to rotate clockwise or counterclockwise. It works by pushing the left stick of the controller to the left and right. Pilots use yaw to change the front of the quad-copter to point into the other direction. This allows the pilot to create circles and patterns. It also serves as a directional control for photographers to follow their target. The roll moves your quad-copter left or right. It works by pushing the right stick of the transmitter right and left. For example, if you push the right stick to the right, the quad-copter tilts at an angle below the right diagonal.

A drone in flight is in the center of a constant fighting of forces. The commitment of these forces is the key to all movements performed in the air. The drone is designed to take advantage of each force. These forces are lift, weight, thrust, and drag (Fig. 2.7). If the main propeller stir up the air and causes lift to be greater than gravity, the drone will rise to the sky.

Lift as an aerodynamic force is generated by the motion of the airplane through the air. To overcome the weight force, airplanes generate an opposing force called lift. "Aero" stands for the air, and "dynamic" denotes motion. Lift is directed perpendicular to the flight direction. The magnitude of lift depends on several factors, including the shape, size, and velocity of the aircraft [28].

Weight is a force that is always directed toward the center of the earth. The magnitude of the weight depends on the mass of all the airplane parts, plus the amount of fuel, plus any payload on board (people, baggage, freight, etc.) [28].

Thrust is generated by the battery of the drone as propulsion system. Thrust is the force which moves a drone through the air. Thrust is used to overcome the drag of a drone, and to overcome the weight of a drone.

Drag is the force that acts opposite to the direction of motion. Drag is caused by friction and differences in air pressure. Drag is the force that tends to hold a drone back. The air resists the motion of the aircraft and the resistance force is called drag. Drag is directed along and opposed to the flight direction. Like lift, there are many factors that affect the magnitude of the drag force, including the shape of the aircraft, the "stickiness" of the air, and the velocity of the aircraft [28].

2.10 Real Flight

2.10.1 Checklist for Drone Status

Before flying the drone, you must check the overall safety status of the drones including essential components such as batteries, radio controllers and propellers. For instance, if the camera is equipped with a drone, make sure the SD card is inserted and enough storage space is available. The battery is the heart of drones, which gives them sufficient power to move in the sky. However, if it is not charged enough, it may cause a rapid fall of drones. This may not only damage or lose the machine, but also attack people below it. Batteries must be removed before doing anything using the drone. Radio controller is also the one to be managed well. While flying, a drone and a controller communicate each other ceaselessly. The connection between a controller and a drone is called a binding, just like connecting a smartphone and a headset via Bluetooth. The method of binding varies by manufacturer and model. Most bindings are performed by manipulating the radio controller after powering the drone. It should be operated within the distance recommended by the manufacturer. It is not possible for the radio controller to steer the drone if the drones are far away from remote controller, because the connection is loose. Thus, it is important to check the condition of communication. In this regard, the controller is a key to decide whether drones can be arms or not. Controllers share the same context with batteries. If a controller is not charged sufficiently, this can suddenly cause the drone to fall down rapidly toward people like missile.

Calibration (fine tuning) is the task of resetting the drones and radio controller. Calibration should be done periodically since an error could occur between the magnetic sensor and the radio controller after a certain number of flights. Calibration methods vary by brand and product. Therefore, it must be operated according to the instructions provided by the manufacturer. The number of GPS satellites being received could determine GPS health, which is a combination of signal strength and satellite orientation. In general, the GPS signal becomes much stronger when the more satellites received. The fewer satellites, the more your drone will drift in flight. You should have at least a minimum of 8 satellites as a standard for flying in view at any one time at any point on earth. There should be noticeable sway while flying when the drone has flown with as few as 7 satellites.

2.10.2 Flight Location

In the central area of cities, you have no choice but to avoid flying drones since the main part of the city is crowded all day and all night. Electric wire spread throughout the whole area of the city is hazardous for flying drone. If drone approach and contact the wire, a terrible accident may happen subsequently. There are many radio waves from military, police, and civilian people although frequency band used is different. Communication disturbance often happens near transmitters or between buildings and buildings. There may be the interruption from electronic jamming signals such as an electromagnetic wave and a high voltage transmission line that can make a drone dead. These disturbances should be observed with caution, because they cause the transmitter's frequency to be reversed and the communication between the drones and the transmitter to be interrupted. Beginners need to choose a place with the smallest impact that any mistake can have. We recommend for the beginner large open spaces like parks or plains. Many people prefer grass, since it will at least be a cushion when landing if the quad-copter crashes. Make sure you have enough space for takeoff and landing. Especially, in the case of autonomous flight, landing space should be secured considering position errors between the landing and take-off point.

A mountain region can be an attractive place to deal with fantastic photos, whereas it also has a plenty of dangerous factor. First, there may be lots of wind and fog in those areas. The strong wind can prevent the drone from moving freely; and the fog may interrupt its safe landing. The northern slope should be observed carefully. Visibility disorder can happen because the insufficient solar radiation in the slope faced at the north can cause fog or clouds in the valley. In mountain, non-visibility flight is often inevitable, so caution should be taken to communication disruption due to mountainous terrain. Also, the steep topography often distorts the communicative wave from a radio controller toward a drone body. Care should be taken as water evaporation due to large forest areas can cause visibility problems. Fog generated by the remaining snow should be monitored carefully since it remained near the top of the mountain for a long time. Finding the drone is almost impossible after missing it in the mountain region.

Water body such as river, lake, and sea can be optimal places you can utilize the drone efficiently since there is not a conspicuous obstacle in these areas. In open areas like rivers, lakes and seas, the field of view is very good. In addition to a fair view, the sensitivity of GPS is explicitly great compared to any other region. In the case of the beach, because the wind blows strongly, it is necessary to check the wind speed carefully to determine if it can fly. Open sea often causes disturbance in the sense of distance, so it is necessary to be careful not to discharge the battery because it may happen to send the drone far away. However, especially in the seas, strong wind can cause your happy memory to be broken. Moreover, it would be very difficult to find drones after an abrupt fall in the water.

An important part of the manual landing is how to navigate to land on a chosen site in unknown terrain, while taking into account the dynamic environmental factors such as crosswinds and gusts, small flying objects (e.g. birds) and other obstacles (tall trees, people or animals). Birds must be careful, as they may run into the drones due to misunderstanding that another bird invades his own area. The drone had to find a safe landing area by navigating through dangerous places such as densely populated areas or roadsides, and artificial obstacles on the ground (e.g. power lines). In order to command the aircraft to the desired landing site, visual information plays a crucial role in the control of the platform. Knowledge of wind direction is important for a pilot's decision on the final destination (for a conventional landing) and also to determine the maximum range the aircraft is able to sway [29]. In the event of an emergency landing due to unforeseen events and failures, the drone needs to be operated according to the following priorities [30]: (1) Minimize expectation of human casualty (2) Minimize external property damage (3) Maximize the chance of aircraft survival and (4) Maximize the chance of payload survival. In many scenarios, the pilot must face to complex trade-off between the risks and uncertainties involved with each possible choice [29].

2.10.3 Flight Weather

When you board on airplane, you can easily notice it is absolutely influenced by weather. If the wind is too strong to go forward normally, the pilot warns the passengers and controls the airplane very carefully. Sometimes, you can even experience the delay due to a terrible weather condition. The same principle applies to drone. Drones are much lighter than manned aircraft and are particularly vulnerable to wind and other meteorological condition. The wind is the biggest enemy in learning the subtle differences of the drone body reacting to pilot's controller operation. It is recommended to practice flying in the morning with relatively stable wind condition. To avoid unexpected dangerous situations, weather forecast should be included as one of the parameters that are taken into consideration before the flight. Other thing that one should have in mind is precipitation and temperature. When it is raining or snowing, it is highly recommended not to fly drone, because it may lead to damage of its electronic components. If the temperature is below 0 °C, batteries should be kept in warmth before takeoff.

If your drone is flying with an air speed of 5 m/sec in the weather without wind, then the flight speed of the drone will also be 5 m/sec. However, this case is extremely unusual. More often there will be some wind, and this can significantly affect the drone's speed over the ground. If you fly the drones at the same speed as the wind, the drones will not be able to advance to the next and will only consume the battery. Imagine you are flying your drone at 10 m/sec, but in opposite direction into wind, and the wind speed is 10 m/sec. Then principally you are flying the drone at 10 m/sec within an enormous mass of air moving in the opposite direction at 10 m/sec. In this case your drone's flight speed will be 0 m/sec. When you throw a drone in this wind condition, the drone cannot go to its destination and only consumes the battery. In particular, if you set up a flight route for autonomous navigation, the drone will land itself at any place according to predetermined instruction when the battery is exhausted after flying on the scheduled route.

In the nineteenth century, British Admiral Beaufort assigned metric wind speeds to 13 wind strength classes (Table 2.12). Basically this explains the detected real conditions to a wind speed. The principle procedure for this metric wind speeds has not changed since that day. The wind speed adequate to flight depends on the type of drones. For professional shooting drones (e.g. Inspire 2), the Beaufort scale under 2 grade is suitable for shooting while grade 3 requires caution in shooting. Taking

Table 2.12 The Beaufort wind scale

Scale force	meter/sec	km/h	Description	Specifications for use on land
0	0–0.2	>1	Calm	Smoke rises vertically.
1	0.3–1.5	1–5	Light air	Smoke drifts slowly.
2	1.6–3.3	6–11	Light breeze	Wind felt on face, leaves and stems move.
3	3.4–5.4	12–19	Gentle breeze	Leaves and small twigs constantly moving, light flags extended
4	5.5–7.9	20–28	Moderate breeze	Dust, leaves, and loose paper lifted, small tree branches move
5	8.0–10.7	29–38	Fresh breeze	Small trees in leaf begin to sway
6	10.8–13.8	39–49	Strong breeze	Larger tree branches moving
8	17.2–20.7	62–74	Fresh Gale	Whole trees in motion, resistance felt walking against wind, walking against wind very difficult.
12	32.7–36.9	118–134	Hurricane	Desolated houses and woods
				Countryside devastated. Enormous damage.

pictures at a grade 4 may cause a considerable risk, and it is a principle not to shoot at a grade 5 or higher. The hand-held wind-gauge device (anemometers) can only measure the localized wind speed at your ground position. The wind speed in the sky that the drones fly is often different from those on the ground. It is necessary to train yourself to observe the wind speed in the sky by utilizing the Beaufort scale [31]. It is worth thinking through the possible airflow pattern around your site, and measuring the wind strength at other positions if there is any doubt.

Weather condition which is sunny and calm, is highly recommended. In the case of manual flight, fog and dust can cause visibility problems. Especially when sunshine faces the pilot's eye, it can cause visibility disorder. Visibility is a measure of the turbidity of the atmosphere. The fog reduces the line-of-sight of the observer to less than 1 km. A visibility disorder such as fog and cloud can cause decisive impact on searching for targets in manual flight. Clouds are a key obstacle when taking overview pictures at high altitudes such as the top of a mountain or a rooftop of the tall building. The drones are made of precision electronic components and are very vulnerable to snow and rain. This is because when the parts get wet, electrical short-circuiting occurs. It is a good idea not to fly the drones in snowy or rainy weather.

2.10.4 Seasonal Drone Flight

Winter is the most difficult season for flying. First, special attention should be paid to strong winds. Special care should be taken when temperatures are low, and flights should be avoided at temperatures below 5 °C. Almost all drones use a lithium-polymer battery, and they are so sensitive to temperature. Therefore, it is recommended not to fly as much as possible in the winter when the temperature is below 0 °C.

The battery, which is the main power source of the drone, has the lowest efficiency in colder winter than other seasons. Batteries will lose much of their capacity when exposed to cold climates. In below 0 °C weather, the electrons slow down and the battery voltage does not come out properly. Moreover, the cold wind over the sky causes the battery to cool to a much lower temperature than the ground, so that the operating time of the drones drops to about 50 percent of normal. This may result in a sudden drop of power to the motors without prior notice, resulting in a crash [26]. If you are going to fly in winter, it is a good idea to preheat the battery. Place the battery near the heater to warm it up. Keep batteries warm before take-off. Batteries can be stored inside a pocket of clothing or in insulated boxes or bags that also might be equipped with extra heating to keep the temperature at a suitable level [26]. There is a way to preheat in a manner that operates the motor alone without the propeller before the full flight. There is also a way to preheat the drones through hovering without sending them away. For winter flights, battery warmers can be an alternative. Battery warmer is a device that warms the battery as its name implies. By inserting the battery in this equipment and setting the temperature, it is possible to preheat to the desired temperature.

Spring and autumn are better seasons for flight. A clear day after the rain is very useful for shooting. Be careful with the drone flight in the summer because there is often a heavy rainfall. Rainy or cloudy days should be avoided. However, even if it is clear, it should be ready to catch up with the sudden rain in summer. You should not be embarrassed if you face a sudden rain during a flight. It is best to land the aircraft as soon as possible. At this time, the drone may fall due to unreasonable operation. Operate the controller slowly and calmly. Autumn is the best seasons of all seasons. It is suitable for aerial photography because the wind is moderate and the air becomes dry and the field of view becomes clear. One thing to note is that autumn is a season with lots of mountain pictures, such as autumn leaves and autumn mountains. However, you should be careful about communication disturbance due to lack of field of views.

2.10.5 Beginner Flight

For the beginner, rather than practicing many functions, you should focus on getting used to the drones through the most essential take-off, landing and hovering exercises. In particular, it is important that you have practiced in the simulator. The beginners become accustomed to the sense of the remote controller while applying it to flying basic as shown below:

Practice taking off and landing at the same place at a height of 1 m instead of elevating the drones.

Practice comfortable landing and hovering in the air.

Practice moving the drones back and forth, to the left and right comfortably. Practice how to rotate.

You should always keep a line of sight so you can always see the drones. Maintaining the line of sight can avoid the drones strike early. As the drones are pushed by the wind, it may fly away from the communication range of the transmitter. Always keep in mind the communication range of the transmitter so that the drone does not go beyond that range. When the drones are floated, they move in one direction. If you lose your sense of direction with respect to the front, rear, left, and right, it becomes impossible to steer the drones steadily. In this case, the pilot should steer drone to the direction that the pilot is aware of and land in a place where field of view is secured. If the drones are moving far away, suddenly lowering or raising the controller output makes it more difficult to steer. It is important to stabilize by moving little by little. Hovering refers to the state where the drones are suspended in one place. Hovering is the basis of drone operation because it is difficult to balance the drone flying in one direction in the sky. GPS hovering is a function that automatically hovers through the GPS sensor built into the drones. This function allows you to hover the drones to a specific location without calibration or any other manipulation. Because it stops based on the GPS position calculation, even beginners can hover easily.

2.11 Conclusion

The drones are not toys but small machines. Your fingers will be cut off if propeller of drone hit your fingers. Flying drones means that you may always face unexpected dangerous situations whenever you turn it on and off all the time. Recognizing and approaching the drones as toys can lead to a situation in which you are injured someday. The higher output is accompanied by the greater risk of injury. Therefore, we would like to recommend the model with the lowest power to those who are starting out. Please choose a product that matches your own maneuverability. Drone can be a solid and dangerous weapon to people if it rushes to them. Whereas using a drone is fun and useful, the first priority should be safety without any exception. Make sure that the propellers are safe and securely fastened. Make sure there are no loose parts. Make sure that the throttle (left stick) is fully lowered (to prevent the drones from working). You have to step back from the drone's body at a few meters or a safe distance. Do not put your hands on the propeller when the drones are moving, as they may cut your fingers.

References

1. Federal Aviation Administration U (2018) Unmanned Aircraft Systems. U.S. Department of Transportation. https://www.faa.gov/uas/. Accessed 30 Sept 2018
2. Civil Aviation Authority (2015) Flying drones. UK Civil Aviation Authority. https://www.caa.co.uk/Consumers/Model-aircraft-and-drones/Flying-drones/?flip=true. Accessed 30 Sept 2018
3. International Civil Aviation Organization (2011) Unmanned Aircraft Systems (UAS). International Civil Aviation Organization, Quebec
4. Aldridge E, Stenbit JP (2002) Unmanned aerial vehicles roadmap 2002–2027. Office of the Sectary of Defense, Department of Defense USA, Washington, DC
5. Schwab K (2016) The fourth industrial revolution: what it means, how to respond. World Economic Forum, Geneva
6. Kesteloo H (2018) The 2018 winter olympics close with another spectacular "Shooting Star"drone show from Intel. DroneDJ
7. DeGarmo MT (2004) Issues concerning integration of unmanned aerial vehicles in civil airspace. Center for Advanced Aviation System Development, Virginia
8. Sale J (2013) The secret history of drones Guardian, Sunday 10 February 2013
9. Mahulikar SP, Sonawane HR, Arvind Rao G (2007) Infrared signature studies of aerospace vehicles. Prog Aerosp Sci 43(7):218–245. https://doi.org/10.1016/j.paerosci.2007.06.002
10. Rao GA, Mahulikar SP (2016) Integrated review of stealth technology and its role in airpower. Aeronaut J (1968) 106(1066):629–642. https://doi.org/10.1017/S0001924000011702
11. Dillow C (2014) A brief history of drones. FORTUNE
12. Meola A (2017) Drone market shows positive outlook with strong industry growth and trends. Business Insider
13. Gibbs Y (2017) NASA Armstrong fact sheet: helios prototype. National Aeronautics and Space Administration. https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-068-DFRC.html. Accessed 7 Aug 2018
14. Ackerman E (2017) DragonflEye project wants to turn insects into cyborg drones. IEEE Spectrum
15. Padmanabhan A (2017) Civilian drones and India's regulatory response. Carnegie India. Carnegie India, New Delhi
16. DJI (2015) Inpire 1 user manual. DJI
17. Perrit HH Jr, Plawinski AJ (2015) One centimeter over my Back yard: where does Federal Preemption of state drone regulation start. N C J Law Technol 17(2):307–389
18. Forrest C (2018) 17 drone disasters that show why the FAA hates drones. TechRepublic
19. Authority CAS (2017) Review of RPAS operation. Civil Aviation Safety Authority, Australia
20. Jones T (2017) International commercial drone regulation and drone delivery services. RAND Corporation, Santa Monica. https://doi.org/10.7249/RR1718.3
21. Dunn T (2015) What You Should Know about Getting an FCC License for Flying FPV. TESTED
22. Hazel B, Aoude G (2015) In commercial drones, the race is on. Oliver Wyman
23. Ungerleider N (2016) Amazon's holiday shipping rush brings growing pains. Fastcompany
24. Air AP (2015) Determining safe access with a best-equipped, best-served model for small unmanned aircraft systems. Air, Amazon Prime. https://images-na.ssl-images-amazon.com/images/G/01/112715/download/Amazon_Determining_Safe_Access_with_a_Best-Equipped_Best-Served_Model_for_sUAS.pdf. Accessed 28 Sept 2018
25. Smith K (2017) Everyone is buying drones these days. But here's 5 things you should know. MyFirstDrone
26. Axelsson D, Ader M (2017) Drone legislation guide: integrating activities for advanced communities. Interact, International Network for Terrestrial Research and Monitoring in the Arctic
27. Dronethusiast (2018) Drone flight simulator – analysis & comparison. Dronethusiast. https://www.dronethusiast.com/drone-flight-simulator/. Accessed 28 Sept 2018

28. Hall N (2018) Four forces on an airplane. NASA. https://www.grc.nasa.gov/WWW/K-12/airplane/forces.html. Accessed 28 Sept 2018
29. Mejias L, Fitzgerald D, Eng P, Liu X (2009) Forced landing technologies for unmanned aerial vehicles: towards safer operations. In: Aerial vehicles. InTech
30. Cox TH, Nagy CJ, Skoog MA, Somers IA, Warner R (2004) Civil UAV capability assessment. NASA, Tech Rep, draft Version
31. Wheeler D, Wilkinson C (2004) From calm to storm: the origins of the Beaufort wind scale. The Mariner's Mirror 90(2):187–201

Chapter 3
Cyber Systems

Abstract The main layers of CPS are the cyber layer and physical layer. CPS is analyzed and defined in various ways. But basically, it enables collecting the data of the real world and then providing the feedback of the results to the real world across society as a whole. Specifically, the sensor is attached to the control target (person, car and manufacturing apparatus, etc.). Various data transmitted from the sensor are collected as big data in the cloud with IoT tools. Building a DIY (Do It Yourself) drone offers a good opportunity to understand cyber domains of the CPS system. This chapter introduced various technologies for the cyber system by the drone DIY process to establish a systematic roadmap in relation to the physical system that will be introduced in the next chapter.

3.1 Introduction

CPS enables us to reduce costs, improve infrastructures, and deliver innovative and high quality services (drone, self-driving car and smart factory, etc.) by using data transmitted from the sensor [1].

A cyber-physical system (CPS) is a mixture of computers and physical systems. The cyber is a combination of terms: the computer hardware/software and computer network with the means of the information technology. In practice, it refers to the intangible, algorithmic, and software components of the system and their data, the computer network and systems dependent on the computer hardware. UAS (Unmanned Aerial System) embraces fundamental components as the total platform needed to operate the CPS system. It includes the UAV (Unmanned Aerial Vehicle) body itself, the remote ground control system, sensor (camera, GPS etc.) and actuator, the software needed to operate the system and additional hardware such as battery, ESC, and motor.

In this book, the cyber system is interpreted as actual aircraft body that flies to support the physical system carrying built-in sensors. So to speak cyber is focused on computerized hardware before monitoring the real world (physical world) by sensors. The DIY (Do It Yourself) drone assembly process lets you understand what makes

J.-S. Um, *Drones as Cyber-Physical Systems*,
https://doi.org/10.1007/978-981-13-3741-3_3

drone parts, not only in the body frame and the wing frame but across the flight control including motor to wing, ESC to motor, the transmitter to the receiver etc.

This procedure let you understand the cyber components and extendibility. In this regard, our interpretation of 'drone cyber system' covers typical the DIY drone assembly process. The DIY drone assembly is fairly simple once you know what you're doing. It is expected for us to realize how DIY drone assembly is to put together individual components of a cyber-system. An in-depth knowledge about drone parts enables you to understand drone related literature (such as technical manual) written by its own expert language. The drone physical system will be introduced to integrate the real world versus cyber world in the next chapter.

3.2 Drone Cyber-Systems as CPS Components

CPS refers to a new generation of systems with integrated computational and physical capabilities that can interact with each other and with humans in real time [2]. Digital twin technology is a methodology that enables autonomous objects (products, machines, etc.) to link the current state of their processes and behaviour in interaction with the environment of the real world. In this manner, manufactured products could increasingly employ converged cyber-physical data to become smart products that incorporate self-management capabilities based on connectivity and computing technology. Human decision making is increasingly supported and influenced by computers as progress of IT technology allows more and more assistance function. Stand-alone desktop computers are combined into a single web to improve the computational and informational capacity of the world. Further, integrating mobile devices enable communication between users in social networks and access to the Internet, regardless of the location of the person [3]. Embedded computers communicate with real life systems, usually with feedback loops, where real life processes affect computations and vice versa.

Cyber environment (also known as cyberspace) comprises interconnected computerized networks including services, computer systems, embedded processors, and information storage or sharing [4]. The most prominent example of a cyberspace is the internet, but we must be careful not to confuse two terms (cyberspace and internet) as they are not interchangeable [5]. The smartphone is increasingly replacing the computer in daily routine such as web access and email-work. Further, the trend is going forward to use smartphones as a virtual master key for ordinary daily life such as online banking, control of smart homes, energy supply by smart grid and control of the upcoming self-driving car. The 'bring your own device (BYOD)' concept describes the option operating multiple key intelligent devices thorough wireless coordination [6]. As widespread distribution and utilization of computers and the Internet took place one after another, BYOD revolutions were followed by the IoT/AI/data era, and subsequently, technological advances led to the connectivity among things (Internet of things; IoT) and connectivity among people, things, spaces (Internet of Everything; IoE). Currently, beyond the IoT and IoE, the hyper-connected society in which the real world and cyber space are connected and intelligent IoE is expected to be realized gradually [1].

Until now, the cyber system has been mainly used to connect human beings, but in the near future, it is expected that the physical system equipped with various sensors (e.g. drone) will be directly connected to the cyber system. An Unmanned Aircraft System (UAS) is a Cyber-Physical System (CPS), creating a reciprocal relationship (CPS) between the real world and the cyber world. The progress of unmanned device has made it possible to collect real world data by sensors available in the drone, and provide the feedback of the analysis results from the cyberspace to the real world [1]. In this manner, drone could increasingly collect converged data between cyber and physical system. Such converged data would play a key role in operating the smart device (e.g. self-driving car) that incorporate self-management capabilities based on connectivity and computing technology. Under Cyber-Physical data twinning, drone could become software-enhanced machinery equipped with sensors and actuators that can respond quickly to uncertain situations. Computational tasks and communication of data need to be classified as cyber resources since drone as the physical system will connect directly to the cyber system without human intervention, as a result of processing information (data) in the physical space. In addition, the cyber system enables the operation of computing resources in the virtual world and is focused on connecting things to the Internet, while the physical system performs basic sensing (video collection, image processing, storage) and further autonomy tasks (e.g., obstacle avoidance, localization) in relation to the real world.

3.3 DIY Drone

Right now, the drone market is flooded with manufacturers who can offer a customer-friendly system at a reasonably acceptable price. Drones can be roughly classified into finished products and assembly types in a similar manner to a computer. Among finished products, RTF stands for Ready To Fly, meaning the drone is completely built, everything is included and ready to experience a basic flight. RTF drone (Table 3.1) can be recommended for beginners getting into the hobby because it is relatively cheap and offer simple components for basic flight. Plug-And-Fly Aircraft (PNF) means that it is ready to fly when plugged in a receiver along with the recommended battery. It means that assembling parts will work without any further setup. Thus, drones can be obtained by buying finished RTF products or assembling parts and accessories sold in the market. In the case of beginners, the price of RTF drones is not so expensive. In the case of finished products, prices are very different depending on the release date and performance. There are many reasons for assembling the drones (e.g., saving money, hobbies, and expertise etc.). When purchasing finished products in the market, it may fail to reflect customer requirements. If you choose to go the DIY route, the price may not be your primary motivation. There are great benefits that can’t be gauged in terms of monetary value if you build your own drone

Table 3.1 Comparison of RTF versus DIY drone

category	RTF drone	DIY drone
Price	Indoor flight drone: inexpensive	For indoor drone RTF is recommended rather than assembly.
	Outdoor flight drone: relatively expensive	Professional shooting drone can be assembled at low expense by purchasing assembling parts.
Part replacement and adding components	Parts cost is much higher than assembly in the event of a drone breakdown.	Only necessary parts can be replaced when parts are damaged.
Difficulty for beginners to get started	Easy	Hard
Durability	Limited	Durability is not a big issue compared to finished products since it is possible to replace each parts.
Understanding drone hardware	Limited	Possible to identify details
Components accommodating user requirements	Impossible	Possible

cyber system. It would be an excellent opportunity to learn about drone components and how they fit together. It is a chance to scratch intellectual curiosity and desire to explore what kind of parts are going into your drone cyber system, how upgradeable they are, or how new they are to the market. If you build your own drone cyber system, you can choose your parts and upgrades for yourself, since the upgrade process is much the same as the building process [7]. If you know how to assemble it, you can reassemble and repair only the failed parts when the equipment is damaged. Knowing your drone components actually affect the maximum performance required for the specific type of drone operations. Knowing how to put in another flight controller, more motor, or a faster network card will make it a valuable experience.

As the drones became popular, ARF drone kit (Almost Ready-to-Fly) were released with almost all the components needed for drone assembly. You do not need to purchase parts for drone assembly separately, but you buy all parts at once. This drone kit has everything you need for a basic flight. But all parts are unassembled. It is very well known as a DIY (Do It Yourself) drone kit. The ARF (Almost Ready-to-Fly) option may or may not include a remote controller, so you need to check out the list of what that drone kit comes with before purchase. If a user simply attaches a DIY assembly module (equipped with a motor, battery, propeller, and communication chip) to aircraft body frame, anyone can easily make a small drone. Unlike buying RTF drone, assembling your own allow you to learn the basics of how a drone cyber system works, the essential parts, and how to put it all together. DIY route will guide you through choosing the peripherals that meet your needs while explaining why you need them.

3.4 Basic Knowledge for the Drone Assembly

In order to enjoy the advantages of such assembled drones, a basic knowledge for drone assembly is required. The assembling procedure of the drone is largely divided into aircraft body frame assembly and an actual operation. Drone parts are largely divided into remote controller, frame, motor, propeller, ESC, battery, Flight Controller, a transmitter (remote controller), and a receiver (Fig. 3.1 and Table 3.2). The assembling process of the drone body is similar in most types (small aircrafts and large aircraft), because the basic driving principle is the same. The major difference depending on the frame is the ESC, a brushless motor. The bigger frame

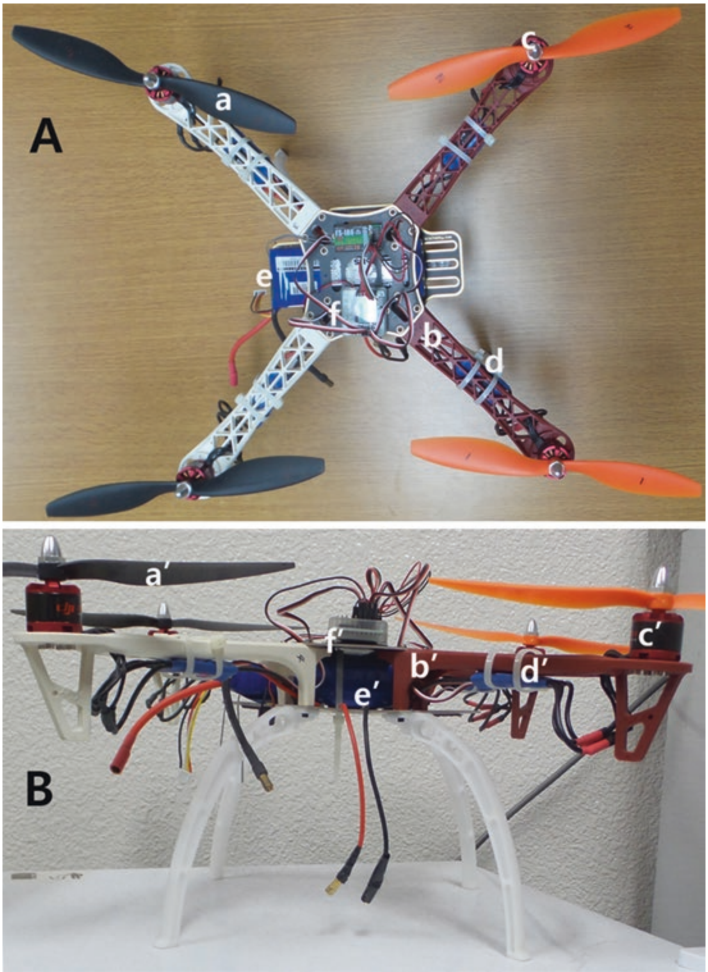


Fig. 3.1 Vertical (**A**) and horizontal (**B**) photograph of assembled drone a: Propeller b: airframe c: motor d: ESC, e: Battery f: FC (flight controller)

Table 3.2 Drone parts divided largely and its description

Category	Description
Airframe (The skeleton of the drones)	The airframe is the main body of the quadrotor, including four arms. The frame acts as a skeleton to support the drone body. It houses the controller, telemetry, battery and the payload. Each arm carries a motor, a rotor and an Electronic Speed Controller (ESC).
Propulsion system	The motor turns the propeller to fly.
	Rotary wings/propeller: When rotating, the rotor generates a lift force providing the aircraft with propulsion.
	An ESC (electronic speed controller) is used for regulating the speed of an electric motor (controlling the brushless motor). It can be called the muscles of the drones. This provides the power and control to fly a drone.
Flight controller (FC)	A flight controller is the brain of the aircraft. It controls the speed of the rotors based on user input and sensor data. It's basically a circuit board with sensors that detects orientation changes of your drone. It also receives user commands, and controls the motors in order to keep the quadcopter in the air.
Battery	Power source
Telemetry	Wireless communication between the quadrotor and the hand-held remote control
Payload	This payload consists of things such as camera, first response emergency equipment, sensors, landing gear etc.
	Sensor shows the current state of drones as a tool to recognize the five senses of the drones. Sensors belong to the physical system since it performs basic missions necessary in relation to real world.

generates the stronger power. The ESC and the motors are needed to support the weight of the bigger frame. The price of the other parts will also be increased. The process of assembling drone is similar to making a built-in PC. The drones are assembled in the following order (Fig. 3.2).

1. Connect the body frame and the wing frame.
2. Connect the motor to the wing frame.
3. Connect the ESC to the motor and carry out ESC calibration.
4. Then connect the transmitter to the receiver. The drone can fly mechanically and awkwardly at this stage. However, it is very difficult to steer drone since there is no flight control board.
5. Connect the flight control board for further stable flight.
6. Check the directional movement of the controller stick
7. Check the motor value in the configuration after starting up the machine.
8. You can assemble various parts according to your purpose.

The first thing to look at is the frame. In the computer, it is a main board (Fig. 3.3), and it corresponds to the visible external shape of drones. It is a matter of choosing a motherboard, by considering compatibility. The frame constitutes the basic skeleton of the drones that install various parts such as camera, battery, remote controller, gimbal, etc. necessary for drone shooting. Because the force and weight of the aircraft body are proportional to the size of the frame, the frame is made of light and hard material.

Fig. 3.2 Major drone parts used in assembly procedures a: propeller b: airframe c: motor d: ESC, e: Battery f: FC (flight controller) g: remote controller

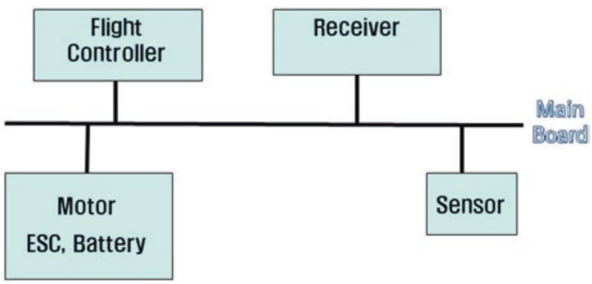


Fig. 3.3 Schematic diagram showing main board and its attached parts

The number and type of parts that can be attached to the drone depends on the frame of the drones. Depending on the size of the frame, the battery, ESC, and wing size will vary, so the frame size must be determined according to the application you are using. The frame size is estimated by the diagonal length of the facing motor. The frame used in the drones is available in 250, 210, 280, 360, 450 and 550 mm sizes. You can select the airframe for your purpose. If you want a stable flight, a frame weighing about 4–5 kg is required. As the frame size is big and the number of motors is increasing, drone is stable in the wind. Further it is easy to stand the weight of the camera when taking aerial photographs and to get rid of the risk of falling accident. For racing drones, you should use a lighter frame. It is advantageous to fly faster with the power and speed due to the small frame and drive by the goggles using the FPV. It is better to purchase the frames recommended by the manufacturer rather than experiencing trial and error by yourself.

3.5 Motor

Motor is a device that let propellers turn by converting electric energy into mechanical energy. Mechanical energy means energy used for movement. Our lives are supported by various motors. For example, the number of products in our daily life is operated by motors such as elevators, escalators, refrigerators, air conditioners, bullet trains and plant equipment etc. The motor obtains turning power by electricity while the engine obtains power by exploding the fuel. The motor is the most commonly used engine for drone flight. Motor is connected to the propeller and let it rotate to generate downward propulsion force, and serves to fly the drones in the air. Technological advances producing lightweight and powerful motors have led to the commercialization of automatic takeoff and landing drones without the runway. The motors are classified into DC motors and AC motors.[1] In civilian drones, it is common to use brushless DC motors nowadays. Brushless DC Motor is very useful in applications where space and weight are critical factors. Brushless DC motors are currently used in specialized applications where higher turning force, longer product life or even more precision is required; such as office products (computer hard drives, DVD players and PC cooling fans, laser printers and photocopiers). A brush (made of a silver, copper, or graphite compound) is an electrical conductor that allows current to flow through a motor, and gradually wears out as the motor is used (like a pencil lead). In order to keep the tool running, the brushes have to be replaced once in a while. The principle behind the internal working of both a brushless DC motor and a brushed DC motor are essentially the same, except the electromagnets(poles) are stationary and the permanent magnets are on the spinning portion of the motor. Since the electromagnets are stationary, there is no need for brushes. Brushless motors don't require that maintenance [8].

[1] While both A.C. and D.C. motors serve the same function of converting electrical energy into mechanical energy. The most basic difference is the power source. A.C. motors are powered from alternating current (A.C.) while D.C. motors are powered from direct current (D.C.), such as batteries, D.C.

Table 3.3 Sample specification of motor

Category	Specifications	Remarks
KV(RPM per voltage)	3100	
Stator diameter	13 mm	
Stator length	6 mm	
Shaft diameter	2 mm	
Motor dimensions (Dia.*Len)	17.7 × 15 mm	
Weight(g)	11.2 g	
Maximum RPM	12,800	
Max continuous current(A)180S	6 A	Maximum current tested for 180 s
Volt	7.4	
Max continuous power(W)180S	44 W	Amps (6 A) × Volts (7.4) = 44.4 Watts
Battery	2–3 LiPo	
ESC(A)	18 A	

Tigermotor MT1306, available in Fig. 3.4

Fig. 3.4 Typical sample of motor (Tigermotor MT1306)

Most motors have a few letters followed by 4 numbers (Tigermotor MT1306). The letters indicate a model or series name, such as MT series motors (Table 3.3). Generally, the first two digits in the BLDC motor (Brushless DC electric motor, BL motors) indicate the diameter of the stator[2] (millimeters) and the last two digits can indicate the height of the stator (Fig. 3.5). A stator is a stationary portion of a rotary system covered by the coil which empowers. The rotating force varies depending on the diameter and thickness of the stator. Generally, the larger the diameter and thickness of the stator, the better the torque is. In this case of the MT1306, we have a 13 mm stator diameter, and a 6 mm stator height. The size of the motor can give you an idea about what size drone you will use with the motor. Typical FPV racing mini-

[2] A portion of a machine that remains fixed with respect to rotating parts.

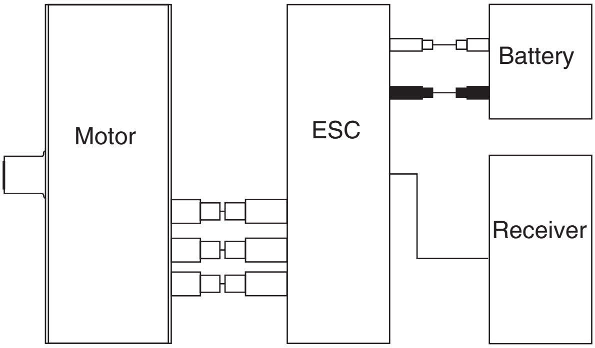


Fig. 3.5 Schematic diagram showing power delivery mechanism

quads will use 1806 or 2204 motors, whereas larger quadcopters that are designed to carry a gopro camera will typically be around the 2212 size [8].

KV rating[3] simply means the RPM (revolutions per minute) value of the motor per volt with no load. If KV is low, the speed is slow, but the force is stronger. Conversely, if KV is high, the speed is fast but the force is weak. The math here is RPM = KV × voltage. KV rating is important to you because it will help you choose your motor's speed and force. For example, in the case of a brushless motor with a kV rating of 4600 and 12 V, the max RPMs (55,200 RPMs) that this motor can reach under no load can be calculated by the 4600 × 12. The watts rating (e.g. 44.4 W) stated in the brushless motor spec sheet are the power rating or the horsepower equivalent of your brushless RC Motor. The math here is Amps × Volts = Watts. This is the magnitude or intensity of power rating that can be operated safely and must not be exceeded. Running anything over this rating could damage your motor, especially over a long period of time [10].

The ideal RPM number of a motor is dependent on what type of drones you're looking for. For example, if you're looking for a small size, acrobatic copter, a high rpm motor is needed for you, meaning a high KV rating. This is intuitive because these acrobatic copters are the smaller size, meaning a smaller motor, leading to smaller propellers. When you have these smaller propellers, the motors need to produce more rpm in order to produce the necessary thrust [8]. The KV value, battery voltage, and propeller size have an important correlation (Table 3.4). This higher kV value is not necessarily better or faster, but should be carefully chosen depending on the size and weight of the drones. Choosing a too large propeller can cause problems because of excessive current flow through the system. However, too small propeller can reduce the efficiency of the motor. The motor manufacturer indicates a propeller suitable for the voltage connected to the motor (Table 3.4). It is not good or bad that the number for the motor is large, or small. The most important thing is how to assemble the drones together by harmonizing these complicated items.

[3] You should not to be confused with *kV*, the abbreviation for *kilovolt*.

Table 3.4 Example of data sheet for multi-copter motor (MT1306-3100KV)

Prop Item no and test condition	Throttle	Amps(A)	Watts(W)	RPM	Thrust(g)
MT 1306	30%	1.1	8.14	10,021	37.5
KV3100	50%	1.6	11.84	11,841	57
T-Motor	65%	2.1	15.54	13,361	73.5
6*2CF (Prop)					
Operating temperature	85%	3	22.2	15,569	98.5
(63 °C)					
Prop (4045) 7.4 V	100%	3.7	27.38	16,750	120

Note: It is a data sheet about propeller, battery (voltage, current, power) combination when using this motor. The test condition of temperature is motor surface temperature 100% throttle while the motor run 10 min [9]

The motor is often broken. The most common cause of motor failure is overheating. The most common mistake of the beginners is to buy five or six additional batteries and keep the drones running continuously. Apart from the battery supplying the power, the motor continues to rotate, which causes the motor to overheat. Most drones do not have a separate cooling system, so the motor must be rested to prevent overheating. Because of the high RPM rotation, the motor generates a lot of heat naturally. The heat generated by the motor should be cooled to prevent overheating. To avoid overheating of the motor, fly the drones in less than 10 min at a time.

3.6 Electronic Speed Controller and Propeller

An Electronic Speed Controller (ESC) is system that controls the speed of the electric motor through a speed reference signal transmitted from an FC (flight controller) as shown by Fig. 3.5. The torque[4] of the motor, i.e., the rotational force, relies on the electric power delivered to the motor every second. The motor receives the current from the battery through the ESC and adjusts the number of revolutions. It serves as the vehicle's accelerator and brake. The ESC regulates the amount of electric current and voltage required to perform a specific mission. The ESC converts the signal received from an FC (flight controller) to V (Voltage) and rotates the motor quickly or slowly. For example, launching the drones in the sky requires electric power to increase the propulsion of the drones. The ESC allows the drones to float at a constant altitude and steer the drones already floating in the air. When selecting the ESC corresponding to a specific motor, it may be selected by considering the motor output (W) and battery voltage (V) in the formula of Amps × Volts = Watts. It is better that the ESC current value is slightly higher than the motor current value (approximately 20%). Too much current will damage the ESC very quickly. The motor manufacturer indicates an ESC suitable for the

[4] Loosely speaking, torque is a measure of the rotational or turning force on an object such as a **propeller**, bolt or a flywheel.

voltage connected to the motor and select the ESC capacity recommended in relation to the motor.

The propeller must be selected considering the weight of the motor and airframe since it is tightly connected to the frame and the motor. Depending on the propeller design (e.g. aerodynamics and material), the efficiency of the power supplied by the motor varies. The durability and balance of the propeller plays a very important role in the drone flying with a moderate amount of propulsion. For example, the speed and direction of the drones is determined by adjusting the propulsive force, or speed, of one or several propellers. Therefore, the propeller should be selected to accommodate application purpose of drones in consideration of payload. There are four digits in the propeller, for example, 1045, 1230, 5032, 6045 and so on. Taking 1045 (called "1.0 to 4.5"), as an example, the length of the propeller is 10 inches and the pitch distance is 4.5 inches (11.43 mm). Pitch represents the distance (thrust) that advances forward when the propeller rotates one turn. That is to say, it is like talking about a screw. So what about 5032? Based on the above example, the propeller can be thought of as a 50 inch propeller. But this is not true. It is too big that the drones with 50 inch TV size are flying. The correct answer is 5.0 inches. For propellers larger than 10 inches, it would seem more appropriate to use these numbers, such as 100 or 120. In practice, there are only two digits excluding decimal point.

3.7 Battery

The flight time of the drones depends on battery performance, since propulsion devices such as motors and propellers are driven by the energy powered from battery. Batteries must be purchased in consideration of the frame size of the drone and the specifications of the motor. Most drones now use lithium polymer batteries. However, this battery has short flight times, frequent recharging, and limited battery life.

3.7.1 Essential Concepts Related to Battery

If the battery is too large relative to the size of the drones, the drones will not fly properly. If the battery does not accept the output of the motor, the motor may stop rotating due to overheating. It is important to select a suitable battery to take advantage of the power and speed of the drone (Fig. 3.6). The discharge rate is a measure of how quickly you can extract electricity within a range that does not damage the battery. In the case of 30C 2000 mAh battery, maximum current consumption can be estimated as follows; 30C * 2000 mAh = 60 A. This battery can safely consume current up to 60 A. The battery will overheat if it is consumed at a discharge rate greater than 60 A. For example, if it is labeled 3700 mAh, it is the amount that can be used for 1 h when discharging 3.7 A (3700 mA). The higher the discharge rate, the more expensive the battery is. If the motor demands a higher current than the

Fig. 3.6 Typical sample of battery (Byrobot Petrone)

discharging capacity of the battery, it will cause the battery to swell due to over-discharge, shortening the service life. The discharge rate of the battery indicates the power of the drones. The motors used in the drone require an intensively high discharge rate within short flying time.

To understand battery performance, it is necessary to understand the voltage and current as essential concepts. The easiest way to understand those two concepts is to consider electricity as water. Amps or amperage denotes the flow of electricity much like the flow of water. When two water bottles of different height are connected, the water in the higher bottles flows into the lower height bottles. The energy source for the water flow is the water pressure difference between two water containers. The flow of water means current and the difference in pressure means voltage. The current describes how much electrical charge is on the flow in a set amount of time (like flow rate change per hour). The Amp hour (Ah) is the number of Amps that how much electricity 'flow' can be sustained at a constant rate if the battery is drained over the course of an hour. It is understood that a battery's mAh rating works on the same principle as the volume of its electric gas tank; the bigger a battery's mAh rating, the more run-time you get per charge. Using a 2200 mAh battery instead of 1100 mAh one, for the sake of argument, would roughly double your model's run time [11]. Volt means pressure or density. The best example when describing voltage is water. As water flows from high to low, electricity moves from high to low, and the difference between high and low, that is, the larger the potential difference, the greater the force.

A battery is a power generator that converts the energy stored in the substance into electrical energy, which is released when a chemical reaction or physical change (temperature difference, light, etc.) occurs. The battery packs includes several cells in one bundle. Thus, the battery can be roughly divided into physical cells and chemical cells. The chemical cells are divided into primary, secondary, and tertiary batteries. The battery used for drone is divided into the physical battery and chemical battery. Physical batteries use physical phenomena (photovoltaic effects) where electricity is generated when light is applied. For example, solar battery is a device that can convert solar energy into electrical energy. Chemical batteries are divided into the primary, secondary, and recently defined tertiary battery. A primary battery is a disposable battery after it has been used once because the electrochemical reaction in the battery is irreversible. Unlike the primary battery, the secondary battery is capable of charging and discharging. It replaces external electric energy in the form of chemical energy and stores it. It is a device that stores by converting the external electric energy into the form of chemical energy and generates electricity when it is needed. It also means "rechargeable battery" because it can be charged many times. The tertiary battery is not required to be charged. If only the fuel is continuously supplied, it is possible to continuously generate electricity. Thus, the term fuel cell is used instead of 'battery' because the tertiary battery is close to generators.

3.7.2 Comparison of Lithium Ion Batteries and Lithium Ion Polymer Batteries

Among rechargeable batteries, lithium ion batteries and lithium ion polymer batteries are most commonly used (Table 3.5). Lithium polymer battery is mainly used as the power source of the drone because it is lighter than other batteries of similar capacity, and has a high discharge rate. This is an important factor in allowing the drones to float in the air even when the wind is blowing. In general, lithium ion batteries are used due to high volumetric energy density and very high charging efficiency. Conversely, due to the high energy density, there is a risk of overcharge, over-discharge, overcurrent, and explosion. In contrast, a lithium polymer battery uses a polymer electrolyte configured in the form of a solid or a gel. Even when the battery is damaged in an accident, the electrolyte does not leak out. Even if the electrolyte is leaked, it is a rechargeable battery with low risk of explosion. Lithium

Table 3.5 Comparison of lithium ion batteries versus lithium ion polymer batteries

Lithium ion batteries	Comparing category	Lithium ion polymer batteries
3.7 V	Voltage	3.7 V
Relatively heavy	Weight considering voltage vs. discharge rate	Light
Liquid	Electrolytes Type	Solid, polymers
Shorter than	Life	Longer than
Higher than	Risk	Less than
Limited	Product design	More freedom
Cheap	Price	Expensive
Galaxy smartphone, notebook, electric vehicle	Example products	Drone, iPod, iPhone

ion polymer battery is a solid type battery, unlike lithium ion battery which uses liquid electrolyte inside. It can be transformed into various shapes due to solid type and is about 20% lighter than a lithium ion battery. It is convenient because there is almost no natural discharge. Lithium-ion polymer batteries are relatively more expensive, since they are thinner, lighter than the lithium-ion battery and can be manufactured in a variety of desired shapes. As lithium polymer batteries have higher capacities, there is also a risk of explosion by heat. Lithium polymer batteries are widely used in general remote control (R/C) aircraft, model cars, mobile phones and notebook computers due to high power capacity.

Lithium polymer batteries mounted in the drones usually use a rectangular shaped battery. The lithium-polymer battery capacity is expressed in cell units (one cell is 3.7 V). It should be noted that this battery is the most stable at 3.7 V and the battery is suddenly damaged, at 4.2 V above or 2.8 V below. So the battery should be configured with the voltage required for the drone. For example, if it is labeled as 3700 mAh, it is an amount that can be used for 1 h when operating at 3.7 A. The higher the number of cells, the more power and speed the battery can provide, but there are many things to consider as you have to choose the right motor, ESC, and propeller. When the battery capacity is excessively large, the gravity center of the drones may be shaken and shifted much. The discharge rate also has a significant effect on the selection of the lithium polymer battery.

The discharge rate is determined according to how much current is required depending on the specification of the motor to be used. The cell phone battery is equipped with double and triple safe system, but the lithium-ion polymer battery in drone has no such function and should be used more carefully. It is possible to reduce the time required to recharge the existing drone batteries. However, if you charge your existing lithium-polymer battery six times faster than before, the battery life will be shortened by six times. The electric car industry is rapidly growing. The electric car requires the compact battery with large capacity and fast charging in a short time. When the electric car spreads, the advanced battery technology would be combined with the drones. It will not be too distant future to have drone equipped with batteries that have a longer life span even at the fast charge with a very high energy density.

3.7.3 Common Mistakes by Many Beginners

When the drones were first delivered, you must use it after charging because you do not know the battery charging status. Be sure to charge it with a dedicated charger. The charger must be charged by the power supply voltage specified by manufacturer. There are some key things to keep in mind in order to safely manage the battery as presented below;

To avoid over-discharging, if the battery output is weak, it should be used after charging.
Do not expose the charger and battery to water, rain, or sea water.
Do not charge batteries that are damaged, aged, leaks, etc., or batteries that are wet with water.
Do not bring the battery near a fire or put it in a fire.
Do not charge or store under direct sunlight or near a hot place or near fire.
Do not overcharge the battery or use a different charger other than the dedicated charger provided by the manufacturer.

When the rechargeable battery is left unused for a long time, the performance of the battery deteriorates. It may be over-discharged by the self-discharge of the battery, resulting in deterioration of battery performance and life span. If you have to keep the battery without using it for a long time, it is better to keep it in a charged state rather than in a discharged state. This will reduce the likelihood of over-discharging and causing catastrophic damage to the battery even months later. The battery should not be completely discharged since it may happen that recharging is impossible if over-discharging occurs. The situation becomes similar to the situation where it is necessary to re-ignite and burn the fully disappeared fire. A big problem also occurs when the battery is discharged during flight. If the drone falls, it may be damaged and human accidents may occur. For these reasons, when using a lithium-polymer battery, you must use a battery checker that indicates the remaining battery level.

If you do not fly the drones for a long time, you should remove the batteries from the remote controller. If stored for a long period of time in contact with equipment connected to the battery, the internal chemical reaction proceeds more rapidly than in the untouched case, which leads to increasing leakage. When replacing the batteries in the remote controller, replace them all with new ones and do not use different types of batteries. If batteries with different voltage or type are used, the equipment will not operate normally since the discharge performance of each battery will be different. Also, if you mix a new battery with a used battery, the old battery will become over-used, it can cause leakage.

Lithium ion polymer batteries are best stored at 20 °C because they have the longest lifetime at 20° and the slowest cell corrosion. You should keep the battery in a cool place away from direct sunlight. In this regard, it is absolutely prohibited to store the battery in the car in summer. Basically, batteries produce energy through chemical reactions. But they do not react well when the weather is cold, so the capacity of the battery is reduced. If you use or store the battery at above or below the proper temperature range, the life span of the battery may begin to decrease rapidly and may become swollen. Sometimes it is said that the battery life is prolonged if it is stored in the refrigerator. But it is a right way to store it at an appropriate temperature. At low temperature, because the chemical reaction slows down, it does not generate enough electricity. The temperature of the battery itself should be in the range of −5 to 45 °C. If the temperature of the battery is too low or too high, life span may decrease rapidly and swell. You should observe the battery condition while charging the battery to prevent fire hazards.

3.8 Flight Controller

Flight controller (FC) is the core part of the drones, which means the head of the aircraft and aircraft dedicated computer. It is a central processing unit that controls the drones with a built-in CPU for flight control. It is a device that allows the pilot to fly the aircraft as desired using steering command and the embedded sensor signal. Until the FC (flight controller) came out and the computer grabbed it automatically, this imbalance had to be handled by the pilot's fingertips. It was the only alternative to reduce crashes by improving pilots' maneuver skills through practice for both manned and unmanned aircraft. It is almost impossible for the drones to hover at a certain position manually. That's why we need a controller board. It is a device that adjusts the motor speed, based on the signal from the remote controller. If it is the ideal aircraft, it should keep its balance by itself although you do not touch the joystick of the remote controller.

Nearly all flight controllers have basic sensors such as Gyroscopes and Accelerometer. Some FC might include more advanced sensors such as barometer (barometric pressure sensors) and magnetometer (compass). It is responsible for motor control and attitude control calculation for the drone to fly. However, when the aircraft is actually floated, there are various factors to cause the aircraft to shake itself, such as left/right/front/rear weight imbalance, thrust imbalance, wind and so on. The controller board constantly receives data from various sensors to control the direction and altitude of the drone. Based on this information, controller board determines the driving force of the motor and the movement direction of the drones. The development of various technologies such as GPS (Global Positioning System) sensor, INS (Inertial Navigation System) sensor, data processing capability, and MEMS, further speed up the performance of the onboard flight controller.

Flight controllers are commonly equipped with small MCUs (Micro Controller Units). A microcontroller or Micro Controller Unit (MCU) is called a small computer on a chip and is available in numerous sizes and architectures. Microcontrollers allow the drone to interface sensors and specialized control electronics such as motor. Microcontroller units (MCUs) are widely embedded from toys to moving device (cars, planes, trains, space vehicles), consumer electronics(cameras, cellphones, GPS, robots and toys), office appliances, network appliances. For example, the drone employs several dozen microcontrollers in their actuator and sensor systems. The MCU is similar to the CPU in the PC, but the other most important feature is that power consumption during operation process is low and the manufacturing cost is very low. It includes many peripherals to be used for automatic control. Currently, the distinction between MCU and CPU is determined by the purpose of the processor. When a high-performance OS (***Operating System***) is installed and used in a PC, a server, or a supercomputer, it is generally referred to as a CPU. It is called MCU when installed using the low performance OS or used for automatic control depending on the firmware alone without an OS. However, there are cases where the boundary between CPU and MCU is ambiguous.

The flight controller board is a self-sufficient autonomous computer that controls all the electronics of the drones. The ESC continuously signals how much power is currently being sent to the motor. This generates the appropriate level of propulsion, helping the drone to reach a certain altitude and maintain its altitude. The information generated by the in-flight gyro serves to indicate the current bearing and altitude. Based on this information, the ESC regulates the propulsive force and accordingly the drone can reach its required height and orientation. Accelerometer information, along with GPS information, determines the speed of the drones and calculates the time taken to reach a given destination. The flight controller board monitors battery life and tells the ground station the amount of battery remaining.

In recent years, a wide variety of FCs has been released on the market. In the course of assembling the drones, you must choose FC based on certain criteria such as function of the FC, compatibility for specific drone, and the difficulty of the tuning. There are many types of FCs (KK2, Naza, Multiwii, CC3D, WK-M [12]), some of which have been proven on the market for a long time. There are a number of inexpensive products with low-quality components. Depending on which flight controller you are using, the flight of the aircraft will vary greatly. Many FCs have similar hardware and sensors, but software and computational algorithms are very different. Even if the drones are equipped with the same hardware, they have different flight characteristics according to the FC. A good pilot needs a good FC, but a particular FC is not always better than another. It depends on the type of drones and the type of flight. For example, some products are easy to set up for beginners and some are suitable for small drones. It is important to select the appropriate FC for the drone size and application area. The inexpensive KK2 Flight Control Board (FC) at the beginner level offers simple settings, boot time and excellent flight performance. The hobby-level drones are equipped with NAZA-class FC.

KK2 (Fig. 3.7) is the most familiar FC for a beginner who wants to learn assembly procedures for the first time [13].[5] It is designed exclusively for HobbyKing by the grandfather of the KK revolution, Rolf R Bakke. The KK2 was manufactured to introduce multi-rotor flight to beginner. The KK2 is a flight control board for multi-rotor Aircraft (Tricopters, Quadcopters, Hexcopters etc.). It doesn't require a PC to set up and the LCD screen and built in software makes install and setup easier as KK2.1 user manual explains below [14].

> The HobbyKing KK2.1 Multi-Rotor control board is to stabilize the aircraft during flight. It takes signals from on-board gyroscopes (roll, pitch and yaw) and passes these signals to the Atmega324PA processor, which in-turn processes signals according the users selected firmware (e.g. Quadcopter). It passes the control signals to the installed Electronic Speed Controllers (ESCs) and the combination of these signals instructs the ESCs to make fine adjustments to the rotational speeds of the motors which in-turn stabilizes the craft. The HobbyKing KK2.1 Multi-Rotor control board also uses signals from your radio system via a receiver (Rx) and passes these signals together with stabilisation signals to the Atmega324PA

[5] Although the KK 2.0 is being phased out, KK 2.0 boards are well known as one of the best flight control boards. Understanding how this FC works will help you understand other FCs as well.

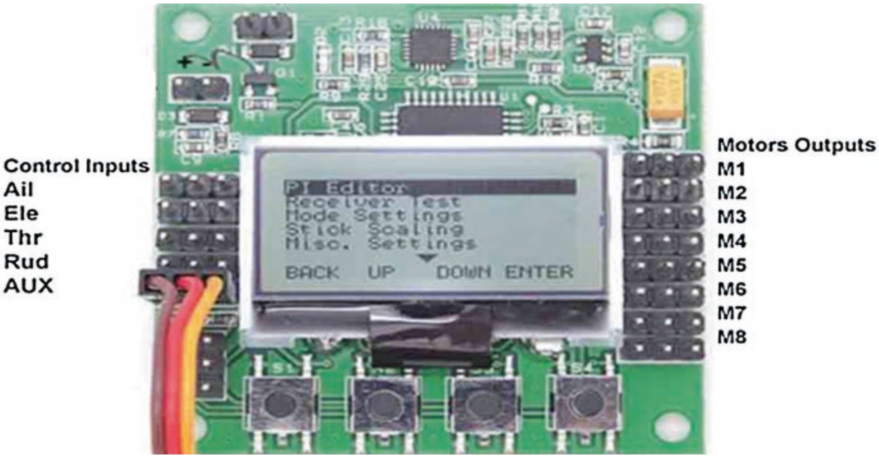


Fig. 3.7 Typical sample of FC (KK 2.1 Multi-rotor control board)

Table 3.6 Comparison of beginner-level FC versus hobby-level FC

Model	KK2	Naza-M Lite
Number of compatible motors	3–8 Tricopters, Quadcopters, Hexcopters etc.	4–6
Has built-in GPS	No	Yes
IMU	Two InverSense gyros[a] as well as a 3-axis accelerometer, no built-in magnetometer	3-axis gyroscope, 3-axis accelerometer and barometer
Intelligent orientation control	No	Yes (altitude hold, position hold, waypoint navigation, telemetry, automated missions)
Built-in gimbal stabilization function	No	Yes
Computer interface for setup	No	Yes

[a]InvenSense's 3-axis gyroscope and 3-axis accelerometer family of parts support a wide range of applications including sports, and image stabilization [15]

> IC via the aileron; elevator; throttle and rudder user demand inputs. Once processed, this information is sent to the ESCs which in turn adjust the rotational speed of each motor to control flight orientation (up, down, backwards, forwards, left, right, yaw) [14].

The KK2 controller is the flight controller that doesn't need GPS or waypoint navigation and automated missions (Table 3.6). KK2 does not have a magnetometer to know the orientation. It does not support serial port – so you will not be able to connect a GPS, barometer, ultrasonic sensor or any other additional sensors. The KK2 controller uses two InverSense gyros as well as a 3-axis accelerometer, driven by a Mega324PA microcontroller. You can set these values for roll, pitch and yaw, with the option of locking roll and pitch values together. Below is a complete list of the features available with the KK2 controller:

Specs.
Size: 50.5 mm × 50.5 mm × 12 mm
Weight: 21 g (Inc Piezo buzzer)
Microcontroller: Atmega324 PA
Gyro: InvenSense Inc.
Accelerometer: Anologue Devices Inc.
Auto-level: Yes
Input Voltage: 4.8–6.0 V
AVR interface: standard 6 pin.
Signal from Receiver: 1520us (5 channels)
Signal to ESC: 1520us
Firmware Version: 1.2

There's no doubt about it, the Naza FC, has been extremely popular with hobbyists all over the world [16, 17]. For entry-level enthusiasts, DJI now offers the NAZA-M Lite flight control system intended for multi-rotor stabilization of various platforms (e.g. Inspire 1) or heavy payloads in aerial photography. As the simplified version of NAZA-M, it brings out the most cost-effective solution and inherits the high reliability and stability of NAZA-M. The All-in-one design innovatively simplifies the installation and saves space and weight. It contains 3-axis gyroscope, 3-axis accelerometer and barometer in its light and small Main Controller. It can measure flying altitude, attitude and therefore can be used for autopilot/automatic control. The controller includes GPS, compass, LED indicators, intelligent orientation, and home return features [18]. Below is a complete list of the features available with the NAZA NAZA-M Lite:

All-in-one Design
Intelligent Orientation Control
Built-in Gimbal Stabilization Function
New Assistant Software & Firmware Online Update
Multiple Flight Control Modes/Intelligent Switching
Enhanced Fail Safe Protection
Advanced & Improved Attitude Stabilization Algorithm
GPS Module Available/Accurate Position Hold
Two Levels of Low Voltage Protections
Independent LED Module
Supported ESC output: 400 Hz refresh frequency
Hovering Accuracy (GPS Mode): Vertical (±0.8 m), Horizontal (±2.5 m) Max Yaw Angular Velocity (200°/s), Max Tilt Angle (45°) Max Ascent/Descent Speed (6 m/s)
Dimensions: MC (45.5 mm × 31.5 mm × 18.5 mm), GPS & Compass (46 mm diameter × 9 mm)
Assistant Software System Requirement: Windows XP SP3; Windows 7

3.9 Radio Control Transmitter

The communication network is one of the most important technologies for enhancing bi-directional coordination between the cyber system and the physical system. It enables the transfer and exchange of information between the mobile and fixed devices such as tablet PCs and desktop computers. The transmitter is a radio transmitting device operated by the ground operator. The radio transmitter is a device that transforms the flight intention of the pilot into electronic signals. The receiver mounted on the drones is equipped with a thin antenna wire to receive the transmitted radio waves, the command wave from the ground pilot. There are a variety of options to consider when purchasing a good transmitter, such as the display screen (resolution, backlight, etc.), how the sticks feel, gimbal control quality and so on. It is important to note the receiver and the transmitter are interconnected and must be purchased together. This is because most receivers only work with their own transmitters. For instance, FlySky (Table 3.7) is known to be one of well-known brands at a good entry-level radio who produces a highly functional transmitter at a low price. FlySky FS-i6 [19] includes all of the most important features required to fly mini-drone without a lot of deliberations. Associated with a high sensitivity receiver, the FlySky FS-i6 transmitter guarantees a jamming free long range radio transmission (1 km + range) with multi-directional antenna. Each transmitter has own unique ID when binding with a receiver. The receiver saves that unique ID and can only accept data from the unique transmitter. This avoids collecting another transmitter's signal and dramatically decreases signal interruption.

The number of channels refers to each separate controllable function of the drone. Two or three-channel drone can only be lifted up, or it can move back and forth only. A typical 4 channel drone will have rudder, elevator, throttle and ailerons, as four primary functions for airplane control. There are no specific standards for how many channels are appropriate.

This depends entirely on the functionality the user desires to mount on the drones and on the performance of the drones. This channel number cannot be upgraded, so you should purchase the number of channel that matches your purpose when you first purchase to avoid redundant investment. Drones with various functions have at least 6, 7, 8 or more channels to operate the primary controls plus any additional

Table 3.7 Specification of FlySky-i6 transmitter and receiver

<table>
<tr><th>FlySky – i6 transmitter</th><th>FlySky – i6 receiver</th></tr>
<tr><td>Radio frequency: 2.4 GHz ISM</td><td>Channel: 6</td></tr>
<tr><td>Bandwidth: 500 kHz</td><td>Radio frequency: 2.4 GHz ISM</td></tr>
<tr><td>Wireless communication distance: 1 km</td><td>Power: 4.5 V ~ 6.6 V/<30 ma</td></tr>
<tr><td>Output power: <=20 dbm (100 mW)
Working current: <=100 mA</td><td>Net weight: 6.4 g</td></tr>
<tr><td>Working voltage: 1.5 V × 4 AA</td><td>Dimensions: 40.4 × 21.1 × 7.35 mm</td></tr>
<tr><td>Dimensions: 174 × 89 × 190 mm</td><td rowspan="2">Requires: 4 × AA type battery for operation</td></tr>
<tr><td>Weight: 392 g</td></tr>
</table>

Table 3.8 Specification of DJI Inspire 1 transmitter

Operating frequency	Transmitter to transmitter: 5.728–5.850 GHz
	Transmitter to aircraft: 2.400–2.483 GHz
Range	Line-of-sight: Up to 6561.7′/2000 m
Receive sensitivity	1% PER:−93 dBm
EIRP	8 dBm at 5.8 GHz; 20 dBm at 2.4 GHz
Connectivity	1 × USB type A female for mobile device
	1 × Micro-USB for firmware updates
	1 × Mini-HDMI (type C) for FPV glasses or a monitor
	1 × CAN-bus port for future accessories
Dual user capability	Host-and-slave connection
Mobile device holder etc.	Tablet or smartphone, dedicated buttons for video and photo capture, Gimbal control dial
Output power	9 W
Power requirements	1.2 A at 7.4 VDC
Battery	6S LiPo; 6000 mAh
Charging temperature	Less than 3 months: −4 to 113 °F/−20 to 45 °C
	More than 3 months: 72–82 °F/22–28 °C
Storage temperature	<3 months: −4 to 113 °F/−20 to 45 °C
	>3 months: 72–82 °F/22–28 °C

functions such as retractable landing gear, landing lights and camera operation to name a few. The FlySky FS-i6 model is great if you only need 6 channels (4 for the movement of the quadcopter, 1 for an emergency beeper, and 1 to change flight modes) [20].

The transmitter for DJI Inspire 1 Quadcopter is used to operate the drones and gimbals. Two transmitters for one aircraft could be operated simultaneously, one person to pilot the drone and the second person to operate the camera. The transmitter uses a 2.4 GHz band for the control signal, plus there is a 5.8 GHz radio, allowing two controllers to be bound together for dual operators. An antenna's effective isotropic radiated power (EIRP) is calculated by the transmitter's radiated power and the antenna's gain. It is often stated in terms of decibels over a reference power emitted by an isotropic radiator with equivalent signal strength. The higher the transmitter output and antenna gain, the higher the EIRP. As a result, the wireless communication distance becomes longer. A complete list of the features available with the Transmitter for DJI Inspire 1 is shown in Table 3.8 [21].

3.10 Radio Communication

The drone system largely consists of aircraft, ground control system (GCS) and wireless communication system. In order for the drones to perform their assigned tasks properly, the most important thing is the wireless communication system that continuously connects the drone body and the ground control system. This is because the remote controller or the ground-based control system can give commands for controlling the task-performing instrument through wireless communication. It is easy to think that the ground control system here is a large-scale control system such as broadcasting station, telephone stations, airline ground control station and satellites ground control station, etc. But actually, the remote controller in drone flying as a hobby plays the role of such a ground control system. Wireless communication in drone is a far more important than manned aircraft, because it operates in a manner that monitors the state of the aircraft in real time without human pilot. Wireless communication technology plays a role like the umbilical cord[6] of a fetus in a drone because drone cannot exist without wireless communication, and it operates solely on wireless communications, unlike a manned aircraft. Unmanned aerial vehicles are equipped with sensors that monitor the movement state of the aircraft (speed, altitude and location coordinates, etc.) and the operating status of various components such as motor and battery. Wireless communication plays a role a real-time transfer of information essential for monitoring aircraft status to the ground control station, and serves to transmit the command data of the ground system to the unmanned airplane. This requires real-time, high-reliability communication capabilities, and the development of a user interface that displays aircraft status properly and dictates its mission.

3.10.1 Basic Knowledge for Radio Communication

The transmission of radio waves is a technique used in various fields such as satellite communication, mobile communication, TV and radio broadcasting and terrestrial wireless link (mobile phones, wireless telephones used at home, wireless automobile starters, traffic cards, ID tags, Barcode tags, GPS, weather radar, etc.). From the very beginning, the original meaning of the word radio was that it had no wire, and it has the same root term as radiate (to send out, rays, electromagnetic waves, waves, heat etc.). Ultimately, the fundamental definition of the word radio is to refer to the whole concept of 'wireless'. The term radio (meaning that transmits voice by radio wave broadcasting), has become the most familiar radio medium, as it is the first time to inform the wireless medium to the public, thus the name "radio" is settled to mean wireless audio broadcasting. An electromagnetic wave allows information to travel without a line. Wireless communications is a communication technology that utilizes radio waves to transmit information to a remote location without connection by wires. Examples of the technologies include microwave transmission technology, antenna design technology, radar technology, mobile telecommunication, satellite communication, and short-range wireless communication technology.

[6] The umbilical cord is a tube-like structure that connects a fetus to the mother's placenta, providing oxygen and nutrient-rich blood and removing waste.

Because the electromagnetic wave itself means wave, there is always frequency. Also it exhibits a undeniably different characteristics depending on the frequency. There are too many wireless devices (TV, radio, mobile phone, computer etc.) around us. When we try to allocate a new frequency, we are forced to use higher frequencies. Long waves with relatively long wavelengths can travel considerably farther along the surface of the earth. However, since short waves do propagate only to the visible range on the surface, radio waves should be relayed every 50 km. The amount of information that can be transmitted by one radio wave increases as the EMR (electromagnetic radiation) frequency increases (the wavelength is short). It is necessary to use a radio wave having a short wavelength for communications that need to send a lot of signals even if the transmission range is somewhat short (Fig. 3.8). Bandwidth of EMR is closely related to the amount of information. The band of AM broadcasting is only 9 kHz so that it can transmit only the voice of a person. However, FM (200 kHz) is called a high fidelity medium because it can perform high-quality broadcasting in stereo. In this manner, various types of EMR are used in wireless communication so that they can utilize advantages of each transmission scheme.

The hertz (symbol: Hz) is the derived unit of frequency in the International System of Units (SI) and is defined as one cycle per second [22]. It is named for Heinrich Rudolf Hertz, the first person to provide conclusive proof of the existence of electromagnetic waves. Hertz are commonly expressed in multiples:

Kilohertz: 10^3 Hz, kHz 1000 cycles per second
Megahertz: 10^6 Hz, MHz, 1,000,000 cycles per second
Gigahertz: 10^9 Hz, GHz 1,000,000,000 per second
Terahertz: 10^{12} Hz, THz 1,000,000,000,000 per second

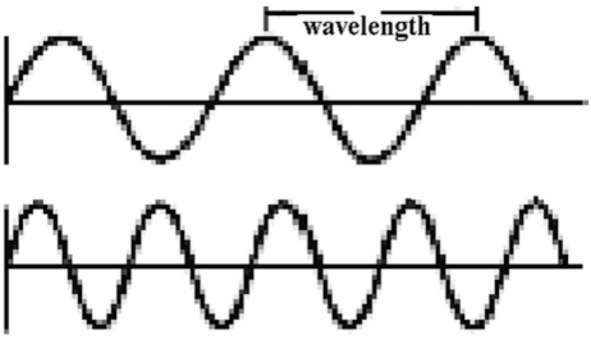


Fig. 3.8 The conceptual diagram for wavelength and frequency
The figure above shows an electromagnetic wave with a low frequency at a long wavelength while the figure below shows an example of an electromagnetic wave with a high frequency at a short wavelength. Since frequency and wavelength are inversely proportional, the frequency decreases as the wavelength increases. Wavelength of light λ (m) = velocity of light v (m/s) / frequency of light f (Hz), $\lambda = v/f$

There are many kinds of waves. Sound is called sound wave, so there is frequency. Human vocal cords can produce sounds with a low frequency (about 100 Hz) to a high frequency (about 8000 Hz). The human ear is a little more sophisticated, it is possible to distinguish between sound waves from 20 Hz to 20 kHz. It is easy to distinguish between the high and low frequency of a sound by considering that female voices are high-frequency soprano while male voices are low-frequency bass. The difference between radio waves and sound waves is the velocity.

The velocity of the sound wave is as low as 340 m/s, since it spreads due to the vibration of the air. Meanwhile the radio wave is as high as 300,000 km/s, since its propagation is caused by the interaction of the electric field and the magnetic field. The transmission performance of a communication system depends on the bandwidth of the channel used. Bandwidth refers to the difference between the highest and lowest frequencies of signals available in the network as a range of frequencies that a channel can transmit.

The radio spectrum is the part of the electromagnetic spectrum from 3 Hz to 3000 GHz (3 THz).[7] Electromagnetic waves in this frequency range, called radio waves, are extremely widely used in modern technology, particularly in telecommunication. To prevent interference between different users, the generation and transmission of radio waves is strictly regulated by national laws, coordinated by an international body, the International Telecommunication Union (ITU) [24].[8]

Frequencies below 300 MHz are mainly used for radio broadcasting (AM, FM) while microwave frequencies between 300 MHz and 3 GHz are mainly used for mobile communication [25]. And frequencies above 3 GHz are currently used in various radar equipment or satellite communications (Table 3.9).

Although we listen to the radio at the frequency, the radio is not visible and it is everywhere in our lives, but it is not owned by individuals. If the same frequency as the radio is used in the drone, the radio may not be heard every time the drones fly. It can happen that the drones that fly in the sky are hit by the latest radio songs, and may be falling down. The frequency used for radio control distinguishes it from other frequencies by using a specific region among the radio waves around us. Telecommunication companies pay frequency fee to use the specified communication frequency band for a certain period. Technologies are being developed that can use frequencies in areas that were difficult to access. Techniques for dividing a finite frequency into more details allow more people to use it. If the baseband information is to be transmitted over the radio, the information signal should be converted to a high frequency signal. This process is called modulation, which means loading

[7] **Radio frequency** (**RF**) is any of the electromagnetic wave frequencies that lie in the range extending from around 20 kHz to 300 GHz, which include those frequencies used in radio communication or radar. This is roughly between the upper limit of audio frequencies and the lower limit of infrared frequencies [23].

[8] As a matter of convention, the ITU divides the radio spectrum into 12 bands, each beginning at a wavelength which is a power of ten (10^n) meters, with the corresponding frequency of $3 \times 10^{8-n}$ hertz, and each covering a decade of frequency or wavelength. For example, the term *high frequency* (HF) designates the wavelength range from 100 to 1 m, corresponding to a frequency range of 3–300 MHz.

Table 3.9 Radio spectrum range simplified from conventional bands divided by the International Telecommunications Union (ITU)

Frequency and wavelength in air	Example uses
Very low frequency 3–30 kHz (100 km–10 km)	Navigation, submarine communication, wireless heart rate monitors, geophysics
Low frequency 30–300 kHz (10 km–1 km)	Navigation, AM long-wave broadcasting, RFID (radio-frequency identification), amateur radio
Medium frequency 300–3000 kHz (1 km–100 m)	AM medium-wave broadcasting, amateur radio,
High frequency 3–300 MHz (100 m–1 m)	Shortwave broadcasting, RFID, marine and mobile radio telephone, FM, television broadcasts, line-of-sight ground-to-aircraft and aircraft-to-aircraft communications, land mobile communications, amateur radio, weather radio
Ultra high frequency, 300–3000 MHz (1 m–100 mm)	Television broadcasting, microwave oven, microwave devices/communications, radio astronomy, mobile phones, wireless LAN, Bluetooth, ZigBee, GPS, satellite radio
Super high frequency, 3–3000 GHz (100 mm–100 μm)	Radio astronomy, microwave devices/communications, wireless LAN, most modern radars, communications satellites, satellite television broadcasting, amateur radio, satellite radio, computing/communications, remote sensing

information on radio waves. The purpose of modulation is to transfer the information to the remote party at a distance without loss. When a person speaks with only his voice without any equipment, the sound can be transmitted over a few ten meters. When loading voice information to radio waves through modulation, it is possible to transmit distances of several hundred kilometers or more.

3.10.2 Various Network Techniques of the Wireless Controller

A wireless communication of the drone is enabled to communicate with each other by the transmitter and the receiver using the same radio wave. Civilian drone communications systems typically operate on frequencies of 2.4 and 5.8 GHz. Drone communications systems work by using one frequency to control the aerial vehicle from the ground via a remote pilot while the other frequency is used to relay First-Person View (FPV) video [26]. Currently almost all remote controllers use transmitters that communicate over a frequency of the 2.4 GHz band. 2.4G Hz remote controllers rarely overlap with each other due to extensive frequency range. Further, some remote controllers and transceivers have the ability to instantaneously convert frequencies and to connect to a new frequency band when overlapping frequencies occur. This has resulted in the prevention of drone crashes due to frequency confusion. Generally, original information signal such as video, audio, and text is present in the lower frequency band, that is called a base band. There are Bluetooth, Wi-Fi

Table 3.10 Various networking techniques of wireless controller in drone

characteristics	Bluetooth	Wifi direct	RF modem	LTE D2D (LTE direct)
Spectrum	Unlicensed	Unlicensed	Licensed	Licensed[a]
Operating frequency	2.4–2.48 GHz	2.4–2.48 GHz, 5 GHz	2.4–2.48 GHz, 5.8 GHz	Works over 2–300 GHz frequency[b]
Transmission speed	1 Mbps[c] to 24 Mbps	1–54 Mbps Wi-Fi P2P: 300 Mbps	1, 2 Mbps	Maximum 300 Mbps
Transmission distance	Up to 50 m, but most devices only achieve10 m	Around 50 m indoors and 100 m outdoors	Depend on antenna about 100 ~ 200 m per 100 mW	500 m-hundreds of kilometers Around 500 m at 2 GHz
Power output	1 mW	50 mW	2.4 GHz:300 MW, 5.8 GHz: 10 MW	200 mW can cover radius of 500 m.

[a]Operators can control the devices and beacons that can access that spectrum, which gives better control, management and privacy
[b]There are very many frequency bands used for LTE versions. The spectrum allocated for LTE varies around the world and as a result there many LTE bands and frequency allocations [27]
[c]**Mbps** means *megabits per second*. Mb is used in reference to **download and upload speeds**

direct, RF (Radio Frequency) modem, LTE D2D (Device-to-Device), available for civilian drones (Table 3.10). Satellite communication is mainly used in military drones. Even a drone of the same specification can perform its best according to these various kinds of wireless communication techniques.

3.10.2.1 Bluetooth

Bluetooth is mainly used when low-power (100 mW) wireless communication is needed over short distances (about 10 m). Bluetooth use ISM[9] band (the industrial scientific and medical) between 2.4 and 2.48 GHz, which is available to anyone in the world for free without government permission. In this frequency band, low power output is used to minimize interference since it is based on the assumption of joint use that allows mutual interference.

Various short-range wireless technologies like Bluetooth, WiFi Direct and LTE Direct can be used to enable D2D (Device-to-Device) communication. For example, Bluetooth 5 supports a maximum data rate of 50 Mbps and a range close to

[9] ISM refers to the operation of equipment or devices used in restricted areas by generating radio wave energy for industrial, scientific, medical, household, and similar other than telecommunications. Since they are used in common, they do not pay a separate fee for using the frequency. Users have no regulatory protection for interference generated by ISM device operation. We use this frequency band in wireless LAN where we can get around us easily.

240 m, WiFi Direct allows up to 250 Mbps rate and 200 m range while LTE Direct provides rates up to 13.5 Mbps and a range of 500 m [28]. If one Bluetooth device finds another Bluetooth device within 10 m, both devices are automatically connected. Bluetooth is a 1: 1 connection between devices, so there is no crosstalk. When reconnected, it remembers the previous device information, so it is easy to connect again after the initial connection. Recently devices equipped with Bluetooth, are rapidly spreading, such as smart phones, tablet PCs, notebooks, hand-free devices, and network access points. It offers a slower transmission speed (up to 24 Mbps), compared to 300 Mbps of Wi-Fi P2P (Peer-to-Peer) and making it unsuitable for high-quality multimedia content transmission. In general, Bluetooth is a technology that provides low-power communication, rather slower than Wi-Fi, so it is suitable for drones that do not require a lot of data transfer. In this regard, there is a disadvantage in that it is difficult to transfer high-capacity data such as photographs or moving pictures. Due to limitation of short distance communication it is mainly used for toy drone that can be controlled indoors or steerable by smartphones.

3.10.2.2 WIFI

Wifi is the abbreviation of ‘Wireless Fidelity’ which means superior quality comparable against the wired cable. Currently, most wireless LAN (Local Area Network) devices are recognized as “Wi-Fi = wireless LAN” because they conform to the Wi-Fi standard. In the early days, it was installed mainly in personal computers, but recently it has been applied to various devices such as smart phones, printers, TVs, refrigerators, and washing machines. It is spotlighted as a wireless technology indispensable for building an Internet of Things environment by connecting smart phones with various devices. The WiFi frequency band uses Industrial Scientific and Medical (ISM) bands 2.4–2.48 GHz and 5.8 GHz.

Wi-Fi Direct, initially called Wi-Fi P2P (Peer-to-Peer), is Wi-Fi standard enabling devices to easily connect with each other without requiring a wireless access point. Wi-Fi Direct allows two devices to establish a direct Wi-Fi connection without requiring a wireless router [29]. Wi-Fi direct is rapidly becoming popular since product certification in 2010 and is being currently installed in most smartphones and tablet PCs on the market.

Thus, Wi-Fi direct is the wireless communication technique, we contact the most commonly in our everyday life. As it is the most popular wireless communication technique, there are several convenient points. First, data transmission speed is faster than Bluetooth, and it is possible to transmit video in real time along with signals controlling the drone. Drone flight planning programs (e.g. Pix4D capture) have a tendency to utilize in conjunction with a smartphone, because it is possible to connect to a smart phone without a separate receiver. Wi-Fi, however, is not the best option for drones. First, since Wi-Fi modules have limited range of communication to control the drones (Home AP, Access Point: around 20–30 m, the enterprise AP: approximately 100–200 m).

Second, if the communication range is expanded, interference problems with devices using the same channel occur because Wi-Fi uses the unlicensed ISM band. Multiple devices can be connected at the same time within a valid range to enable stable communication. This is not only a matter of the drones but also the limitations of all IOT devices using Wi-Fi. Conflict between them would frequently occur since it is so popular. There is an advantage that can be installed at a low cost compared to other wireless communications such as satellite communications. Due to these limitations, Wi-Fi wireless communication is not enough to activate drones in a wider variety of applications. Such limitations of wireless communication caused the drones to fly only at the level of the individual hobby activity.

3.10.2.3 RF Modem

Radio modems transfer data wirelessly across a range of up to tens of kilometers. Using radio modems is a modern way to create Private Radio Networks (PRN). Private radio networks are used in critical industrial applications, when real-time data communication is needed. Radio modems enable user to be independent of telecommunication or satellite network operators. Typical users for radio modems are: Automatic Meter Reading (AMR) systems, land survey differential GPS (Global Positioning System), telemetry applications and many more [30]. The RF modem communication enables bidirectional data communication of about 19,200 bps. The RF modem can maintain communication performance of an ordinary telephone in a region where the communication environment is not suitable, such as a sea, a mountain, and islands. Unlike Wi-Fi, RF modems require users to install individual devices and antennas. This extends the communication distance to be longer than Wi-Fi. Unlike Wi-Fi, which always maintains the same channel, there can be a difference in communication distance of individual outputs.

However, it is difficult for the general public to install RF modems easily because it is necessary to equip each device individually. Since applications usually require high reliability of data transfer and very high uptime, radio performance plays a key role. Factors influencing radio performance are: antenna height and type, the sensitivity of the radio, the output power of the radio and the complete system design [30]. Also, by installing a directional antenna at a fixed location, it is possible to transmit and receive data with a power of 10 W ~ 50 W, and it is possible to transmit and receive data every minute without any loss of data at 30–40 km in any weather condition. Professional drone is equipped with 'RF' modem suitable for long distance communication. While some cheap drones exchange signals in low frequency bands such as 27 and 40 MHz, most professional drones are transmitting far away at the 2.4 GHz band.

The main reason that professional drones equipped with the RF modem, is that they can control the aircraft at relatively high speeds over long distances. Even with the same 2.4 GHz frequency, the communication range varies from 30 ~ 50 m to km distance depending on the output power. The transmission distance is about 100 ~ 200 m per 100 mW. It is usual to fly about 200 mW on a hobby level while

600 mW or more is applied when high power is desired. When generating a high power output, we have to consider the cooling because it is very hot. It should be also taken into account heavy weight caused by a high powered output. The 2.4 GHz band controls the signals of the remote controller and the receiver while the 5.8 GHz band is used to receive video and photo data taken from the drones. However, there are limitations at 2.4 and 5.8 GHz band. The radio wave interference can be occurred because they use the same bandwidth as Wi-Fi. In particular, in case of operating multiple drones simultaneously in the downtown area, there is a risk of safety accidents such as the drone crash due to radio-wave interference between drone-WiFi and drone-drones. In order to generate high-powered output (e.g. 300 mW) with license-exempt radio equipment, it is usual to be approved by the national competent authorities in order to minimize safety accidents due to radio interference.

3.10.2.4 LTE

A cellular network or mobile network is a communication network where the link is wireless. The network is distributed over wide geographical areas called cells, strategically interconnected through a central exchange. A cell typically uses a different set of frequencies from neighboring cells, to avoid interference and provide guaranteed service quality within each cell. This enables a large number of portable transceivers[10] (e.g., smart phone) to communicate with each other and with fixed transceivers and telephones anywhere in the network, via base stations, even if some of the transceivers are moving through more than one cell during transmission. Since 1G (generation) was introduced in the early 1980s, new wireless mobile telecommunications technology has been released roughly every 10 years. All of them refer to the technology used by the mobile carrier and device itself; they have different speeds and features that improve on the generation prior to it. Long Term Evolution (LTE) is a 4G wireless broadband technology, and new high speed data cellular telecommunications technology [31].

In recent years, the overwhelming spread of smartphones and tablet devices has resulted in a rapid increase in high-capacity mobile internet traffic each year, which is making the cellular network overloaded. If new mobile communication market between people and things or communication between things is activated, the traffic to the base station is expected to increase to such an extent that it cannot be supported. Direct communication between terminals is getting more attention in order to reduce the overhead of the base station. This is a method of directly exchanging traffic between terminals without going through a network infrastructure. LTE D2D communications is a peer to peer link which does not use the cellular network infrastructure, but enables LTE based devices to communicate directly with one another when they are in close proximity [32]. D2D is a method of directly communicating between terminals without going through the base station in a similar manner to the Internet of Things (IoT) developed from M2M (Table 3.11). Machine-to-machine (M2M) com-

[10] A **transceiver** is a device comprising both a transmitter and a receiver in a single housing.

Table 3.11 Comparison of M2M versus IoT

Category	M2M	IoT
Definition	M2M as the name describes is all about interaction between machine and machine. Machines use network resources to communicate for the purposes of remote monitoring and control.	The term used to describe the network of objects that communicate with each other via IP (internet protocol) networks without any human interaction.
Foundation technique	Remote access machines and connect back to central human management	Sensors and other cyber-based physical systems usually employ cloud platform.
Number of devices connected	Isolated instances of device-to-device communication (point-to-point communications) using either cellular or wired networks	The IoT refers to a wider variety of devices and equipment, beyond what's encompassed within the realm of M2M.
Internet connection and big data collection capability	Not necessary rely on internet connection.	Require an active internet connection
	M2M with internet protocols could be considered a subset of the internet of things	Big data with sensor is a core concept behind the emerging Internet of Things [34].
Use case	Primarily commercial and industrial service management through remote diagnostics, remote troubleshooting, remote updates	Dealing with all forms of machinery, vehicles, electronic equipment, and a vast array of devices: personal devices (smartphones, tablets, speakers, cameras and wearables); vehicles (cars, trucks, boats and aircraft, including drones). Smart home, smart grid, smart factory, smart city

munication refers to data communication among IoT devices without any human intervention. M2M devices cover a broad variety of applications (e.g. surveillance, security and intelligent transport system, etc.), influencing different markets and environments. M2M is considered as the key enabler of the IoT vision [33].

If the LTE modem is installed in the drones, it is possible to communicate directly between the terminals without going through the communication base station. It has the merit of activating Internet of things in a real sense since D2D can overcome the drawbacks of the existing drones that could only be controlled at close range. Advances in telecommunication technologies enable controlling the drones flying at high altitudes from considerable distances. 4G LTE systems as well as the upcoming 5G system have the ability to provide reliable mobile connectivity to drones for aerial data collection, processing and analysis [33]. The LTE D2D drones have the advantage of transmitting real-time Full HD video and controlling the camera by sending a take-off command from a distance of thousands of kilometers away. For instance, an experiment succeeded in piloting the drones located in South Korea in Germany, 9300 km away. The drones, commanded in Germany, kept a height of around 50 m and flew over about 200 m of lawn open space for 5 min. During the flight, the images taken by the drones were sent to the pilot's smartphone in

Germany. The advance communication technologies among these IoT devices on board of drone will support reliability, connectivity and high mobility of the drones flying in the air. For example, drones will gain benefits using 5G for real-data and high resolution video streaming [33].

If the drones use a cellular system, the drone manufacturer should build the drones with equipment that can be associated with the telecommunications company. Customers using drones are charged monthly communication fee. It's easy to understand that the data usage fee on smartphones is applied to drones. As the drones are used in various fields, the farther they fly, the higher the cost of the data. This can be a burden for drone user. In addition, LTE networks are currently available only on the ground, making it difficult to operate at high altitudes. However, it will not have a significant impact on the majority of drones since they do not need to fly over 1 km altitudes.

3.10.2.5 Satellite Communication Systems

If the wireless communication techniques so far have been mainly used in civilian applications, satellite communication is a wireless communication technique that is mainly used for military purposes. Satellite communication is a long-distance communication method in which a satellite plays the role of a relay station, delivering a communication signal through a satellite launched in the sky. Satellite communication enables two stations on the earth to communicate through radio broadcast. The satellite communication is advantageous over terrestrial communication because of the enormous coverage.

A satellite is classified as a military satellite, a weather satellite, a scientific satellite, or a communication satellite. Among them, a communication satellite circulates the earth to relay a communication signal. Communication satellites provide an effective platform to relay radio signals between points on the ground. The users who employ these signals enjoy a broad spectrum of telecommunication services on the ground, at sea, and in the air. Among the satellites, there are geostationary satellites that appear to be stationary on Earth's orbit, revolving at the same speed as the earth's rotation. Communication satellites mainly use this geostationary satellite. Satellite links have long been used to carry telephone calls to extend the reach of public and private networks. Satellite communications is a natural facility for serving users while they travel by various means. These include ships on oceans, rivers, and lakes; commercial and private aircraft; land-based vehicles of various types; and individuals using portable and handheld devices [35].

The most basic type of satellite communication systems employs one or more geostationary satellites (space segment) and a tracking, telemetry, and ground station. The ground segment is very diverse because the Earth stations are installed and operated by a variety of organizations (including, more recently, individuals). Importantly, we have moved out of the era when the space and ground segments are owned and operated by one company. Over time, the Earth station has become more specific to the purpose and lower in price. Currently very sophisticated small Earth stations can be purchased for about the price of a personal computer [35].

Satellite communication uses a microwave whose frequency is higher than 1 GHz to pass through the ionosphere because the communication range is continental. Therefore, it is possible to communicate at high speed and large capacity than any wireless communication on the ground. In addition, since the satellite as a base station is located outside the earth, communication is not restricted even if a disaster occurs in the earth.

Unlike cellular systems and Wi-Fi environments, where communication networks are mostly deployed on the ground, they can be used in situations where ground-based communication facilities are collapsing due to disaster or war. However, because the communication distance in the earth is very long, the round-trip time of radio waves becomes long. There may be a delay during communication utilizing satellite communications. Satellite communication makes a high-performance wireless communications possible due to the use of satellites. However, there are many restrictions to be used in the private sector in addition to military purposes as listed below; highly expensive satellite launching costs, base station construction costs, satellite production costs, the short lifespan of satellites relative to high initial investment, saturation of satellite orbits and frequencies, difficulties in hiring professional workers.

3.11 Software

3.11.1 Essential Background for Drone Software

The term hardware refers to the tangible parts of a drone system, that is, the physical equipment of the drone. A motor, ESC, and propeller are examples of drone hardware. Understanding the various physical components of a drone system will help you understand how the system works as a whole. Hardware consists of tangible objects such as: electronic circuits, input/output devices, cables and the likes while software refers to intangible side such as ideas, algorithms or instructions. An intermediate form between hardware and software is called firmware. Software is anything that controls hardware such as programs, routines, and symbolic languages. Software controls any electronic hardware such as car, drone, phone and coffee maker. The hardware by itself, even when powered-up, is incapable of producing useful outputs for users. The hardware must be instructed by software how to direct its operations in order to transform input value into suitable output to the user. This is the role of software that controls the operation of a drone system. If the FC (flight controller) is the physical brain of the drone, then software is its mind.

In the modern society where various electronic devices are flooded by the rapid development of science and technology, software is an essential element to closely link human and hardware. Recently the role of software continues to grow rather than simple hardware in all areas of IT because it can enhance application value of hardware much more than past. Software has become an indispensable element not only in the IT industry, but also in all industries including defense, aviation, security, and environment. The software industry itself has been referred to as a key infrastructure in the digital economy, since it plays a key role as a source increasing the added value of the hardware. Such software-focused IT ecosystem is spreading through PCs, smart phones, internet, smart cars, and robots. In this regard, drones could not be exceptions.

Any drone (e.g., RTF drone or Plug-And-Fly Aircraft (PNF), or ARF drone kit (Almost Ready-to-Fly) consists of multiple layers of software. These layers are commonly referred to as the software stack. Each layer relies on other layers for its proper operation and function (Fig. 3.9). Practical drone systems divide software into two major classes between the user and the system software, although the distinction is somewhat arbitrary, and often blurred. System software helps run the drone hardware and drone system. It includes operating systems, firmware, device drivers, middleware, utilities and more.

The general model of a drone consists of a system software (firmware, device driver) and application output system. Software is a crucial element in connecting the user to the aircraft hardware, since it is the foundation to develop and run various applications for a variety of hardware. Yet, most drone software has been developed to operate in certain drone alone. Typically, main concern of users utilizes the drones to get the results desired by the users themselves. Therefore, the main interest of the users is in the application program. Especially, it is difficult to expect the extended application and commercialization of the drone as the CPS, without developing the application software. Since the application software depends on the operating system (OS), an OS as platform must be standardized beforehand so that a foundation for utilizing the drone in various applications can be provided. The software development to lead the drone OS market share is being under way, as Microsoft window in the PC, Google Android in the smartphone. In order for drones

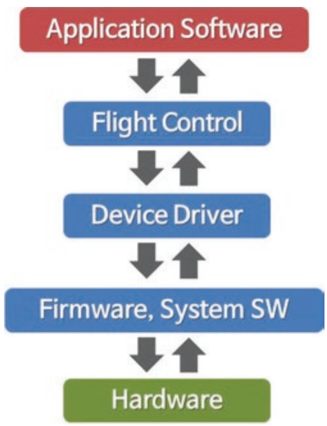


Fig. 3.9 Schematic representation of drone software hierarchy

to become important devices for human life such as smart phones, it is necessary to develop a variety of software extending its functions.

3.11.2 Hierarchy of Drone Software

Basically, both drone and GCS (Ground Control System) can be considered as a computer system consisting of peripheral hardware, operating system and user software. The hardware for drone systems includes the sensors, actuators, communication modules, processor and etc. The operating system resides in the processor which is responsible for interfacing with peripheral hardware. As shown in Table 3.12, there are various layers in the software system starting from the bottom hardware to the top application software (Fig. 3.9). Each lower layer provides services requested by the upper layer, such as device drivers, networking services and so on. The software system design thus involves all the layers from hardware interfaces to user applications. At the very bottom there is a separate device driver and firmware layer for running the hardware. More commonly known as a driver, a device driver or hardware driver is a group of files that enable one or more hardware devices to communicate with the drone's operating system. Middleware is software which lies between an operating system and the application software. The software operating the FC (flight controller) includes a communication handler, an algorithm monitoring the state of the aircraft, an alarm signal, and a hovering algorithm. At the top level, the user can actually use various interfaces depending on the application such as navigation function, mapping function, mission execution function, vision processing function, video streaming and collision avoidance function etc. The application software consists of user data, user programs and protocols. It is in the top layer of the software architecture.

Table 3.12 Hierarchy of drone software

Hierarchy	Application examples
Top application SW User SW	Taking pictures, vision processing, obstacle avoidance, video streaming[a], flight planning (Pix4D capture), flight simulating (Real flight simulator), 3D mapping (Photoscan), and specific mapping purposes (agriculture, building, road etc.)
O/S (software operating the FC)	It is a program that helps users to fly drones even without knowing the complicated hardware. Monitoring the state of the aircraft, an alarm signal, low battery warning
Flight control	Attitude control, hovering (roll/pitch/yaw, throttle)
Embedded system software/embedded firmware	Hardware drivers, middleware, communication protocol handling, power managing
Bottom hardware	Motor, gimbal, battery, sensor (e.g. GPS), actuators, communication modules, processor

[a]Video streaming is a type of media streaming in which the data from a video file is continuously delivered via the Internet to a remote user.

3.11.3 Types of Software

3.11.3.1 System Software

System software controls the drone hardware directly, whereas application software is targeting user as interface for hardware. System software is an interface or buffer between application software and hardware and controls the drone hardware and acts as an interface with applications programs. System software enables the various hardware components of the drone to communicate and makes the hardware respond to the user's needs. The operating system provides an interface between the drone hardware and the user or the application software. There are no standardized operating systems for drone until now. The operating system has two primary functions. First, it manages the drone hardware and any external devices. For example, the operating system controls the FC, receives input from the remote controller or other input device. Second, the operating system contains instructions for running application software. For this reason the operating system software is frequently called the software platform. Most application software is written for one particular operating system. Some application software, however, are capable of running on multiple operating systems and are referred to as cross-platform applications.

3.11.3.2 Application Software

Application software is what most people think of when they think of software. Application software is also called "App" or "Application" and is also known as an application program. Application software interfaces with the operating system which interfaces with the hardware. Application software works at the closest position to the user when viewed its roles and functions. It is programs to achieve the purpose of an embedded system (taking pictures, checking location coordinates in drone, etc.). Application software can be written for a specific user's application (custom software), or it can be mass-produced for general use (commercial or packaged software). A safety diagnosis package for a specific building using drone might cost many thousands of dollars, whereas a commercial word processing package such as Microsoft word might cost only a few hundred dollars at a retail store.

A typical example of application software associated with the drones is DJI GO, a mobile application distributed by Chinese drones company DJI. DJI GO has the function to control the hardware that are mounted on the drones sold by DJI. DJI GO also has an operating system aspect since it provides an environment to monitor, operate and manage the state of the drone hardware (FC, motor, IMU, GPS, battery etc.). DJI GO displays the remaining battery level and the numbers of GPS satellites available. The drones transmit the images taken by the camera to the user in real time. It also provides functions such as waypoints to set the drones' automatic flight path on the map. The auto track function (active track) newly released from DJI is also available through DJI GO. Application software comes in an incredible variety.

It is available for flight planning (Pix4D capture), flight simulating (Real flight simulator), 3D mapping (Photoscan), and specific mapping purposes (agriculture, building, road etc.).

3.11.4 Embedded System

As its name suggests, Embedded means something that is attached to another thing. A precise definition of embedded systems is not easy. Simply stated, all computing systems other than general purpose computer (with monitor, keyboard, etc.) are embedded systems. An embedded system is a computer system (a microcontroller or microprocessor based system) designed to perform a specific function or a specific task. Today, embedded systems are found in cell phones, digital cameras, camcorders, home security systems, washing machines, alarm systems, anti-lock brakes and many other devices. In this regard, a drone is an embedded system. An embedded system has two components. It has hardware and application software.

Embedded software is a piece of software that is embedded in hardware or non-PC devices. Embedded software is increasingly being used in smart devices. Examples of embedded software include those found in dedicated GPS, INS devices of drone. Hardware makers use embedded software to control the functions of various hardware devices and systems. Embedded software controls device functions in the same way that a computer's operating system controls the function of software applications. Embedded software is similar to firmware, as they usually serve the same function. However, the firmware is a special type of embedded software that is written in non-volatile memory (such as ROM, Read Only-memory), which cannot easily be modified. Hence the name "firm" is used primarily for running or booting up the device. In contrast, embedded software is used for the overall operation of the device [36].

Embedded software can be very simple, such as that used for controlling lighting in homes, and can run on an 8-bit microcontroller with just a few kilobytes of memory, or it can be quite complex such as the software running all of the electronic components of a modern smart car. The main difference between embedded software and application software is that the embedded software is usually tied to a specific device, serving as the OS itself, with restrictions tied to that device's specifications. Thus updates and additions of embedded software are strictly controlled, whereas application software provides the functionality in a computer and runs on top of an actual full OS, so it has fewer restrictions in terms of resources [36].

The SW industry can be largely divided into a package and an embedded industry. Embedded SW is SW embedded in HW and implements only certain functions. A package SW refers to a case where a license can be purchased as stand-alone product (Table 3.13). The necessary functions for specific application are packed well so that users can easily use the desired functions by purchasing the package SW. Package SW is the foundation product of IT industry such as MS Office, OS (Operating System) and DBMS (Database Management System). Packaged soft-

Table 3.13 Comparison of package SW versus embedded SW

category	Package SW	Embedded SW
Special feature	Comprehensive universal software for personal and business use	It is the SW which operates only in a specific product.
	It is being monopolized by certain companies in the United States.	The first stronger does not exist.
	It is expanding its role as providing additional functions in traditional HW control.	
Key cases and development characteristics	MS Office, MS window (It is developed focused on SW.)	Because it is developed in connection with HW, knowledge and experience about HW are needed.
End user side	It works when the user installs package SW using GUI.	It is automatically operated on the embedded system HW and distributed with HW.

Table 3.14 Three ways to implement the algorithm

category	Software	Firmware	Hardware
Speed	Slow	Intermediate	Fast
Production expenses	Cheap	Intermediate	Expensive
The condition of being extendible or upgrade	Easy	Intermediate	Hard

ware is a key driver of the SW industry because customers cannot use IT devices without these products. The major products of global software companies such as Microsoft (MS office, Window) and Oracle (DBMS) are also package SW. For this reason, companies and governments around the world are actively involved in developing package SW. The package SW company continues to grow at an ever-increasing rate every year.

3.11.5 Updating the Firmware

Algorithms are widely used throughout all areas of IT (information technology). It is set of rules for solving a problem in a finite number of steps and a sequence of instructions telling hardware what to do. There are three ways to implement the algorithm: software or firmware, or hardware using a mechanical or electrical circuit (Table 3.14). Firmware tends to be embedded into the hardware at a manufacturing factory. In addition, firmware is not lost when hardware loses power, whereas software, in the traditional sense, does not remain in memory when the hardware loses power [37]. Recently as the expandability of various electronic devices is increased and the functions are complicated, the logical circuit system of existing hardware has reached the limit. To solve this problem, a special storage space is created inside the hardware, and a micro-program installed to control such hardware is called firmware.

Firmware is the software most closely related to the hardware, which reinforces and controls the basic operation in accordance with the intended use of the equipment inside the hardware. It is functionally close to software. However, it has hardware characteristic that it is mounted inside the hardware and the user cannot easily change the function. The firmware contributed greatly to the growth of the electronic device industry such as the drone in that it can be manufactured with relatively simple and low cost. Recently, a flash memory has been developed in which the contents of stored data are not erased even after the power is turned off. As a result, the contents of the firmware can be modified relatively easily, so that the firmware can be updated and upgraded more easily. Drone manufacturers such as DJI often release regular firmware updates to keep their hardware compatible with the new media. For example, let's say you buy a brand new drone such as DJI inspire 1 and try to operate some of the function such as intelligent flight battery, but it doesn't work. One of the first things the manufacturer would probably suggest is to update the firmware for the battery.

Updating the firmware can be the most frustrating part of operating a drone. For instance, DJI is always improving the DJI GO App and the capabilities of their products (e.g. battery management system to optimize power supply during flight). Thus a firmware update is required once these updates are ready. Sometimes the firmware will fully control your drone and disable it from the takeoff. Thus the firmware update is mandatory because the firmware will prevent the drone from shutting down during flight. One thing to keep in mind during the firmware update process is that the batteries for the remote controller and aircraft must be fully charged since the update takes more time than expected.

3.12 Conclusion

This chapter illustrated that drone cyber systems are smart systems that consist of computational components that are seamlessly integrated through highly networked communications. In a modern, fully autonomous drone, the cyber system becomes the gateway for virtually all aspects of the smart system (smart home, smart factory, smart grid, smart city etc.). DIY drone let you know that a UAV is transformed into cyber systems as a total system of interlinked systems ('a system of systems'). Drone assembling operations as cyber system are likely to expose to lead, so wear protective gear and follow safety rules. If overheated at over 450 °C ~ 500 °C, lead fume is generated and flux is vaporized. The smoke produced by the vapor evaporates and contains other substances that are harmful to the body even if there is no lead. Be sure to wear protective equipment such as gloves and masks in well ventilated areas and do not forget to wash your hands after work. While the DIY drone assembling operations are not exact cyber systems representing traditional computer and internet, they provided opportunities to combine these typical cyber components with more complicated UAV behavior.

References

1. Kim S, Park S (2017) CPS (cyber physical system) based manufacturing system optimization. Procedia Comput Sci 122:518–524. https://doi.org/10.1016/j.procs.2017.11.401
2. Gupta A, Kumar M, Hansel S, Saini AK (2013) Future of all technologies-the cloud and cyber physical systems. Int J Enhanc Res Manag Comput Appl 2(2):1–6
3. Hahanov V, Chumachenko S, Amer TB, Hahanov I 2015 Cloud-driven traffic control: feasibility and advantages. In: 2015 4th Mediterranean conference on embedded computing (MECO), Budva, Montenegro, 14–18 June 2015. IEEE, pp 17–20. https://doi.org/10.1109/MECO.2015.7181885
4. Boyes HA (2013) Maritime cyber security – securing the digital seaways. Resilience, security & risk in transport. Institution of Engineering and Technology. https://doi.org/10.1049/PERRSR3E_ch9
5. Refsdal A, Solhaug B, Stølen K (2015) Cyber-systems. In: Cyber-risk management. Springer, Cham, pp 25–27. https://doi.org/10.1007/978-3-319-23570-7_3
6. Saalbach K (2018) Cyber war: methods and practice, 14th edn. University of Osnabruck, Osnabruck
7. Johnston C (2011) How to build your own computer: ask Ars DIY series, part I—hardware. Ars Technica. https://arstechnica.com/gadgets/2011/04/how-to-build-your-own-computer-ask-ars-diy-series-part-i/. Accessed 30 Sept 2018
8. DroneTrest (2012) Brushless motors – how they work and what the numbers mean. Springer. https://www.dronetrest.com/t/brushless-motors-how-they-work-and-what-the-numbers-mean/564. Accessed 30 Sept 2018
9. HobbyKing (2018) LDPOWER MT1306-3100KV multicopter motor (CCW), product description. HobbyKing. https://hobbyking.com/en_us/ldpower-mt1306-3100kv-brushless-multicopter-motor-ccw.html?___store=en_us. Accessed 30 Sept 2018
10. Scale Unlimited Hydroplane Association (SUHA) (2018) Understanding R/C brushless motor ratings. Scale Unlimited Hydroplane Association (SUHA). http://suha.co.nz/index.php/ct-menu-item-21/ct-menu-item-42/ct-menu-item-44. Accessed 30 Sept 2018
11. Warehouse H (2013) Understanding lithium polymer batteries: the practical guide. Hobby Warehouse. http://www.hobbywarehouse.com.au/articles/understanding-lithium-polymer-batteries-the-practical-guide.html. Accessed 30 Sept 2018
12. The-One-Who-Never-Crashes (2015) Which flight controller should you choose? Flite Test. https://www.flitetest.com/articles/which-flight-controller-should-you-choose. Accessed 30 Sept 2018
13. FPV Central (2012) KK 2.0 (KK2) multicopter controller review. FPV Central. http://fpvcentral.net/2012/07/kk-2-0-kk2-multicopter-controller-review/. Accessed 30 Sept 2018
14. Bird D (2014) KK 2.1 multi-rotor control board. The HobbyKing
15. InvenSense (2018) 3-axis. InvenSense. https://www.invensense.com/products/motion-tracking/3-axis/. Accessed 30 Sept 2018
16. Mulcahy C (2013) DJI NAZA M V2 – review. Horizon Hobby
17. Bartman (2014) Product review: DJI NAZA-M V2 w/ GPS. Dronevibes. https://www.dronevibes.com/forums/threads/product-review-dji-naza-m-v2-w-gps.17877/. Accessed 30 Sept 2018
18. DJI (2014) NAZA-M LITE user manual. DJI
19. James (2016) FlySky FS-i6 review. Propwashed
20. Technology FRM (2013) FS-i6: digital proportional radio control system (instruction manual). FlySky RC Model Technology
21. DJI (2015) Inspire 1 user manual. DJI
22. Morris W (1969) American heritage dictionary of the English language. In: American heritage. Houghton Mifflin, Boston
23. Ghirardi AA (1932) Radio physics course, 2nd edn. Radio Technical Publishing Company, Rinehart Books, New York

24. Union IT (2012) Radio regulations. Radiocommunication sector. ITU-R. International Telecommunication Union, Geneva
25. Ransom G (1955) Nomenclature of frequencies. Electr Eng 74(8):683–685
26. BATS I (2017) Drone communication systems. BATS, Inc. http://www.extendingbroadband.com/aerial-tracking/drone-communication-systems/. Accessed 28 Sept 2018
27. Wang C-X, Haider F, Gao X, You X-H, Yang Y, Yuan D, Aggoune H, Haas H, Fletcher S, Hepsaydir E (2014) Cellular architecture and key technologies for 5G wireless communication networks. IEEE Commun Mag 52(2):122–130
28. Kar UN, Sanyal DK (2017) An overview of device-to-device communication in cellular networks. ICT Express https://doi.org/10.1016/j.icte.2017.08.002
29. Wi-Fi Alliance (2018) Wi-Fi Direct: portable Wi-Fi that goes with you anywhere. Wi-Fi Alliance. https://www.wi-fi.org/discover-wi-fi/wi-fi-direct. Accessed 30 Sept 2018
30. Wikipedia (2018) Radio modem. Wikipedia
31. Fendelman A (2018) 1G, 2G, 3G, 4G, & 5G explained. Lifewire. Dotdash publishing family, Springer,
32. Lei L, Zhong Z, Lin C, Shen X (2012) Operator controlled device-to-device communications in LTE-advanced networks. IEEE Wirel Commun 19(3):96–104. https://doi.org/10.1109/MWC.2012.6231164
33. Motlagh NH, Taleb T, Arouk O (2016) Low-altitude unmanned aerial vehicles-based internet of things services: comprehensive survey and future perspectives. IEEE Internet Things J 3(6):899–922. https://doi.org/10.1109/JIOT.2016.2612119
34. Polsonetti C (2014) Know the difference between IoT and M2M. AutomationWorld
35. Elbert BR (2004) The satellite communication applications handbook, 2nd edn. Artech House, Norwood
36. Techopedia (2018) Embedded software. Techopedia. https://www.techopedia.com/definition/29944/embedded-software. Accessed 30 Sept 2018
37. Darian Muresan D (2011) Software, hardware and firmware. Digital Multimedia Design. http://dmmd.net/main_wp/software-development/software-hardware-and-firmware/. Accessed 30 Sept 2018

Chapter 4
Physical Systems

Abstract The main layers of CPS (Cyber-Physical System) are the virtual layer and physical layer. CPS requires the connection of numerous physical domains and cyber world to support AI (Artificial Intelligence) bridging IoT, Cloud and Big Data. The deep learning procedure of AI requires a numerous degree of complicated data at spatial and temporal scales which closely sense the changing state of the physical world in real-time. For the physical layer, sensors are major elements and an intelligently deployed network of sensors collects information for the real life system. IoT sensors produce vast amounts of spatial information through hundreds of millions of devices connected to people, products, and locations. Spatial data, like energy in the first and second industrial revolutions, is a key factor that determines the competitiveness of the enterprise in the 4th industrial revolution era because learning of artificial intelligence requires location and imagery data as spatial information. This spatial information makes the world we live in as digital twin. This chapter explains the relationship between sensors and spatial information as data essential to train artificial intelligence in terms of CPS such as a self-driving car.

4.1 Introduction

In CPS, the term sensor built-in the smart phone is used very broadly to define anything that senses or provides data to AI. The spread of the smart phone, which plays a key role in the sensor expansion, ultimately provides new possibilities for diverse solutions utilizing the physical layer of CPS. The sensor plays a key role in collecting 'Big Data' to support deep learning of AI which is still in its early stages.

Spatial information is necessary information to operate the CPS and acts as a public good such as air and water [1]. All the information that is used to move an autonomous vehicle is spatial information such as imagery data (visible, infrared, thermal) and location data (speed, position, and navigation map, etc.) A high-precision road map is required for the operation of self-driving car. Precise 3D–4D spatial information to implement the digital twin is required for virtual reality (VR),

J.-S. Um, *Drones as Cyber-Physical Systems*,
https://doi.org/10.1007/978-981-13-3741-3_4

augmented reality, and IoT service in various CPS such as smart home, smart city, and smart factory. A self-driving car representing CPS technology is also a platform collecting spatial information that enables the interaction of cyber versus physical system. So far, spatial information has been produced for human use, but it will be manufactured to support deep learning of artificial intelligence in the fourth industrial revolution era.

4.2 Importance of Sensors in CPS

4.2.1 Sensors as CPS Components

Sensors and actuators are twofold essential components of all CPS. Typically, the actuator is used in combination with the power supply and an assembly mechanism. Sensors and actuators cooperate with each other to monitor and react to the surrounding world. Sensors perform sensing and deliver the sensed data to the actuator, while actuators make decision and react to the environment with the right motion action. More specifically, an actuator is a device that coverts energy into action or mechanical energy. The most common electromechanical actuator is a motor that converts electrical energy to mechanical action. Sensors and actuators can be found in the macro-scale (those visible to the naked eye) and the micro-scale (those nonvisible to the naked eye).

The imaging sensor (such as CCD) mounted on the drone is not visible to the naked eye since it is micro-scale sensor. Nanotechnology is a technology manufacturing such devices in micro-scale (nano-scale). Micro-sensors can be found in chemical sensor arrays, optical sensors and acoustical sensors; temperature sensitive resistors, strain gauges, flowmeters and pressure sensors. Micro-actuators have been used for years in automobile airbags. These actuators sense a crash and actuate the airbag. Regardless of the scale, the operational principle of these devices remains the same [2].

Many types of the Internet, created over the past 40 years, are a closed cyber-physical system of the world [3]. It combines the physical and virtual worlds to improve the quality of human life. The internet combining desktop computers into a single web improves the computational and informational capacity of the world. The internet integrating mobile devices enables communication between users in social networks, regardless of location of the person. In CPS, sensors need to be interconnected such that communication can take place between offline (physical) to online (cyber). This implies that providing interoperability (e.g. data representation, data storage and data exchange) between online to offline (O2O) is the most fundamental requirements in a CPS.

In the open cyber-physical system of the world, Internet of Things (combining smart objects) monitors and control physical phenomena located between offline (physical) to online (cyber). All moving mechanisms such as the self-driving car autonomously interact with each other through the Internet. Unmanned control of artificial appliances and vehicles enables the precise positioning and optimal navigation without human intervention. Since actuators perform actions in response to the sensed events, it is necessary to design a real-time communication framework to support event detection, reporting, and actuator coordination. In area-wide CPS such as smart city, sensors and actuators are highly distributed, heterogeneous and nodes should be able to recognize the locations of the events in order to monitor, report, and react between O2O. This is quite natural that sensors in CPS need to be interconnected such that communication can take place between O2O in different location.

4.2.2 Defining Sensor

A sensor is a device that receives and responds to a signal. This signal must be produced by some type of energy, such as heat, light, motion, or chemical. Once a sensor detects one or more of these signals, it converts it into an analog or digital representation of the input signal. The smartphone is a representative product that can easily identify the sensor in our daily life which is equipped with various sensors such as imaging sensor and position sensor. Ears detect acoustic energy, eyes detect light energy, a nose and a tongue detect certain chemicals, and skin detects temperatures and pressures. The tongue, nose, eyes, ears and skin receive these signals then send messages to the brain generating a response (Table 4.1). For example, when you touch a hot dish, it is your brain that speaks you it is hot, not your skin [2].

Humans have five basic senses – sight (eye), hearing (ear), smell (nose), taste (tongue) and touch (skin) correspond to the human sensory organs respectively. Many similarities are seen between living organisms and machines when modern sensor and living organism make observations, accumulate data and process it into usable information. However, human sensory organs have practical limitations in expressing data range as digital number, and they are not suitable for particular offline measurements for the physical system. For instance, it is possible for human

Table 4.1 Human sensory organ versus man-made sensor

Human five basic senses	Sensor type
Sight(light)	Photo sensor, optical sensor, imaging sensor, photodiode
Auditory sense	Acoustic sensor: sensor which detects the sound waves of the voice and phone ringtone (e.g. microphone).
Smell	An electronic nose is a device intended to detect odors or flavors. It is chemical gas sensors that use pattern recognition to recognize, identify, and compare odors [4].
Taste	Namely an electronic tongue is a taste evaluating device that uses sensors mimicking the human tongue. It is being used to distinguish between real honey and fake.
Touch sense	A touch sensor is a type of equipment that detects touch or near proximity without relying on physical contact. Touch sensor replaced mechanical buttons in mobile phones, and is slowly replacing the mechanical objects like mouse and keyboard in computer.

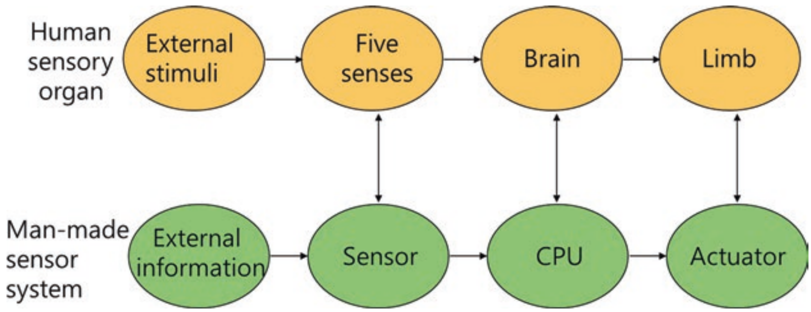


Fig. 4.1 Comparison of human sensory organ versus man-made sensor

sensory organs to make an analogue temperature observation about their immediate surroundings, but human sensory organs cannot make digital temperature observations over a period of time for remote offline target. The human eye perceives about 30 shades of gray and does not show histogram as visual and quantitative reflectance data for the target. Human eye does not produce maximum contrast in the area of interest, from the entire scene to small subsets.

Man-made sensor has the same ability as human sensory organ. Sensors are miniaturized devices which convert physical/chemical/biological state into an electrical signal (Fig. 4.1). The sensor converts any type of energy into electrical energy. Man-made sensor generates an electric signal that can be interpreted by computer or control instrument, by responding to a stimulus, such as heat, light, or pressure. Man-made sensors measure physical characteristics of offline real-world as physical system of the CPS and convert them into digital data, which can be handled into information through cyber-system of the CPS. An actuator as physical system component in CPS may be defined as a device playing the opposite role to a sensor. It converts electrical signal into non-electrical energy. For example, an electric motor as an actuator converts electric energy into mechanical action.

4.2.3 Application Examples of Sensor

Sensor is one of two fundamental components in the operation of physical system in CPS and is based upon a very wide range of underlying physical principles of operation. Sensors transform stimuli from the physical offline world into cyber observations and thereby allow us to monitor the offline observed properties. The information gathered through such processes is very closely related to our daily lives. Our popular smartphone uses about 20 kinds of sensors such as acceleration sensor, gyro sensor, temperature sensor, luminance sensor, proximity sensor, sound sensor, imaging sensor, fingerprint sensor and touch screen. Smart cars use about 150–200 sensors per vehicle, while 2000–5000 sensors are built for aircraft engines.

Today's technology has enabled the use of an increased variety of sensors responding to more kinds of physical, chemical and biological variables. For example, the kinds of sensors used on automobiles [5] has expanded very rapidly, in response to the need for safety (seat belt, door lock sensors) and improved performance and fuel economy (mass air flow, oxygen sensors). Anti-locks brakes use sensors to keep cars from skidding off the road. When a car is backing up, a sensor will discern objects behind it and let out a shrill warning to the driver. These sensors are used to keep people and an automobile safe. But sensors are used in more than just cars, they are all around us. From industry through home, sensors are used to make the world around us easier.

The stimulus can be electromagnetic, acoustic, mechanical, thermal, or chemical in origin (and so on), while the measured signal is typically electrical in nature, although optical, hydraulic and air-filled signals may be employed [6]. Sensors provide valuable data into the hands of decision makers such as manufacturing supervisors, environmental engineers, IT managers, and others. For example, sensors can monitor cooling systems for drone motor to enable more efficient operation and reduce energy costs, and detect variations in a motor's vibration to reduce failure. The vast amount of data collected through sensors will become an indispensable element not only in the contemporary world but also in the future CPS society.

Together, sensing provides the mechanism for the harvesting of digital data. Applications include environmental monitoring in the water and soil, labeling small animals unremarkably, or cataloguing small and light objects in a factory or hospital setting. The availability of micro-sensors and low power wireless communications enables the deployment of densely distributed sensor/actuator networks for a wide range of applications [6]. The sensor is basically entered into the Internet of things. Networked sensors can collaborate and aggregate the huge amount of sensed data to provide continuous and spatially dense observation of biological, environmental and artificial systems. Wireless networks of sensors greatly extend our ability to monitor and control the physical world.

Human cannot work tirelessly through simple and repetitive tasks. The repetition of existing simple jobs or basic labor is rapidly being replaced by AI machine. A few decades ago, the word sensor was not commonly used. Today, however, sensors are becoming ubiquitous in our daily lives. Sensors and their observations are at the core of the cyber-physical system. In 1609, Galileo invented the telescope and observed our cosmos in an entirely different way. He proved the theory that Earth and other planets in our solar system revolve around the Sun, which until then was impossible to observe [6]. There will be a radical change in traditional theory of many empirical sciences since humans utilizing AI machines would realize a new addition of insight and discoveries in future sensor society.

4.2.4 Sensor Classification

Sensor classification systems range from very simple to complex. Depending upon the classification purpose, different classification criteria may be selected. Extremes are the often-seen division into just three categories (physical, chemical, and biological) according to measurement variable (Table 4.2) and further subdivided

Table 4.2 Sensor classification based on conversion phenomena

Sensor type	Examples
Physical (sight sense, auditory sense, sense of touch)	Light sensors (photo-detectors) detect light and electromagnetic energy.
	Acoustic wave sensors measure the wave velocity in the air or an environment (sound pattern recognition, speaker recognition and speaking understanding).
	Touch sensor measures pressure, acceleration, distance, etc. in mobile phones, home appliances, car and many other industrial applications.
Chemical (sense of smell and taste)	It recognizes the concentration, components and pressure of the chemical (H_2, O_2/O_3, CO/CO_2, propane, methane, etc.)
	air pollutant: CO, NOx, SO_2, lead, Particulate matter (PM)
	Water pollutant: Dissolved Oxygen, pH, Suspended solid
	Ion: positively-charged ion, negatively charged ion
	Major Ionic Species (Cl^-, Na^+), Nutrientsa (Nitrate, Ammonium), Heavy metals, Organic Compounds, Electrical Conductivity, Catalytic reaction, etc.
Biological	According to the broad definition, biosensors are devices used to detect the presence or concentration of a biomaterial, such as enzyme, antibody, nucleic enzyme, biomolecule, organic compounds, gases, biological structure or microorganism (virus, bacteria).
	The various types of biosensors: enzyme-based, tissue-based, Antibodies, DNA biosensors, and thermal biosensors

hierarchical categories [7]. Chemical sensors detect the occurrence of certain chemicals and calculate the amount and type of chemical detected. Carbon dioxide sensor measures the percentage of CO_2 in a gas or liquid being examined. Biosensors are devices for measuring a wide range of biological elements including an antibody, organic compounds, enzyme, nucleic acid and bacteria. Canaries in cages used by mineworkers to detect gas leaks can be thought of as biosensors. Glucometer is a representative example of using biological sensors in our daily lives. Glucometer measures the amount of glucose in human blood. Physical quantities such as light intensity, temperature, and position displacement can easily be converted into energy and ultimately converted into electrical signals. Temperature (heat) sensor is a sensor that senses heat and emits electric signals. It is generally divided into contact type and non-contact type. Temperature is the most commonly measured by physical sensor. A thermometer senses temperature and converts it into a readable output. The mercury thermometer utilizes mercury's property of expanding or contracting when heated or cooled, respectively.

Sensors can be classified, among others, according to one of the following criteria: passive and active (power supply requirements), nature of the output signal (digital and analog), imaging versus non-imaging sensors etc. A passive sensor does not need any additional energy source since it uses existing energy sources (commonly, the sun). It directly generates an electric signal in response to an external stimulus. Passive sensor measures energy emitted from an object (e.g., infrared) or amount of solar radiation reflected by surfaces and objects (e.g., typical camera mounted on smartphone). The active sensors (e.g., RADAR: RAdio Detection And Ranging, laser: light amplification by stimulated emission of radiation) require their own energy for their operation. Active sensor sends signal and measures energy reflected back. The intensity of reflected signal shows characteristics of target (e.g., texture, surface roughness).

4.2.5 Physical Sensors in CPS

Sensors for laboratory instruments or medical diagnostic tests, provide information to be displayed and/or stored for human interpretation. Chemical sensors and biosensors, for example, may require human intervention for calibration before and after a measurement and may be disposable. However, a sensor in CPS does function by itself, thus, the sensor as a part of CPS system provides a robust electrical output without human supervision or intervention. These applications generally require sensors that are unattended; they must gather information without human intervention. This is clearly a requirement for sensors in autonomous control systems such as self-driving cars. The sensor in CPS could be a part of a larger CPS system (e.g. smart building in smart city) and a part of some kind of a data acquisition system that includes various feedback mechanisms. The sensor always may incorporate many other signal processors and low power wireless communication device to enable the deployment of densely distributed sensor/actuator networks.

To illustrate how such a system works, let us consider sensor arrangement on a self-driving car. The obstacle warning system includes physical sensors such as the radar and infrared (IR) detectors operating without human supervision or intervention. The adaptive cruise control system works like this: if the car approaches too closely to a preceding vehicle, the speed is automatically reduced to maintain a suitable safety distance [8]. CPS is an application that really benefits from the use of physical sensor technologies. MEMS physical sensor can detect a wide variety of different physical nature, such as speed, displacement, position, vibration, light, pressure (barometer), temperature and humidity etc.

The advantage of the MEMS physical sensors is that they can be incorporated into CPS systems for continuous sensing required in the self-driving car. These MEMS physical sensors have numerous commercial and industrial applications such as environmental monitoring in smart home, smart factory, and smart city. Such MEMS physical sensors could be referred to an electronic eye or electronic ear. Since CPS is based on the physical sensor technologies, it is called as cyber-“physical” system. In accordance with the detection mechanisms, physical sensors can be classified into electrical, magnetic, thermal, optical, mechanical or radiation sensors (Table 4.3).

4.2.6 Imaging versus Location Sensor

There are different types of senses, for example: vision, hearing, smell, taste, touch, sensation of temperature, feeling of pain, determination of the position and motion of the body. Many animals gain most of their information about the environment

Table 4.3 Sub-classification of physical sensor

	Application examples
Mechanical sensor	Mechanical sensor targets a large number of the physical movement such as mass, pressure, strain, force, movement (gyroscope, accelerometers), vibration, frequency, direction (compass), proximity, location, velocity, weight, sense of touch and among others. Acoustic sensor (microphone) detects the sound waves of the dial tone, voice, and ultrasonic waves.
Electro-magnetic	Electrical activity sensor detects the electric properties of devices and the body: EMG, ECG, EOG, EEG (Dry Sensor Technology)
	EMG: Electro-Myogram, Muscle movement
	ECG: Electro-Cardiogram, Heart activity
	EOG: Electro-Oculogram, Eye movement
	EEG: Electro-Encephalogram, Human Computer Interfaces
	Magnetic field sensor identifies the magnetic field through the property of solid matter such as proximity, position, navigational direction, angular speed (rpm, revolutions per minute), torque and even liquid flow.
	Radiation sensor: GNSS (Global Navigation Satellite System), DGPS (Differential GPS)
Optical (sight)	Vision sensor identifies the visual pattern, location, shape, and movement from the image and video information (face recognition, object recognition, 3-D object measuring, motion)
	Photo sensor detects characteristics of visible, infrared, and ultraviolet light etc.
Thermal	Thermal sensor (thermometer) measures the size and flow of temperature.

through their sense of smell. Your dog's nose smells surrounding environment nearby him all the time and tells him much more about his world. In contrast, in humans, vision is the most predominant sense, and our eye delivers to our brain almost all proportions of the information about the surroundings [9]. The eye acts as the best perception sensor of the environment in human beings, thus, the human eye is capable of understanding it's surrounding in real time. Humans do not have an internal GPS. Humans do not have lasers and receive or emit radio waves and ultrasonic waves. Yet, humans can drive cars by using visual information only. When moving in the world, humans use their eyes to perceive their environment and to assess the driving scenery. Humans generate reliable estimates of our own location and movement in space from the available sensor signals. The senses which tell us something about our position, orientation and motion in space are on one hand the visual sense.

In the same way one of the most important aspects of a self-driving car is the ability to understand its surroundings. The car's performance heavily depends on the accuracy and reliability of its environment perception technologies, including self-localization and perception of obstacles [10]. This accurate perception helps a driver in controlling the vehicle in the desired way. The two main goals of most sensors used for in-vehicle and infrastructure systems are first to determine driving state, i.e. position and movement of the vehicle, and second, to sense the environment, i.e. surrounding vehicles and/or obstacle. In this regard, the sensors used for the self-driving car as a representative CPS can be classified into two types: imaging sensors and location sensors. Location sensor provides both distance and coordinate information, whereas an imaging sensor measures intensity of the light reflected by surrounding objects. Based on the physical phenomenon, self-driving cars measure either by actively searching the position of a moving object or passively perceiving the environment.

Imaging sensors are sensors producing a digital image, with some information about how the input varies in space, not just in strength. Generally this is done with some sort of pixel sensor, like a CCD (Charge-Coupled Device) camera. Almost all relevant information required for autonomous driving can be acquired through imaging sensors. Digital still and video cameras are examples of electronic imaging sensors. All modern remote sensing systems also use some form of electronic imaging sensors. Imaging sensors use images captured by a camera to determine surrounding physical environment. Non-imaging sensors return a signal based on the intensity of whole field of view. The response of the sensor does not record how the input varies across the field of view. The advantages with non-imaging sensors are that the data are easier to process and it has the potential to covers a larger area. If you know the platform location, and the field of view of the instrument, you can likely build up a profile of how the parameter varies in time and space like ground altitude, average cloud cover and surface heat, etc.

One of the most important aspects of a self-driving car is to know where it is. Although localizing a car within a certain tolerance is possible using existing technologies like GNSS without much effort, it is often not sufficient for autonomous driving. In this case, with a given map, self-driving car needs to establish correspondence between the map and its local perception, and then determines the transformation between the map coordinate system and the local perception coordinate system based on these correspondences. Knowing this transformation enables the self-driving car to locate the surrounding obstacles of interest within its own coordinate frame. It is an essential prerequisite for the self-driving car to navigate through the obstacles. This means that the core problem of self-localization is actually a registration problem between map and localization and can be solved via matching high-resolution map.

Another approach relies on fusion of location and imaging sensor. GNSS data is used to localize a car within a certain tolerance (approximate localization) while imaging sensors (such as visible, infrared, thermal) recognize its surrounding environment. Such a fusion system uses GNSS location data to refine the positioning information in conjunction with visual images captured by onboard cameras. Frame-by-frame comparative analysis between location and imaging sensor reduces the error range of the GNSS signal. Location sensors perform distance and direction measurements on a much larger scale than imaging sensors. The location sensor has become dominated by GNSS systems, which are generally viewed as representative navigation sensors in the nautical and aerospace industry and are therefore included along with other navigation sensors such as INS (Inertial Navigation System) in the sensor marketplace. So far, the fusion of available sensors is not capable of recognizing the self-driving car's surroundings as accurately as a human being can. Humans use a combination of different types of senses to monitor happening events as they drive and guess further consequences. For example, if a child were to running in front of the car, a human driver might guess that parent could follow to take care of the child. Such sensor fusion cannot yet provide that level of inferential thinking, further it is still so hard to communicate in real time with the surrounding environment.

4.3 Deep Learning

4.3.1 Deep Learning versus Human Brain Sensor

Artificial intelligence (AI) is the core technology of the fourth industrial revolution. It means that the computer can imitate human intelligence such as thinking, learning, self-development, etc. that human intelligence can do (Table 4.4). Artificial Intelligence aims to create intelligent machines operated by sensors that are capable of perceiving, reasoning by processing data, and taking action to achieve success. The definition of AI is slightly different for each academic field and the approach to AI can also be divided into engineering and scientific perspectives. The engineering perspective is to implement a machine which can perform tasks that require human intelligence. Scientific perspectives, on the other hand, are academically related to psychology and linguistics, which clarify the nature and thinking process of human intelligence using computers.

Although scientists are quite far away from understanding the detailed working mechanism of the human brain, including how it processes the visual data, recent advances in machine learning have proven to be very successful in mimicking some of the human visual system. The term artificial intelligence was first used in 1956. After that AI faced many recessions and it was revived in 1990 by the development of the Internet. Search engines have been able to collect large amounts of data and the development of deep learning algorithms has further stimulated the study of artificial intelligence.

The ultimate goal of AI is to enable machines to behave like a human being. Machine learning (ML) is one of the most substantial branches of Artificial Intelligence (AI). Humans are able to perform many different tasks, from recogniz-

Table 4.4 Comparison of human brain versus computer

	Human	Computer
Processing element	10^{14} synapses	10^{8} transistors
Element size	10^{-6} m	Depends on MEMS
Energy use	30 W	Depends on MEMS equipped in CPU.
Processing speed	100 Hz	Depends on technology development
Style of computation	Parallel, distributed	Serial, centralized
Fault tolerant	Yes	No
Learning capability	Yes	A little
Intelligent, conscious	Usually	Not (yet)

ing numerous surrounding objects, to understanding languages and complicated decision making etc. Among the versatile abilities of human beings, the human visual system is one of the most outstanding sensors. The whole visual system contains billions of neurons, which are responsible for decision-making in driving a car. It not only enables us to recognize the lively world, but also can rapidly target our attention to eye-catching objects in the surrounding environment.

Machine perception is the ability of a machine to observe environments by sensors, such as cameras and microphones. Based on the observations, the AI machine makes decisions on certain aspects of surrounding environment. For instance, a self-driving car stops before obstacle. The aim of machine learning is to train a computer in such a manner that it can classify an observation to the correct category or class (Table 4.5). The term "deep" refers to the number of layers in the network; the more layers, the deeper the network. Traditional neural networks have only 2 or 3 layers, while deep neural networks can require hundreds. Although there is no universally accepted definition of how many layers constitute a "deep" learner, typical deep neural networks are at least four or five layers deep. Deep learning is especially well-suited to identification applications such as face recognition, land mosaic classification, landscape recognition, and advanced driver assistance systems, including traffic sign recognition and lane classification.

Table 4.5 Comparison of machine versus deep learning

	Machine learning	Deep learning
Hierarchy	An important subset of AI Machine learning is not something inherently different from deep learning.	An important subset of machine learning, a technique for implementing machine learning
Number of layers	Usually one to two layers Shallow learning is a term that usually have at most one to two layers.	Multiple layers (at least four or five layers), hierarchical identification of complex concepts, a form of machine learning that is inspired by the structure of the human brain
Big-data requirement	Generate good results with small data sets	Require very large data sets for hierarchical identification, largely works with high-dimensional raw data (e.g. pixels in an image)
Self-learning capabilities	Requires manual intervention for different features and classifiers to achieve the best results	Learning is performed through a deep and multi-layered network of interconnected neurons. The term "deep" usually refers to the number of hidden layers in the neural network.
Performance as the scale of data increases	Accuracy is limited to plateaus.	Accuracy is unlimited
Example	Computer vision (the ability of a machine to recognize an object in an still picture or motion picture)	Google's AlphaGo, Self-driving cars

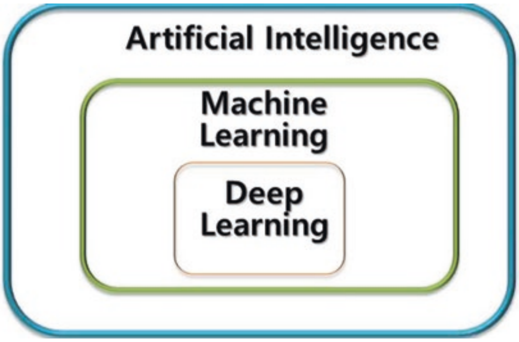


Fig. 4.2 Schematic representation of AI hierarchy

Table 4.6 Comparison of biological neuron versus artificial neural network components

Human brain biological neural networks	Artificial neural network
Soma, nerve cell	Node
Dendrite	Input
Axon	Output
Synapse, nerve cell connection	Connection weight

Deep learning is a subset of machine learning algorithms that use deep neural networks (Fig. 4.2). The idea of deep learning is simple; the machine is learning the features and decision making (e.g. classification). A deep neural network (DNN) is an artificial neural network (ANN) with multiple hidden layers between the input and output layers. Similar to shallow ANNs, DNNs can model complex non-linear relationships. Artificial intelligence system consists of input system, internal system, and output system. Input information such as language and sight is entered to input system. In the internal system, it solves problems by searching for input systems, processing and inferring uncertain knowledge, learning and planning. The output system then outputs in the form of dialogue, action, and manipulation. Neural networks initially stemmed from biological theory on how neurons in a brain are connected, and allow for the processing of information (Table 4.6). The artificial neural network mimics the operating principles for neural network of human brains (Fig. 4.3). Just like many nerve cells connected to the brain, the neural circuitry is a network that connects the tiny components of the brain, which correspond to the neural cells of the brain. The processing part of the human brain consists of billions of neurons and each neuron receives information from thousands of other neurons. A neuron can be studied as an input/output device. The connections of the most vital nerve cells of the brain are simulated by the connection weights of nodes. Neural networks have been used on a variety of tasks, including image classification, social network filtering, face recognition, computer vision, speech recognition, machine translation, playing video games, medical diagnosis and in many other domains (Table 4.7).

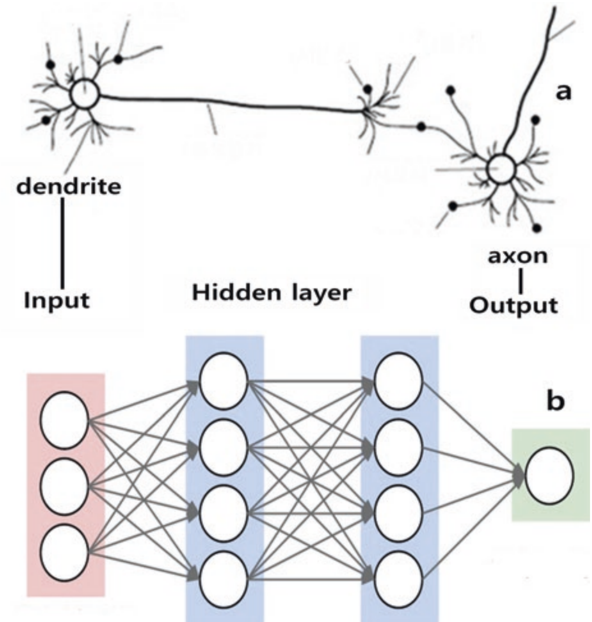


Fig. 4.3 Comparison of biological versus artificial neural networks. (**a**) biological neural networks, (**b**) artificial neural networks

Table 4.7 Comparison between biological versus artificial neural networks

	Biological neural networks	Artificial neural network
Adaptability	Continue to change with new thoughts and experiences	Able to perform learning in new environment
Learning with incomplete information	Able to learn on their own without having an exact answer for a given input pattern	Able to produce appropriate outputs with imperfect information
Reconfiguring nerve cells	Able to reconfigure nerve cells through learning process	Able to reconfigure by supervised, unsupervised learning
Processing method	Parallel distributed processing	Parallel distributed processing
Information delivery structure	Nerve cells convey information	Implement function of neural network through HW, SW

Deep learning is a subtype of machine learning in which a model learns to perform classification tasks directly from images, text, or sound. With deep learning, the raw images directly feed into a deep neural network that learns the features automatically. Deep learning often requires hundreds of thousands or millions of images for the best results. It's also computationally intensive and requires a high-performance GPU (Graphics Processing Unit). With deep learning methods, similar to human eye, relevant features of an image can be extracted; spatial (size) and spectral (color) information. Moreover, motion detection algorithms such as optical flow can recognize temporal changes just like detecting accelerating speed of precedent car in our eyes.

4.3.2 Deep Convolutional Neural Networks

The deep convolutional neural networks (CNNs), which are recognized as the most prosperous and extensively applied deep learning approach, are now the leading methods in the mainstream of image recognition and detection tasks. Convolution is probably the most important concept in deep learning right now. Convolutions are an extremely general idea since it is the mixing of information. Imagine two boxes full of information which are poured into one single box and then mixed according to a specific rule. Each box of information has its own recipe, which describes how the information in one box mixes with the other. So convolution is an orderly procedure where two sources of information are intertwined. Convolutional Neural Networks are aimed to distinguish visual patterns directly from pixel images with least pre-processing. They can recognize patterns with great inconsistency (such as human face). That output can be a single class or a probability of classes that best describes the image (Fig. 4.4). So far it has been shown that, with features learned by deep CNNs, a simple patch-based method can achieve promising results on a variety of challenging object extraction tasks from high spatial resolution imagery.

Pixel-based imagery classification is one of the most popular topics in the spatial information science and remote sensing community. However, from the deep learning point of view, most of the existing methods can extract only superficial structures of the original data. The classification step of the shallow learning can also be treated as the top level of the network), which is not strong enough for the classification task. Deep learning-based pixel classification for remotely sensed images involves constructing a deep learning architecture for the pixel-wise data representation and classification. By embracing deep learning techniques, it is possible to extract more strong and intellectual feature representations and thus improve the classification accuracy [11]. The primary advantage using CNNs in vision based localization is its ability to pre-process images through its layers. Deep convolutional neural networks (CNNs) can be utilized in numerous application, ranging from a simple dog breed classification, skin cancer diagnosis from scratch images, to self-driving cars transporting people and goods from one place to another. For example, if a user uploads a photo of his cat, the CNN service website should return a prediction with rather high confidence, given several pictures of cat breeds as training data.

CNNs are multilayer neural networks that can hierarchically extract deep features. Typical convolution neural networks are mainly composed of input layer, convolution layer, sub-sampling layer (down-sampling, pooling layer), fully-connected layer and output layer. The layers are interconnected via nodes (neurons), with each hidden layer using the output of the previous layer as its input. The role of hidden layers is to apply convolution and pooling operation alternatively and adjust the

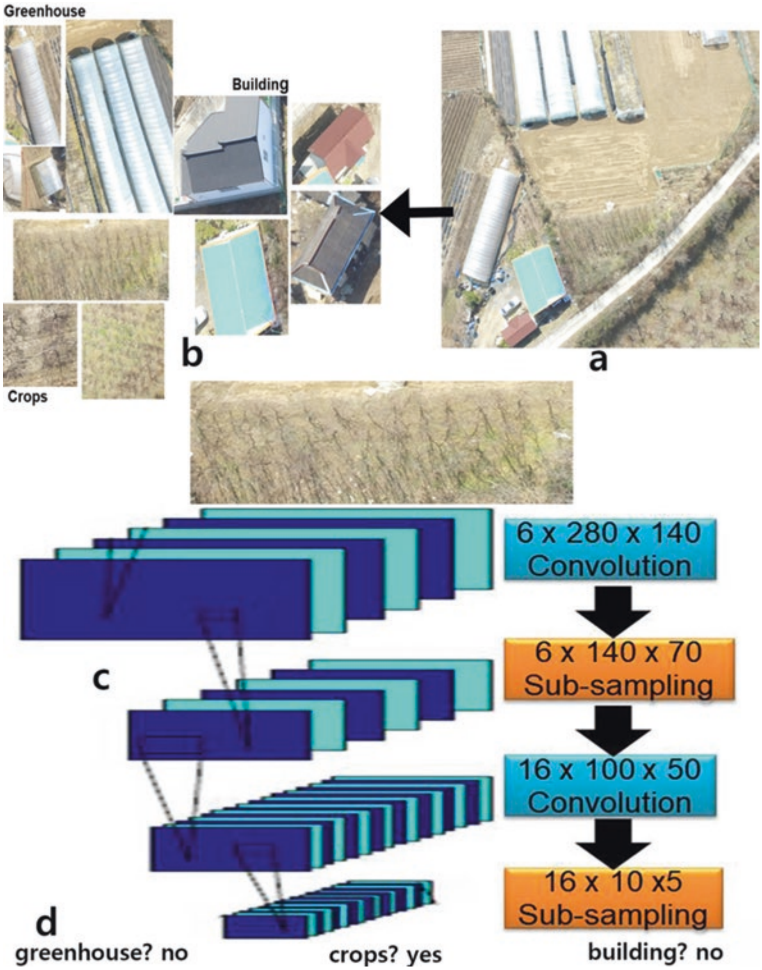
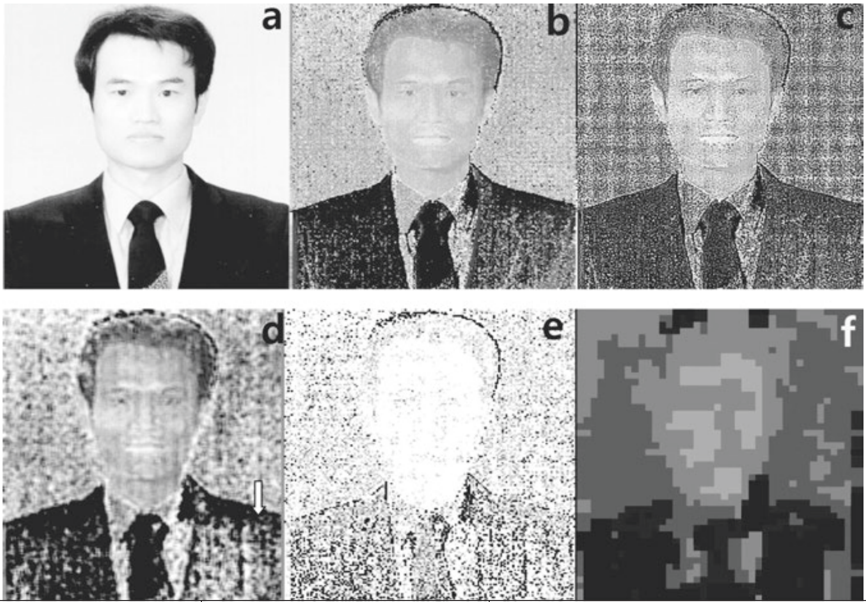


Fig. 4.4 Regions with convolutional neural network features. (**a**) input image, (**b**) extract region proposals, (**c**) compute CNN features (**d**) classify regions

weights and biases of the network according to the input. The convolutional layer offers filter-like function to generate convoluted feature maps, while the sub-sampling layer generalizes the convoluted features into higher levels which makes features more intellectual and strong. As a class of deep models for learning features, the Convolutional Neural Networks (CNN) learns a hierarchy of increasingly complex features (Fig. 4.5). Each layer in the network takes in data from the previous layer, transforms it, and passes it on. The network increases the complexity and detail of what it is learning from layer to layer.

1. Input Layer: Contains the input image or the raw pixel values. It is the entry layer to all the other layers. Thus, the input image can be considered to be the first layer in a CNN. The masks at the first layers of the CNN typically learn basic



Layer	Filter versus sub-sampling	Number of pixels (gray level)
1 (a)	Input imagery	1337:1471 (256)
2 (b)	3 by 3 low pass filter	1337:1471 (256)
3	Down-sampling	334:368 (256)
4 (c)	3 by 3 high pass filter	334:368 (256)
5	Down-sampling	167:184 (128)
6 (d)	3 by 3 low pass filter	167:184 (128)
7	Down-sampling	167:184 (16)
8 (e)	3 by 3 high pass filter	167:184 (16)
9	Down-sampling	42:46 (16)
10 (f)	3 by 3 low pass filter	42:46 (16)

Fully connected layers to support classification

⇓ Man ⇓ Woman ⇓ Baby

Fig. 4.5 Typical architecture of a deep CNN model

Using this training data, the network can then start to understand the object's specific features and associate them with the corresponding category. Pooling layer samples the volume spatially, independently in each depth slice of the input volume. In this example, the input volume of size [1337:1471 (256)] is pooled with filter size 3 by 3, progress into output volume of size [167:184 (128)]. Pooling layers simply take the output of a convolution layer and reduce its dimensionality (by taking the maximum of each (2, 2) block of pixels for example). Notice that the volume depth is not preserved. Pooling is applied to the resulting filtered images. These steps can be repeatedly applied as many times as desired: a new convolutional layer can be applied on the pooled layer, followed by another pooling layer, and so forth

features, and as one traverses the depths of the network, the features become more complex and are built-up hierarchically.
2. Convolutional: A convolution layer is mainly characterized by its number of convolution filters and the size of these filters. Each filter moves within the image to generate a convolved image. Convolution puts the input images through a set of convolutional filters, each of which activates certain features from the images [12].
3. Pooling: This layer is mainly used to resize and accumulate the spatial representations. Pooling simplifies the output by performing nonlinear down-sampling, reducing the number of parameters that the network needs to learn about. The pooling layer reduces the amount of data in spatial domain in order to reduce the number of parameters of the subsequent layers. Additionally, it also decreases the computational cost of the network by discarding redundant.
4. Fully-connected Layer: These are typically the last couple of layers of the network. The fully-connected layers follow the convolutional and pooling layers. Finally, when the layers become small enough, it is common to have fully connected layers before the output layer. The difference between a fully connected layer and a convolution layer is that the an algorithm in the convolution layer are connected only to a local region in the input, whereas all the algorithm in the fully connected layer are connected to all the algorithms of the input (input to the fully connected layer).

4.3.3 Supervised versus Unsupervised Learning

In the real world, occasional work or knowledge learned by human such as driving car is classified in either fully supervised or fully unsupervised scenarios. Most real-world scenarios, however, it is usual that occasional work or knowledge is learned by semi-supervised manner. Learners receive a great deal of unlabeled information from the physical system of real life, coupled with occasional experiences in which items are directly labeled by a knowledgeable source. That is, everyday experience provides a mix of labeled data (in which both an item and its category label are directly observed, such as seeing a dog and hearing the word “dog”) and unlabeled data (in which the item is observed but no label is provided, as when the learner simply views a dog) [13]. There are three broad types of methods used in machine learning (Table 4.8); supervised learning (i.e. learning with a teacher), reinforcement learning (i.e. learning with limited feedback), unsupervised learning (i.e. learning with no help).

In unsupervised learning computer concerns the identification of obscure structures or patterns from unmarked data in a stream of observations. Unsupervised learners do not have access to any output (the correct class labels) since its objective is often to find patterns in the available input data. Supervised learning is known as teaching by showing approach since its objective is to learn from examples (the correct class labels). One example of a supervised classifier learning problem would be

Table 4.8 Comparison of supervised versus unsupervised learning

	Supervised learning	Unsupervised learning
Teacher	A teacher is present during learning process and presents expected output.	Teacher is not present.
Training	Every input pattern is used to train the learner.	The expected or desired output is not presented to the learner.
Learning process	Learning process is based on comparison, between computed output and the correct expected output.	The system learns by itself by discovering and adapting to the structural features in the input patterns.
Training samples	Training samples required	Training samples are not available.

Reinforcement learning: A teacher is present but does not present the expected or desired output but only indicate if the computed output is correct or incorrect. The information provided helps the network in its learning process. A reward is given for correct answer and a penalty for a wrong answer [14].

that of learning how to classify four different types of dogs by observing 200 already classified dogs (50 of each type). The data given in this case, are height, ear shape, body color, length, weight, and foot length of each dog. The type, or class, is one of the following: Affenpinscher, Afghan Hound, American Eskimo Dog or Australian Shepherd. Thus, the probability density of the unlabeled distribution might reasonably be used to adjust conclusions about both the central tendencies and boundary between categories, compared with the conclusions drawn from labeled data alone.

Reinforcement learning gives feedback by means of occasional rewards. This type of learning is often used when the plotting from inputs to outputs requires several steps. For example, learning how to land a drone stably involves hundreds of steps. Instead of just receiving positive or negative feedback after having tried to land the drone (success or failure) it is perhaps more clever to introduce a reward system that gives small rewards for each correctly completed step, or chain of following steps.

TensorFlow is the most recent of all these frameworks developed by Google in 2015. It was developed with the focus of easy access to machine learning models and algorithms, ease of use and easy deployment in different heterogeneous machines like mobile devices. In the future, thanks to rapidly developing machine learning techniques applied to verification, test engineers will determine the most efficient test scenarios based on smart algorithms that can quickly detect failure-triggering patterns. This will allow them to achieve maximum test coverage in less time. Recent revolutionary research in deep learning has produced excellent results in different domains. Tensorflow as deep learning framework had recognized the location of a self-driving car with the help of visual sensors as realistic alternative to traditional approaches (Car Navigation System based on GNSS).

4.4 Concepts of Spatial Information

Spatial information is basically information with location, which is expressed through a map. Spatial information is an essential element of human life, like water or air. For instance, Car Navigation System (CNS) based on spatial information has become a necessity for driving a car. Airbnb and Uber grown as global innovative firm are considered to be a representative example of on-line industry based on spatial information. Spatial information is location information about natural and artificial objects (above the earth surface or below the earth surface or on the earth surface or any combination of the above etc.) surrounding human beings. Geographic location is the core element that distinguishes spatial information from all other types, so specifying location on the Earth's surface is essential in defining spatial information. Time is an optional element in spatial information, but location is essential. Without locations, data are said to be non-spatial or aspatial and would have no value at all within a spatial information system. In spatial informatics, maps have been recognized as an essential tool, such as a biologist's microscope or a medical doctor's stethoscope. If the spatial information is expressed as paints, the map can be expressed as a sketchbook. It is a map that illustrates the theme that you want to express with the spatial information.

In general, each academic discipline has its own research themes and research methodology; for instance, computing, agriculture, botany, surveying, economics, mathematics, geology, hydrology, environmental sciences and geography. Research methodologies collectively refer to methods for obtaining truth in a given discipline. Since the concept of space is defined differently according to academic disciplines, the research theme and method are very diverse. Psychology deals with spatial objects as a subject of study, based on spatial cognitive senses related to visual or tactile feeling. In modern mathematics, space is divided into topological space, linear space and functional space. In spatial informatics dimension, this refers approach to understand as a whole, the spatial target where human and natural phenomena are interconnected. Spatial Informatics is a discipline that provides meaningful information by collecting, storing, managing, and processing spatial data. Spatial Information science is a discipline that borrows theoretical foundations, technologies, and methods from various land-related disciplines and makes maps based on them.

Like petroleum in the First and Second Industrial Revolution eras, data will act as a driving force for all industries in the Fourth Industrial Revolution era. Since location data will play a key role of hub to connect massive data sets, spatial information would be more important than ever. The paradigm of the spatial information ecosystem is completely different from the previous digital map level because the surrounding context can be sensed by artificial intelligence. The CPS has the characteristics of a platform that can maximize the added-value of spatial information by incorporating augmented reality and virtual reality into the real world map [1]. Spatial information science refers to the scientific context of spatial information management and processing, including associated technology as well as social, commercial, and environmental implications. Information management and processing include data analysis and transformations, and information visualization. The individual sub-disciplines covered in spatial informatics is mainly composed of remote sensing and GNSS surveying to build a spatial information database, and GIS (Geographic Information System) to analyze the spatial data.

4.4.1 Comparison of Spatial Information versus Non-spatial Information

Everything in the world has location information. We face location information from everything in everyday life (people, phone calls, and real estate transactions). Everything we contacted in ordinary life has its place, ranging from grocery to digital photos. Spatial information is used not only to continuously detect this information, but also to provide answers to many issues (disaster, land transactions) that need to be addressed socially. Non-spatial information is referred to as attribute data, and is associated with spatial information (e.g., house owner, house price, etc.). The feature distinguished from spatial information is that it does not have information about location (Table 4.9). All of this information could be expressed in a table, with each row corresponding to a different discrete object, and each column to an attribute of the object. This is the data to explain the additional elements constituting the spatial system in the real world. The attribute data is converted into spatial information when it is represented by a map linked with location information.

Spatial information, as opposed to non-spatial information, is defined as a coordinate system based on the geographical location of the input data. It can be said that it is a graphic data base which provides area-wide spatial information at more visualized manner by using a three-dimensional graphic display method of the map. The capabilities and applications that spatial information has opened up have been directly linked to technological developments in the form of smartphone, computers, and drone technology to name a few. If the non-spatial information system is a

Table 4.9 Comparison of spatial Information versus non-spatial information

Category	Spatial information	Non-spatial information
Importance of location	Necessary	Not necessary
Way to present data	Map	Text or picture
Data type	Area-wide (macro)	Point (micro)
Scale	Necessary	Not necessary
Overlay of data	Possible if GIS database is constructed	Impossible
Typical instrument to collect data	Remote sensing	In-situ survey
Data type classification	Point, line, polygon	Text or picture

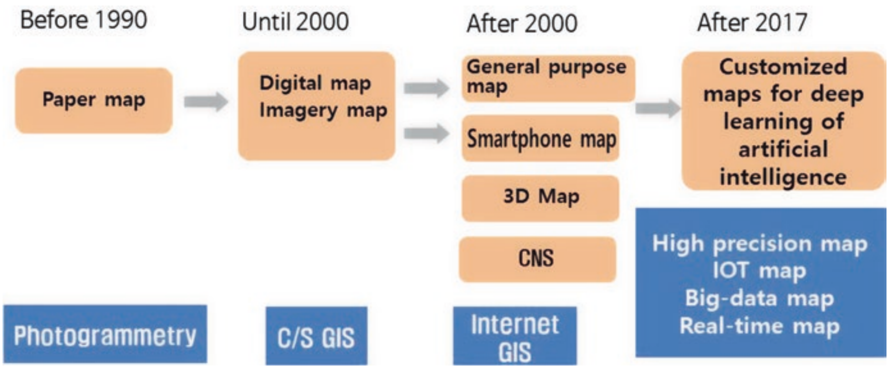


Fig. 4.6 Development history of mapping technology

system for storing character-type information in various rooms of a single-story house, the spatial information may be a system to offer specified information according to each floor at a super high-rise building since it is possible to overlay various types of maps simultaneously.

4.4.2 Development History of Mapping Technology

Spatial information existed even before the computer is used. In the past, it has been largely dependent on paper maps as a means to obtain location information (Fig. 4.6). There is no single definition of a map because the experts in the field themselves are in disagreement as to what to include and/or exclude in the definition. The map is a reduced graphical representation of the space we live [15]. The paper map has long been a powerful and effective means of communicating spatial information. A key property of a paper map is its scale or representative fraction, defined as the ratio of distance on the map to distance on the Earth surface. For example, a map with a scale of 1:24,000 reduces everything on Earth to one 24,000th of its real size [16].[1] The concept of small-scale and large-scale maps needs a short explanation. Consider a football field measuring 100 m on a side. On a map of 1:10,000 scale, the field is drawn 1 centimeter on a side. On a map of 1:100,000 scale, the field is drawn 0.1 mm on a side. The field appears larger on the 1:10,000 scale map; we call this a large-scale map. Conversely, the field appears smaller on the 1:100,000 scale map and we call this a small-scale map. Data are fine-scaled if they include records of small objects, and coarse-scaled if they do not [16]. Scale is often cited as a property of a digital database, even though the definition of scale makes no sense for digital data because the distance on the map depends on the size of the display monitor.

[1] This is a bit misleading, because the Earth surface is curved and a paper map is flat, so scale cannot be exactly constant.

However, the paper map has the following limitations. The paper maps are bulky and may be damaged during prolonged storage. As the number of the paper map increases, various paper maps required a lot of manpower and cost to store and maintain them. It was difficult to implement a function that can display simultaneously the location information and attribute information (e.g. statistical data). It was impossible to share paper maps kept by various organizations, so that the same paper map was produced in duplicate. Thus there was a considerable limitation to the general public to utilize spatial information. It is difficult to perform the spatial analysis superimposing several kinds of drawings and maps. It was hard to quickly analyze and transmit spatial information to decision makers in various spatial planning decisions.

In the era of the Fourth Industrial Revolution, it is time to produce highly accurate map data through IOT such as drone. The CPS era is coming in which artificial intelligence itself searches for maps that are necessary for deep learning and behaves on its own. The current map is designed for people to identify location, but high-precision maps in the era of the Fourth Industrial Revolution are being built for deep learning of AI machines. Thus, the mapping technology is emerging as a representative technology of the Fourth Industrial Revolution due to CPS such as the self-driving car. Everything from autonomous vehicle to smart city in CPS depends on high-precision maps. In order to preoccupy the global market on CPS, it is important to obtain high-precision maps.

Industry players are developing dynamic high precision maps with centimeter accuracy that would afford the car's sensors to calculate its precise position relative to fixed landmarks. We need to ask critical questions about how machines conceptualize and operationalize space? How do they render our world measurable, navigable, usable, conservable? We must also ask how those artificial intelligences, with their digital sensors and deep learning models, intersect with cartographic intelligences as spatial information [17]. There are a lot of others expressed on the map as cartographic subjects for AI. They are active mapping agents with distinct spatial intelligences, such as IOT sensor attached to a traffic light or fixed landmarks. This means that the traditional space subjected to spatial analysis is transformed into the physical system of CPS. Spatial data is evolving into big data linked with CPS in terms of super-connection and super intelligence.

4.4.3 GIS (Geographic Information System)

GIS (Geographic Information System) is more than a database of information and more than a stand-alone map. GIS is designed to be queried and to assist in analyzing a situation or problem. GIS can be thought of as an interactive map made of different layers of geographic data that can be queried; you can change what you see, ask different questions of a database, and display the maps or graphs that your question produced. GIS[2] is a software tool for mapping and analyzing spatial data such as from village to urban landscape, mountain to stream, and university campus to buildings. Locations are the foundation of GIS because they refer to the same place, or to measure distances and areas. Locations are the fundamental reference to produce map and to tie different kinds of information together. GIS technology integrates powerful database with the visual display capabilities of a map.

Any GIS can display maps, and tabular information simultaneously on a variety of output media. This makes GIS unique among information systems. Spatial analysis of GIS is utilized for better-informed decision-making in a wide range of the public and private enterprises. By introducing GIS, the limitations of paper maps are overcome, which saves time and money for map production, updating and maintenance. Once the GIS database is built, the spatial data can be shared using a computer network, so that it is possible to process tasks that need cooperation from other departments at their own desks, thereby doubling the work efficiency. In addition, once a map is constructed based on the survey results, it is possible to expect a reduction in cost and time for the map update since only the changed parts need to be re-entered without the need for a new survey.

There have been great changes for methodology applied in spatial informatics as maps making technology has been rapidly progressed. In the 1990s, due to the spread of personal computers and multimedia technology, paper maps had entered a stage of being replaced with digital maps and imagery maps. This development trend was continued in the 2000s due to the proliferation of the Internet and smart phones. Various kinds of spatial information were provided not only to the enterprise but also to the general public. In recent years, remote sensing and GNSS have become key tools for map production. In addition, due to the rapid spread of smart phones and mobile technologies, the general public can freely use spatial information in cyberspace (e.g. CNS: Car Navigation System).

Spatial analysis performs a series of processes to express the spatial phenomenon or to find an alternative for solving the spatial problem. For this purpose, it follows a series of steps, starting from the stage of a spatial database building to the step of finding the spatial pattern. When using the GIS for spatial analysis, it can quickly and accurately store and manage vast amounts of spatial data, it is possible to perform a complicated analysis that requires a lot of time and labor. The spatial analysis technique of GIS generates new information by superimposing spatial data and by performing spatial query for geometric data and attribute data contained in the spatial database. It is used for scientific purposes to discover the spatial patterns, the spatial rules and spatial theories inherent in spatial phenomena that have not been recognized before. Suitability Analysis is an application that determines the proper location by superimposing various thematic variables such as the natural environment and human environment. It is a representative example that can maximize the benefits of GIS-based spatial analysis. The term "suitability analysis" is derived from the land-use planning method overlaying various thematic variables suggested

[2] There is no one definition on GIS because the experts themselves are in disagreement as to what to include and/or exclude in the definition.

by Ian L. McHarg in the 1960s [18].[3] He proposed a location analysis method that is characterized by the systematic approach to harmonize with the natural ecosystem, rather than focusing only on economics-oriented analysis.

4.5 Concepts of Remote Sensing

Remote sensing is the science (and to some extent, art) of acquiring information about the target without being in contact with the target. This is done by sensing and recording energy reflected or emitted from the target. Remote sensing collects information for the survey target that is not in physical or intimate contact (at a distance) with the object or phenomenon under study. In this regard, the human eye is a remote sensor that can quickly characterize a dynamic scene by exploring enormous visual information. Your eyes see colors and light and send that information to your brain. When we see an object without physical or intimate contact, we can determine our distance from it, its location, shape and color. Thus, our vision, to some extent is analogous to remote sensing.

If cats hear some noise, they can determine its location even in the darkness with the help of hearing. Cat use echo-location for sensing their orientation in space and determine the distance from the object by the return time of the echo-signal. Humans do not have such natural equipment (behind vision), so they had to invent it themselves by remote sensing. Remote sensing can be performed by utilizing any sensing device mounted on a platform such as a satellite, an aircraft, an airship, or a drone, ship or balloon. The technique employs recording instruments such as the vision camera, thermal infrared, lasers, and radar systems and near-infrared sensor. Recently, remote sensing is approaching the stage where it is possible to carry out reliable observation comparable to the field survey since the remote sensor's resolution has greatly improved due to the development of related equipment such as drone and MEMS (Micro-Electro-Mechanical Systems).

4.5.1 Comparison of Remote Sensing versus GIS

Depicting land in the form of paintings had been attempted even in prehistoric and non-literary societies where there were no letters. At that time, the map was drawn while securing a wide field of view at the summit of the mountain. The desire to

[3] Ian McHarg's 1969 landmark book Design With Nature has had a greater influence on the development and application of Geographic Information Systems than any other single event in GIS history. McHarg's Method describes, thorough multidisciplinary analysis of a region's ecological sensitivity, different information can be layered and combined geographically to identify suitability for different types of development and use [5].

look at a wider space and to include it in a map boundary was made to observe the surface of the earth in a balloon. Such desire finally came to invent an airplane. It would be a plausible explanation that today's map is a supplementary outcome derived from human desire to observe the land in the sky. Historically, the invention of remote sensing technology was due to the human desire for presenting a pictorial view of the earth surface.

In reality, the use of remote sensing data to maintain a permanent visual record for a ground target was the most useful application for many different types of applications. People are likely to respond with "Just show me!" because they catch on more quickly when they can see the target rather than reading or listening to instruction. Likewise, many types of environmental information cannot be conveyed effectively with words alone. This information requires a much richer mode of communication that not only includes visual elements to enhance the spoken word, but also captures movement and visual expression. Experience has shown that a verbal or narrative record is inadequate for configuring area-wide target, and it is much better to complement this by extensive remotely sensed imagery.

Mapping techniques have undergone revolutionary changes in the twentieth century due to aircraft development and information processing techniques. Photogrammetry has been able to produce from aerial photographs. Remote sensing transmitting images from satellites, beginning with TIROS-1 in 1960, revolutionized the approach to understanding the earth. The advantage of being able to observe a much larger geographic area than aerial photos made it possible for the first time to collectively survey many regions of the earth within a single scene. Remote sensing data is becoming an indispensable source of spatial information for a wide range of applications. Since around 1970, information science and technology began to be introduced into cartography. It has been free from repetitive and tedious manual work, making maps faster and less expensive.

The maps currently in use are mostly produced by interpreting the remotely sensed imagery. Remote sensing is a starting point of spatial informatics because remote sensing is a technique to produce maps which are essential elements in GIS process. GIS does not have the capability to acquire the map data used for spatial analysis. What we can do with GIS depends on data quality from remote sensing. In order to understand the reality of the GIS process, it is essential to understand the various variables involved in mapping of remote sensing data. For instance, a map is a subjective, since human cartographer always decides what to put on it from remotely sensed imagery, and how to represent it. Remotely sensed imagery in contrast, is an objective recording of the electro-magnetic signals reaching the sensor. Another important difference is that a map is a projection of the earth on paper, without any relief displacements, while a remotely sensed imagery includes both relief displacements and geometrical distortions.

4.5.2 Comparison of Remote Sensing versus Field Survey[4]

At present, monitoring programs for many ground targets such as scattered building and urban streams have been mainly based on field sampling, which relies on attributes of an area at one point in time, reflecting an emphasis on the small number of in-situ data. One of the major disadvantages of traditional field monitoring is that it is costly, laborious and time consuming due to the large number of samples required. Nevertheless, sampling errors can be quite large, especially where geographical variation seriously occurs in the field [19]. Furthermore, point observations have the disadvantage that they provide only limited information on historical trends and spatial distribution of the various ground targets.

For instance, in the vegetation community survey, first the surveyor used to look at the whole vegetation cover at the edge of the survey site and walk around the site (Fig. 4.7). The survey result is recorded based on the surveyor's personal impression from such a community overview and observations from walking over the ground survey target. The observer could locate himself at any direction or point to get such an overall view. Different direction, height and position may show different results for vegetation community. The observer could also start to survey, to get an overall view, in a different direction. Furthermore, the surveyor could walk over a well-growing site and a badly-vegetated site, depending on his mood. It is suspected that the field survey identifies the ground condition reliably in that the ability to perceive visual change is strongly influenced by location of survey points and personal subjectivity. It is usual that the transect survey is carried out for the ground target following the community-based survey. At certain ecologically important sites, transects are recorded across the different types of vegetation community. There are several stage of transect monitoring requirement for vegetation community, before and after growing seasons annually.

These were marked out with one or more wooden stakes, so that recording may be repeated along a similar line in future years. For instance, the transect could be generally 40 m in length, with the vegetation recorded at 2 m intervals. Records are also made by percentage of cover, in 1 m by 1 m quadrats [20]. It is difficult to locate exactly the same transect line as the previous seasons and years, although there is a bare wood stake mark, since the ground is not always flat and growing vegetation height seriously interrupted an accurate measurement of the straight transect stretches. It was noticed that it is easy for whole 40 m transect stretches of 1 m width to be displaced differently leftward or rightward, further or back and forth from the straight line due to vegetation growth and topographic condition change.

[4]This chapter was revised from the papers initially published in Science of the Total Environment (Elsevier) as shown below;

Um, J.-S. and R. Wright (1998). A comparative evaluation of video remote sensing and field survey for revegetation monitoring of a pipeline route. 215(3): 189–207.

Um, J.-S. and R. Wright (1996). Pipeline construction and reinstatement monitoring: current practice, limitations and the value of airborne videography. 186(3): 221–230.

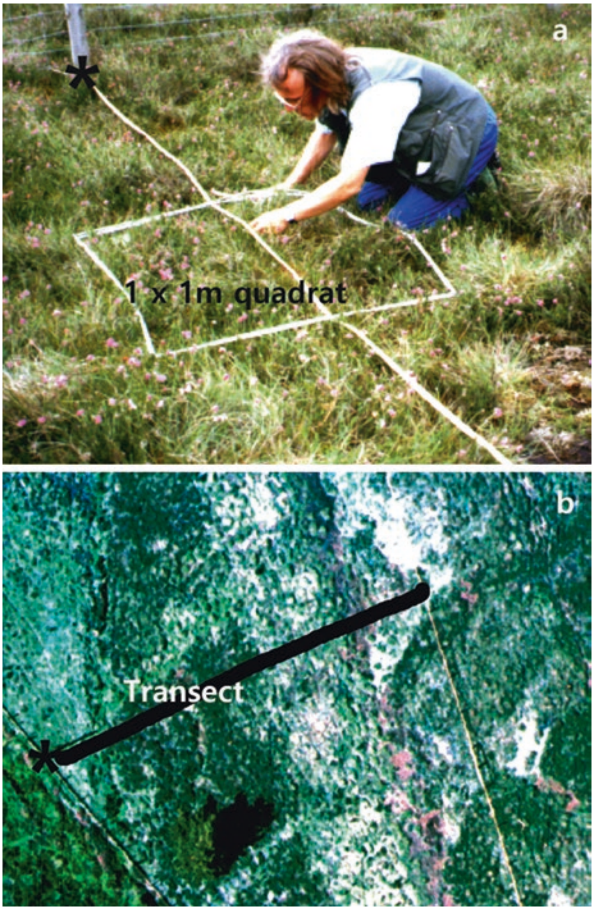


Fig. 4.7 Comparison of field survey photograph versus aerial photograph (same location marked with *). (**a**) field survey photograph, (**b**) aerial photograph of the field survey site

If the initial transect location is different from the previous year by 10 or 20 cm or so, then the succeeding quadrats will be placed in the wrong position. It is very difficult to locate the same 1 m by 1 m quadrat in the same place as the previous year. If the initial quadrat begins from a 10 cm displacement, then subsequent quadrats and the entire transect will show totally misleading results for the vegetation survey. If the 20 quadrats per transect are considered, then it would be impractical to carry out reliable measurement of vegetation growing condition. Present ground-based regular inventories are not practical in terms of either cost or scientific reliability. In this regard, many government authorities have been seeking to strengthen its ability to use remote sensing in natural resources management such as modelling and diagnostic studies. In-situ survey project, observations were subject to various inherent limitations, such as personal subjectivity and error in identification of the ground classes. Many inventorying and monitoring problems are not solved entirely by any one approach: no single data-acquisition methodology can satisfy all of the monitoring needs.

The advantages of acquiring information by remote sensing apply, irrespective of the platform or sensor. It is cheaper than conventional field surveying. Remote sensing data has been considered the most cost-effective means of updating spatial data, especially if these are carried out routinely and where automated. World-wide coverage for a small scale is commercially available, without security, political, or copyright restrictions. It can quickly identify the overall status of a large area, and has advantages in terms of time and cost when collecting data in a large area, and has a lower data acquisition cost than a field survey in the same area. It is possible to collect data in areas that are difficult to access geographically (military or politically inaccessible place, in an extreme area, in a desert area, or in a hill). You can also get information about areas where maps are not built. Compared to field surveys, there are few individual errors, their relative positions are accurate, and the spread of errors across the survey area is almost similar (Table 4.10). By specifying

Table 4.10 Comparison of remote sensing versus field survey

Category	Remote sensing	In-situ survey
Area-wide information	Various geographical phenomena continuously changing in a wide area can be evaluated in a short time.	Provide fragmented information only for survey sites
Objectivity of information	The subjectivity related to surveyor is very limited because it utilizes various thematic maps produced by interpreting remote sensing data.	Since the position of the surveyor changes frequently, there are many limitations in ensuring the objectivity for the target area status depending on sampling techniques
Accessibility to survey points	There are no obstacles to accessing the survey points due to using various airborne platforms.	There is a limit to the accessibility because the representative sampling survey should be performed at the entire survey area. Especially, when the target area is not located near the road, it is difficult to conduct the field survey due to the accessibility difficulties.
Position accuracy	Since the remote sensing data was taken at a vertical vantage point, the position of the real world is accurately displayed.	Since the survey result varies from one point to the other in terms of various horizontal view points, it has a significant limitation in matching the survey result to the mapping position (x, y coordinate) in terms of the vertical view perspective.
Change detection	Change detection can be performed by comparing images of various periods stored as a permanent record.	The results presenting as tables and figures do not reflect the visual evidence as imagery, so there are considerable limitations in performing time series analysis simultaneously considering different times.
Data analysis	By integrating remote sensing images stored in digital data and various GIS databases, it is possible to shorten the map production time and cost.	The data analysis process takes considerable time and expense because it takes much more steps than analyzing remote sensing imagery such as data quality assurance, statistical analysis and comparison of target areas.

the various techniques used in the analytical procedure, reliability in data quality can be enhanced. The same imagery can be used to extract relevant information according to the application purpose.

According to the academic background of the person analyzing the image, the ground reality of imagery is interpreted differently. You can produce various thematic maps such as land use map, road network map, and forestry map according to the analysis method by selecting the desired area and time, such as mountains and the sea, past and present etc. A civil engineering major can extract information about civil engineering works such as geotechnical structure while an archaeologist can grasp the burial place of the historical ruins in the imagery. Because data can be stored as permanent records, current and past information can be extracted and future predictions are possible based on change detection. Since it is possible to observe the same area repeatedly, it is easy to grasp the time-dependent change of land use and natural ecosystem. Satellite imagery data especially from Landsat's TM and SPOT have been used to produce base maps and other revision map. The repeated coverage of satellite data can continuously monitor the terrestrial environment. When sudden disasters such as floods or landslides are encountered, the latest satellite data can be obtained and quickly analyzed to extract required information in timely manner.

Cost is often very important factor when choosing various remotely sensed platforms. The miniaturization of space grade components has resulted in the rise of small satellites, including a great number of remote sensing satellites. With diminishing launch and manufacturing costs, this has led to democratized access to space. Remote sensing requires costly equipment and long-term training to interpret it. Remote sensing is affected by shooting conditions, platform, sensor, and image processing technology. Since aerial photographs or satellite photographs are usually taken at high altitudes, they are often influenced by environmental factors such as clouds, rain, snow, particulate matter, and yellow sand etc. Therefore, images at certain times should be avoided or taken more cautiously in the summer with the rainy season, the winter with the snow falling, etc.

Many human phenomena such as administrative boundaries, population distribution, and income distribution basically cannot be extracted by remote sensing. Remote sensing of a small area is not economical because manpower and labor cost are expensive. Ground-based sensors are often used to record detailed information about the surface, which is compared with information collected from aircraft or satellite sensors. Sensors may be placed on a ladder, tall building, and crane, etc. In recent years, technological advances in micro-electronics have also spiraled into the drone manufacturing industry. Drone has been popularized, and it is possible to acquire high resolution imagery close to the field survey. In the case of drones, remote exploration is often economical even in small areas.

4.5.3 Spatial Information and Satellites

Science and technology have brought the outer space outside the earth, remained as legend or myth, into the realm of exploitation as well as utilization indispensable in human life. The satellite has become an essential tool in order to operate CPS society based on artificial intelligence since the remotely sensed imagery and the location information serve as an indispensable infrastructure for deep learning by artificial intelligence. Usually, the word "satellite" refers to an instrument that is launched into space and circulates around Earth. Thousands of artificial, or man-made, satellites orbit Earth. The satellites are classified into earth observation satellite, meteorological satellite, scientific satellite, military satellite, navigation satellite, and communication satellite according to their functions, and most satellites are used to acquire spatial information (Table 4.11). The typical remote sensing satellite takes pictures of land and sea for earth. The specific purpose satellite takes pictures of the application target. For instance, the weather observation satellite collects imageries that help meteorologists predict weather and track hurricanes. There are many other non-imaging satellites used mainly for communications, such as TV broadcasting and phone calls around the world. A group of more than 20 satellites make up the GPS (Global Positioning System)to help figure out your exact location by a GPS receiver.

There are essentially three types of Earth orbits: high Earth orbit, medium Earth orbit, and low Earth orbit (Fig. 4.8). Satellite orbits are matched to the capability and objective of the sensor(s) they carry. The height of the orbit, or distance between the satellite and Earth surface, determines how quickly the satellite moves around the Earth. Many weather and some communication satellites tend to have a high Earth orbit, farthest away from the surface. Satellites that orbit in a medium (mid) Earth orbit include navigation and specialty satellites, designed to monitor a particular region. Most scientific satellites, including NASA's Earth Observing System fleet, have a low Earth orbit [21].

Table 4.11 Operational satellite related to remote sensing and spatial information

Category	Remote sensing	Spatial information	Operating earth orbit
Earth observation	○		Low Earth orbit (500 and 1500 km altitude)
Weather	※		High Earth orbit (geostationary orbit, 35,800 km from the earth)
Navigation such as GPS		☆	Medium Earth orbit
Communications		☆	High Earth orbit

○: It is possible to acquire remotely sensed imagery observing the land and sea by the satellite
※: It is possible to acquire a remotely sensed imagery by the satellite, but it can acquire specific purpose imagery such as weather observation and military reconnaissance
☆: It is not possible to acquire the remotely sensed imagery with the satellite but acquire spatial information such as the location information

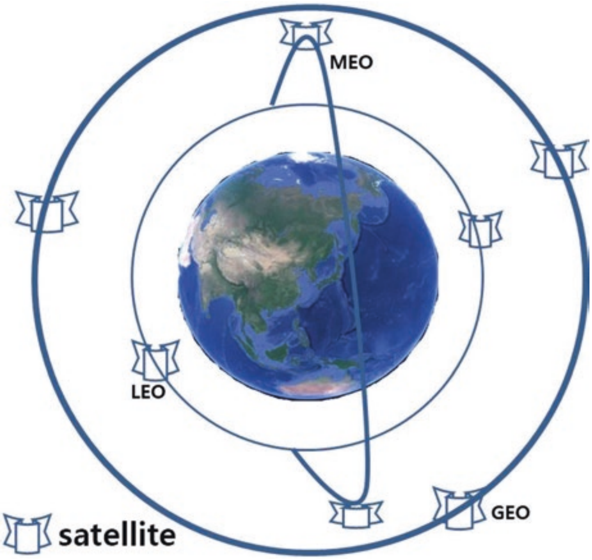


Fig. 4.8 Three different types of Earth orbits: high Earth orbit (geosynchronous), medium Earth orbit, and low Earth orbit

When a satellite reaches exactly 42,164 km from the center of the Earth (about 36,000 km from Earth surface), the satellite orbits at the same speed that the Earth is turning, thus the satellite seems to stay in place over a single longitude. This special, high Earth orbit is called geosynchronous [22]. A satellite in a geostationary earth orbit appears to be in a fixed position to an earth-based observer. This satellite has large coverage, almost one fourth of the earth surface. In this manner, it is capable of taking cloud images of the same area continuously, 24 h a day, covering part of the whole globe. The geostationary orbit is useful for communications or broadcasting applications because it is easy for ground based antennas to track the satellite motion in a fixed position to an earth-based observer.

MEO (Medium Earth Orbit) is the region of space above low Earth orbit and below geostationary orbit around the Earth. A MEO satellite is in orbit somewhere between 8000 km and 18,000 km above the earth surface. Medium Earth Orbit characterizes a series of trade-offs between geostationary orbit (GEO) and Low Earth Orbit (LEO). Medium Earth Orbit enables a satellite worker to cover the earth with fewer satellites than Low Earth Orbit, but requires more satellites than geostationary orbit. MEO satellites have a larger coverage area than LEO satellites and are visible for much longer periods of time than LEO satellites, usually between 2 and 8 h. Most common application for MEO satellites is for navigation, such as the GPS (an altitude of 20,200 km), GLONASS (Global Orbiting Navigation Satellite System, an altitude of 19,100 km) and Galileo (an altitude of 23,222 km).

LEO satellites are much closer to the earth than MEO satellites, ranging from 500 to 1500 km above the surface. LEO satellites don't stay in fixed position relative to the surface, and are only visible for 15–20 min each pass. Many LEO satellite are designed to equip remote sensing platforms. Many of the LEO satellite orbits are sun-synchronous such that the position of the sun in the sky cover each area of the world (called local sun time) when the satellite passes. Local sun time satellite ensures consistent illumination conditions when acquiring images in a specific season over successive years, or over a particular area over a series of days. Low earth orbiting satellites are cheaper to launch into orbit than MEO satellites since they do not require the high signal strength of MEO, due to vicinity to the ground.

Landsat represents the world's collection of remote sensing data. Landsat is a joint effort of the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA). Since 1972, Landsat satellites have continuously acquired space-based images of the Earth land surface, providing data that serve as valuable resources for land use/land change research. NASA develops remote sensing instruments and validates the performance of the instruments while USGS is in charge of managing ground reception of the satellite data, data archiving and data distribution [23]. The Landsat 7 and Landsat 8 satellites both observe the Earth at an altitude of 705 km in a sun synchronous orbit. Landsat 8 launched on February 11, 2013 collects data with a spatial resolution of 30 m in the visible, near-IR, and SWIR wavelength regions, and a 15-m panchromatic band (Table 4.12).

There are more than 400 operational earth observation satellites in orbit. Noticeable shift is recently observed from typical government-funded platforms towards micro-satellites that are industry-funded. Advances in small satellite technology have cut the cost of investing in a specific satellite space segment. These platforms often utilise off-the-shelf components that cost a fraction of the traditional satellites. This trend will lead to the availability of cheap and abundant satellite imagery over the next few years [25]. The fleet of satellites operated by private companies is rapidly expanding. CubeSats called nanosatellites are built to standard dimensions of 10 cm × 10 cm × 10 cm (weigh 1.3 kg) and use smartphone components. STRaND-1 was the first smartphone satellite to go into orbit, built by Surrey Satellite Technology (part of the Airbus group) out of a Google Nexus One smartphone and a 3-unit CubeSat [26].

Table 4.12 Background information and status of Landsat satellites [24]

Satellite	Launched	Decommissioned
Landsat 1	1972	1978
Landsat 2	1975	1983
Landsat 3	1978	1983
Landsat 4	1982	1993
Landsat 5	1984	2013
Landsat 6	1993	*
Landsat 7	1999	**
Landsat 8	2013	**
Landsat 9	2020	***

*Never achieved orbit, ** Operational, *** Anticipated launch

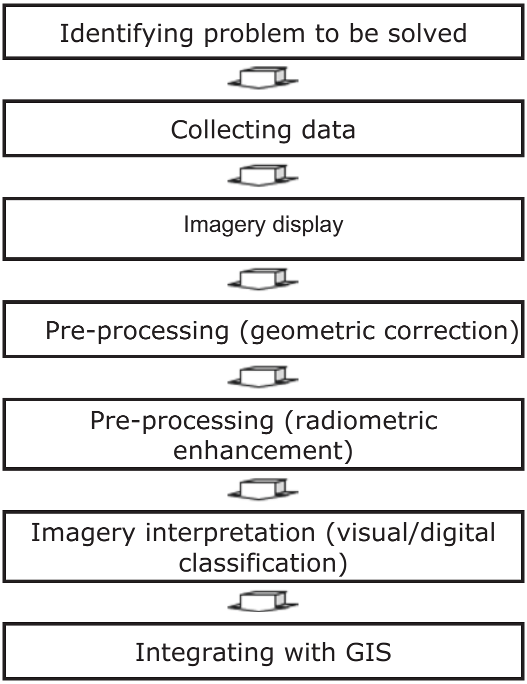


Fig. 4.9 Typical procedures of remote sensing

4.5.4 Typical Procedures of Remote Sensing

Remote sensing generally involves data collection, analysis, and interpretation. The first step in preparing a remote sensing project is a search a problem that can be solved by remote sensing in various disciplines handling field data (Fig. 4.9). The aim of remote sensing is to learn more or to learn more efficiently; to produce information which can be applied in decision-making or problem-solving. Completing the remote sensing task produces information for solving one or more other problems [27]. It is becoming common to reevaluate the validity of information and theory obtained based on traditional in-situ survey. This is because the rapid developed technology of remote sensing is shaking up the knowledge system that has been achieved through traditional theories or thinking systems.

All the disciplines recognize diverse information derived based on the data as the domain of knowledge inherent in the discipline. It is the mission of the remote sensing specialist to discover the various problems arising from new technology on the data collection. The analyst's experience in the application discipline such as forestry and civil engineering is at least as important as his or her remote sensing experience. If confronted with a forestry problem, for example, a remote sensing analyst with a forestry background should respond better than an engineering photo interpreter or a computer data analyst. In contrast, the forester may respond poorly to a soil or geologic problem.

In the remote sensing process, data refers to various documents, human and technical supporting materials to interpret images together with remotely sensed images. The process of selecting an remotely sensed images takes into account various parameters such as resolution, required information, time required for image processing, the number of manpower available, and data collection cost. The preprocessing process of images is collectively referred to as all operations required before the map production through for image interpretation. All remote sensing imagery is inherently subject to geometric distortions. These distortions may be due to several factors, including: the perspective of the sensor optics, the motion of the platform (the platform altitude, attitude, and velocity), the terrain relief, and rotation of the Earth etc. Geometric corrections are intended to compensate for these distortions so that the geometric representation of the imagery will be as close as possible to the real world.

Even though the remotely sensed imagery is geometrically corrected, the atmospheric conditions and terrain characteristics involved in the image acquisition process distort the image information. Radiometric corrections are intended to compensate for these distortions arising from atmospheric disturbance as well as from other sources such as instrumentation. Remotely sensed data are routinely preprocessed before being released for use in other applications. Computer assisted techniques improve the accuracy of the information extracted from remotely sensed data. Moreover, remotely sensed data can also be improved by using ancillary ‘contextual’ data to enhance its usefulness. For example, vegetation analysis using remotely sensed data can be improved by incorporating other data such as slope, aspect, elevation and climate parameters. The effect of such ancillary information is to enhance the image analysis process and enable a better segmentation and labelling of the digital images prior to using image analysis algorithms and prior to distribution for use in GIS.

Digital remote sensing images may be rectified geometrically using various algorithms and these may be verified by overlaying a GIS map layer. When the preprocessing process is completed, it is subjected to the visual interpretation and automatic classification process. Aerial photographs and images may be used directly as data layers in a GIS. Classification is the process of grouping pixels of images into patterns of varying gray tones or assigned colors that have similar spectral values to transfer data into information for determining Earth resources. Multispectral image classification is one of the most often used methods for information extraction. There are many classification methods to produce land cover/use map or to perform change detection. The classification result is produced as a map and used as a tool for spatial analysis in the GIS process.

4.6 Self-Driving Car and Spatial Information[5]

A self-driving car, which is called a connected car or driverless car, is a notable example of CPS [28]. A self-driving car will dramatically improve the way people drive, by implementing improving autonomous driving process through the actuator connected to sensors. Ultimately, in the near future, the era of self-driving car will begin where traffic accidents decrease drastically. CPS technology development is expected to be transformed into a virtuous cycle economy that can create high added value by reconstructing human resources and improving their efficiency through the utilization of artificial intelligence in various economic activities.

In the case of a self-driving car, the role of a driver is replaced by sensors, computers and programs, things are linked to each other, and spatial information is collected and utilized accordingly. So, a self-driving car is a notable example of CPS.[6] A self-driving car refers to a vehicle that CPS can ensure safety by determining the risk and planning the travel route through the recognition of the driving environment without controlling brake, steering wheel, and accelerator pedal by human driver (Table 4.13). In the case of a self-driving car, a series of all activities by human

Table 4.13 Comparison of manual driving versus self-driving in terms of spatial information

	Human driving	AI self-driving
How to sense visual information	Human Eye	Sensor (Radar, Lidar, Visible)
How to sense positional information	Human Eye, CNS (Car Navigation System)	Fusion sensor (GNSS, INS: Inertial Navigation System, CNS)
		Real-time map, high precision map
How to sense sound information	Ear	Vehicle to X communication
		Ultrasonic Sensor
Decision making	Neuron	Deep learning algorithm
Information storage (processor)	Brain	Memory, Real time Maps
Information processor	Muscle movement	Actuator

[5] This chapter and following chapter were revised from the paper initially published in Spatial Information Research (SpringerNature).

Um, J.-S. (2017), Embracing cyber-physical system as cross-platform to enhance fusion-application value of spatial information, 25(3): 439–447.

[6] Although market outlook on self-driving car differs for each research institution, the common atmosphere is that a self-driving car is expected to emerge by 2020, to become popular from 2025, and to become generalized around 2030.

driver, such as a driver's perception and judgment of the surroundings with eyes and head and operation of a car using hands and feet, should be replaced by mechanical language and programs. So, a self-driving car acquires all data necessary for driving a car through sensors, and stores the data in a server using a wired or wireless network. A self-driving car makes a decision necessary for driving by promptly handling and processing an enormous amount of data collected in real time.[7]

It is not an exaggeration to say that a self-driving car is a collection of context aware technology because it recognizes the context of the surrounding space in real time for driving. A diversity of contextual information is needed to provide user-customized IoT services. Self-driving is divided into recognition, judgment, and control. The core of self-driving is to collect spatial information in the recognition stage [1]. In the recognition stage, all data such as the position of a car, surrounding situation, and weather information necessary for driving are collected in real time through various sensors attached to a car. A self-driving car can use a combination of a camera-based computer vision system and several sensors to identify a dynamic driving environment. Typical sensors include light detection and ranging (Lidar), radio detection and ranging (Radar), ultrasonic sensors, and infrared sensors. RADAR is a method based on emitting radio waves and then measuring their reflection. A radar gun is a remote sensor since remote sensing is a tool to measure the reflected or emitted energy from an object. Instead of emitting radio waves (RADAR), LiDAR devices use light to detect and range. LIDAR is an optical remote sensing technology that measures distance to a target or other properties of the target by illuminating it with light. The LIDAR can detect location changes by sending out pulses of light and measuring the time it takes for the pulse to return to the sensor. The return pulse's time indicates the distance to the target.

These sensors have different advantages depending on the sensing distance, the shape of objects, brightness, etc. So, a method of combining various sensors each other is used in consideration of the advantages and disadvantage of sensors. Also, if necessary, in order to backup malfunction of a certain sensor, safety is improved by installing extra sensors that perform similar functions. That is, the front radar sensor and the camera image information are transmitted to the artificial intelligence, and self-driving is performed by combining map information on the surrounding environment.

When a person drives a car, the position accuracy of CNS (Car Navigation System) may be acceptable, but in the case of a driverless car, the location accuracy should be very high. Thus, GNSS needs the accuracy at centimeter level to distinguish lanes, and a precision map should be capable of enabling to distinguish lanes

[7] Automobiles and its parts manufactories are aggressively commercializing ADAS (Advanced Driver Assistance System) as a vehicle control device. Examples of ADAS include Smart Cruise Control (SCC: automatically adjusting the distance from the vehicle ahead), Autonomous Emergency Braking System (AEB: automatically stopping in an urgent situation), and Lane Keeping Assist System (LKAS: maintaining the driving lane without steering control).

and identify road slope. Accurate GNSS and precision maps are needed to reduce the number of sensors attached to a vehicle and mitigate the burden of data processing at the same time. In situations where it is difficult to distinguish lanes because of nighttime or bad weather, a role of precision map is more needed.

Global companies appreciate the value of spatial information and are competing to construct their own map data. In the case of this high-precision digital map, it is most important to accumulate high-precision regional data, and the global leading company for this map is the U.S. Google [29]. Google has already accumulated a large amount of data through Google Maps and Google Earth services, building big data for road section by section in the process of a self-driving car development [29]. Countries around the world are fiercely competing to secure leadership in the spatial information industry such as drones, IoT and big-data which is essential for the operation of autonomous vehicles [30].

4.7 Spatial Information as a Core Technology Operating CPS

CPS collects information for phenomena that take place in physical space using sensors, and transmits them to cyber space. A facility or device equipped with CPS technology acts as a window to connect physical space and cyber space. In cyber space, data are analyzed and predicted to produce spatial information, and the result is fed back to devices and facilities in the real world to solve the problem in real space. Data that CPS collects in physical space using sensors involve location information necessarily. Whether CPS space is a virtual space or a real space, there is a need for spatial information infrastructure that can represent input and output through CPS. So, spatial information is one of the core technologies for constructing and operating CPS.

The fusion of CPS and spatial information is a combination of things in the real world, cyber space on the web, and users (people). For example, when a car accident causes serious congestion, this is detected by spatial information infrastructure and traffic lights are adjusted or detour information is provided. A large number of sensors and devices connected to the internet are located at different positions, and in order to establish a functional link between them, they have to recognize each other's position. CPS is increasingly reducing human intervention through machine learning, and spatial information will gradually have an intelligent structure in CPS environment where tens of billions of things are connected. So, as things or spaces themselves become intelligent and they share and serve information, spatial information will be developed in the way that sensors and devices are easy and convenient to use it (Table 4.14).

In a self-driving car, it is essential to combine sensor information and spatial information to determine the absolute or relative position, understand the spatial situation, and visualize the analysis results. In particular, as various facilities around

Table 4.14 Comparison of spatial information between information society versus CPS society

Category	Information society	Cyber-physical system society
Sensor availability	Limited to specific timing and space	Ubiquitous sensor such as smart device
Connectivity	Focused on human network such as PC, smart phone	Super-connectivity, Internet of Things such as traffic right
Data availability to support deep learning	Limited to cyber space	Extended to Cyber and Physical space utilizing ubiquitous big data
Real-time update	Updated interval of spatial information is very slow.	Real time update of spatial information utilizing ubiquitous sensor
Information diversity	Limited to information offered by Government authority	Big-data from ubiquitous sensors extended to physical space.
Cross-validation of information precision	Limited to cross-validation offered by government authority	Very high, cross-validation of information by sensor fusion in relation to CPS space recognized intellectually

roads (road weather, pavement condition) exist with actual location, it is necessary to reflect this in cyber space to effectively provide the service. Road conditions and traffic information on precision maps are changed from time to time, so they should be reflected in map database in real time. So, data collected by self-driving car should be transmitted to the real-time server through wireless communication, and any changes should be reflected immediately. In autonomous driving, the collected data are processed in real time to judge the driving condition of a car and the surrounding and traffic situations. An enormous amount of data collected through various sensors should be dealt with in real time through the application of a deep learning technology of artificial intelligence, and autonomous driving should be performed under the judgment about various kinds of roads and various kinds of objects (people, traffic police, vehicle type, etc.) that sensor should recognize. Besides, 'Vehicle-Road CPS' can utilize V2V (Inter-Vehicle Communication) or V2I (Vehicle-to-Infrastructure Communication) to implement a variety of applications such as high visibility road marking, battery charging roads by solar power and automatic recognition of vehicles for better mobility and safety.

In the first and second industrial revolution society, physical infrastructures such as roads, ports, and power plant were important social overhead capital. In the third information revolution era, spatial information has been recognized as core social overhead capital which includes information-based facilities such as software, information highway and computer application system. So far, spatial information has expressed size, shape, height, and depth of visible objects in 2D or 3D. However, with a transition to CPS society, many sensors are installed in cities, and different kinds of high-tech devices such as smart phones used by people are equipped with IoT technology. So, physical space and cyber space are linked, and CPS is producing spatial information as a direct platform. CPS facilities and equipment, such as smart phones, play a key role as a place to find the structures of common matters and interactions between cyber space and physical space, to build them into systems, and to share and exchange information, technology, and knowledge under standardized rules for use (so to speak, the platform). A CPS platform concept, as a core object of spatial information science, is an extended and advanced concept encompassing the spatial information infrastructure. Participants in the CPS platform are the subjects of human-thing-space information involved in hyper-connection. As a result, spatial information can play a role of activating CPS hyper-connection network. CPS platform can be a catalyst to increase the added value of spatial information through the intelligent connection and coordination. CPS platform is a place where users in various fields can share and exchange knowledge, technology, and information related to spatial information.

CPS has already begun to infiltrate our society and the visible change has begun to take place. For example, sensors attached to roads, buildings, and bridges provide basic information of 3D facility map, so CPS is expected to dramatically improve efficiency and productivity in a variety of areas such as precision agriculture, building control, disaster response, smart manufacturing, and social infrastructure etc. It can be said that CPS platform is a platform on platform comprised of several small and tangible or intangible platforms. In particular, CPS technology is expected to provide a zero-defect intelligence system that can guarantee high reliability and safety to flexibly cope with unexpected crisis. Spatial information can provide a function of integrating and analyzing the big data of various resources obtained from CPS centered on a place. In the situation where all things are connected, spatial information has a very important meaning. For example, all activities on CPS network play a key role in enabling the overall mechanism to work properly through continuous connections; the position of a friend connected to me, the position of a terminal connected to a car sensor, and the position of a truck loaded with dangerous materials. In the case of CPS network, the output of one subject (e.g. a package delivery drone) becomes the input of another subject (e.g. a self-driving car) by mapping the positions of objects acquired from CPS sensors. The transformation or processing of the input can offer spatial information to trace the movement or analyzing the moving route of package delivery drone. In this process, a virtuous cycle creating added-value of spatial information can be repeated.

4.8 Conclusion

In cyber-physical system, the physical system is a system performing continuously a set of mature and complete quantitative analysis for location data and imagery data collected by employing sensor. Human eyes see colors and light about the target without being in contact with the target and send that information to your brain. In this regard, human eye is a remote sensor. A GIS can be thought of as an interactive map made of different layers of geographic data that can be queried. The spatial analysis technique of GIS enables to generate new information by superimposing spatial data and by performing spatial query for geometric data and attribute data contained in spatial database. Human brain stores information collected by your senses and allows you to search, manipulate, and analyze data. In this regard, human brain is the starting point of GIS based thinking system. You are a Geographic Information System (GIS).

If existing spatial information plays an auxiliary role on existing industries such as land management, spatial information in the fourth industrial revolution is playing key role in developing core technology such as a self-driving car. Whether CPS space is a virtual space or a real space, there is a need for spatial information infrastructure that can represent input and output through CPS. So, spatial information is one of the key elements for constructing and operating CPS. This chapter presents spatial information and CPS linkage around the cyber versus physical world since it identified the functional relationship between CPS and spatial information. This is expected to be a basic framework for a future direction of CPS to link with spatial information. This will be very useful for entrepreneurs that plan new business and services through the fusion of spatial information and CPS. In fact, spatial information specialists do not understand the characteristics of CPS field and CPS specialists do not understand spatial information, so it was difficult to develop these into the convergence industry. This chapter could be foundation to help the specialists in the field of spatial information and CPS to understand the fusion of the two and the further expected outcomes. To do this, this chapter conceptualized CPS, and logically analyzed how spatial information is related to CPS.

References

1. Um J-S (2017) Embracing cyber-physical system as cross-platform to enhance fusion-application value of spatial information. Spat Inf Res 25(3):439–447. https://doi.org/10.1007/s41324-017-0112-8
2. Mexico TRotUoN (2009) Introduction to transducers, sensors, and actuators: participant guide. National Science Foundation, Albuquerque, NM, USA
3. Hahanov V (2014) Cyber physical system – smart cloud traffic control. https://aiukraine.com/2014/presentations/Trafic-Control_Hahanov_AIUkraine2014.pdf. Accessed 30 July 2018
4. Mathas C (2011) The five senses of sensors – smell. Digi-Key Electronics. https://www.digikey.com/en/articles/techzone/2011/jul/the-five-senses-of-sensors-smell. Accessed 28 Sept 2018
5. URISA (2017) Ian McHarg. URISA. https://www.urisa.org/awards/ian-mcharg/. Accessed 30 Sept 2018
6. Dasgupta R, Dey S (2013) A comprehensive sensor taxonomy and semantic knowledge representation: Energy meter use case. In: 2013 seventh international conference on sensing technology (ICST), 3–5 December 2013, pp 791–799. https://doi.org/10.1109/ICSensT.2013.6727761
7. White RM (1987) A sensor classification scheme. IEEE Trans Ultrason Ferroelectr Freq Control 34(2):124–126. https://doi.org/10.1109/T-UFFC.1987.26922
8. Fraden J (2010) Data acquisition. In: Handbook of modern sensors: physics, designs, and applications. Springer, New York, pp 1–12. https://doi.org/10.1007/978-1-4419-6466-3_1

9. Smart Vision Labs (2017) Why vision is the most important sense organ. https://medium.com/@SmartVisionLabs/why-vision-is-the-most-important-sense-organ-60a2cec1c164. Accessed 30 Sept 2018
10. Jin X-B, Su T-L, Kong J-L, Bai Y-T, Miao B-B, Dou C (2018) State-of-the-art mobile intelligence: enabling robots to move like humans by estimating mobility with artificial intelligence. Appl Sci 8(3):379
11. Zhang L, Zhang L, Du B (2016) Deep learning for remote sensing data: a technical tutorial on the state of the art. IEEE Geosci Remote Sens Mag 4(2):22–40. https://doi.org/10.1109/MGRS.2016.2540798
12. Wang L, Scott KA, Xu L, Clausi DA (2016) Sea ice concentration estimation during melt from dual-pol SAR scenes using deep convolutional neural networks: a case study. IEEE Trans Geosci Remote Sens 54(8):4524–4533. https://doi.org/10.1109/TGRS.2016.2543660
13. Gibson BR, Rogers TT, Zhu X (2013) Human semi-supervised learning. Top Cogn Sci 5(1):132–172. https://doi.org/10.1111/tops.12010
14. University of Babylon (2011) Learning in neural networks. University of Babylon, Iraq. http://www.uobabylon.edu.iq/uobcoleges/lecture.aspx?fid=13&lcid=393. Accessed 30 Sept 2018
15. Rystedt B, Konecny M, Virrantaus K, Ormeling F (2003) A strategic plan for the International Cartographic Association. International Cartographic Association
16. Longley PA, Goodchild MF, Maguire DJ, Rhind DW (2005) Geographic information systems and science. Wiley, Hoboken
17. Shannon Mattern (2017) Mapping's intelligent agents. Places J. https://doi.org/10.22269/170926
18. McHarg IL, Mumford L (1969) Design with nature. American Museum of Natural History, New York
19. Um J-S, Wright R (1998) A comparative evaluation of video remote sensing and field survey for revegetation monitoring of a pipeline route. Sci Total Environ 215(3):189–207
20. Um J-S, Wright R (1996) Pipeline construction and reinstatement monitoring: current practice, limitations and the value of airborne videography. Sci Total Environ 186(3):221–230
21. Riebeek H (2009) Catalog of earth satellite orbits. NASA. https://earthobservatory.nasa.gov/Features/OrbitsCatalog. Accessed 23 Sept 2018
22. NASA (2009) Three classes of orbit. NASA. https://earthobservatory.nasa.gov/Features/OrbitsCatalog/page2.php. Accessed 28 Sept 2018
23. U.S. Geological Survey (2018) Landsat project description. U.S. Geological Survey. https://landsat.usgs.gov/landsat-project-description. Accessed 30 Sept 2018
24. U.S. Geological Survey (2016) Landsat – earth observation satellites. Science for Changing World. U.S. Department of the Interior, U.S. Geological Survey. https://doi.org/10.3133/fs20153081
25. Coppa I, Woodgate P, Mohamed-Ghouse Z (2016) Global outlook 2016: spatial information industry. Australia and New Zealand Cooperative Research Centre for Spatial Information. Melbourne
26. Economist T (2014) Nanosats are go! The Economist
27. Philipson WR (1980) Problem-solving with remote sensing. Photogramm Eng Remote Sens 46(10):1335–1338
28. Heather Kelly (2012) Self-driving cars now legal in California. CNN
29. Gomes L (2016) When will Google's self-driving car really be ready? It depends on where you live and what you mean by "ready" [News]. IEEE Spectr 53(5):13–14. https://doi.org/10.1109/MSPEC.2016.7459105
30. Eze EC, Zhang S-J, Liu E-J, Eze JC (2016) Advances in vehicular ad-hoc networks (VANETs): challenges and road-map for future development. Int J Autom Comput 13(1):1–18. https://doi.org/10.1007/s11633-015-0913-y

Chapter 5
Location Sensors

Abstract Artificial intelligence needs to be moved around in various places to replace natural intelligence. Location information for various places must be provided beforehand so that destinations can be set for the movement of artificial intelligence. It is known that about 90% of the information utilized by natural intelligence is based on location. As the artificial intelligence society progresses, it will be evident that the location data are emerging as a necessity in an area of both indoor and outdoor. This is due to the fact that CPS (Cyber-Physical Systems) such as drones possess unique characteristics in being dynamic, easy-to-deploy, easy-to-reprogram during run-time, capable of measuring anything at any location and capable of flying anywhere with a high degree of autonomy. The underlying principle in data acquisition for CPS systems is to select location sensor suitable for operational application based on customer requirements and intended information such as teaching AI (Artificial Intelligence). Together with the expansion of the cyber-physical system across the various sectors of society, sensor society is expected to emerge. The vital aspects of the coming sensor society are characterized by the followings: the increasing distribution of collaborative networked sensors; the consequential explosion of sensor-generated data; and predictive analytical infrastructure devoted to making sense of sensor-derived data [1]. The prerequisite for sensor society is to secure accurate position information for collaborative networked sensors since knowing the location performs a role as fundamental infrastructure for maintaining routine life of a common human in this sensor society. In this regard, the purpose of this chapter is to introduce the location sensor and to provide a background for the navigation technology, progressing from manual navigation to indoor localization. This chapter will give you some basics about how to determine the location by GNSS (Global Navigation Satellite Systems) and how INS (Inertial Navigation System) works in relation to GNSS.

J.-S. Um, *Drones as Cyber-Physical Systems*,
https://doi.org/10.1007/978-981-13-3741-3_5

5.1 Introduction

Together with the expansion of the cyber-physical system across the various sectors of society, sensor society is expected to emerge. The vital aspects of the coming sensor society are characterized by the followings: the increasing distribution of collaborative networked sensors; the consequential explosion of sensor-generated data; and predictive analytical infrastructure devoted to making sense of sensor-derived data [1]. The prerequisite for sensor society is to secure accurate position information for collaborative networked sensors since knowing the location performs a role as fundamental infrastructure for maintaining routine life of a common human in this sensor society. This chapter will give you some basics about how to determine the location by GNSS (Global Navigation Satellite Systems) and how INS (Inertial Navigation System) works in relation to GNSS.

5.2 From Manual Navigation to Indoor Localization

The era known as the Age of Exploration, sometimes called the Age of Discovery, officially began in the early fifteenth century and lasted through the seventeenth century (Table 5.1). The period is characterized as a time when Europeans began exploring the world by sea in search of new trading routes, wealth, and knowledge [2]. During the Age of Exploration, focus was put on the potential to navigate by way of the solar system and stars. However, even with the ability to determine the positioning based on the solar system, many high-ranking officials at that time offered great rewards to anyone who could develop an accurate means of navigation. Manual navigation techniques have changed very little over the centuries. For example, commercial and leisure activities continue to rely on dead reckoning where an initial position is established [3].

Dead reckoning first determines current location on the map, and then calculates the distance and azimuth (bearing) from the destination. The users must constantly update their location on your map, while keeping separate track of distance and azimuth changes, if any, about once every 30 min. The position is then estimated over time using an individual or vessel's speed and direction. The accuracy of dead reckoning calculations depend on the accuracy of the speed input and the effects of environmental factors including wind and current [3]. For hundreds of year, human has wandered the unknown world to find his way by means of a crudely drawn map and a magnetized needle floating on water. Such manual navigation is time-consuming and often requires multiple trips to the same site to gather data and to ensure that the collected data is accurate. Crews are not always able to work under certain weather conditions, such as snow, rain, or extreme temperatures. It was difficult to account for the influence of varying tides or wind speeds using dead reckoning. In addition, there are considerable costs associated with conventional surveying technology

Table 5.1 Development history of navigation technology

Navigation device and technology	What it does	Historical period utilized
Astronomic navigation, celestial navigation, solar system and stars	A method of finding the current position based on altitude, direction of celestial body (e.g., the Sun, the Moon, or a star) and observation time.	Age of exploration: The fifteenth to the seventeenth century
	There was an expert on board (e.g. ship) that specializes in old-time astronomic navigation. Nowadays, such astronomic navigation had disappeared with the Doppler radar and INS navigation technology.	
Geographical navigation, pilotage navigation	A pilot can fly by looking at the shoreline or railroad tracks of the ground with his or her eyes, and cannot use it when there is no fixed landmark. It is the most simple and elementary navigation and requires a flight map (navigation map) to complete this navigation.	Twentieth century
Dead reckoning navigation	It is a method to navigate by guessing direction and distance from already known point. It is the principle navigating by finding out the relative motion (radial direction, wind direction, flight speed and wind speed) between the aircraft and the air current.	Twentieth century
Radio and light navigation	It collectively refers to the method of finding the current position by using radio and light waves emitted from a radio and light facility on the ground: RADAR (Radio Detection and Ranging)	After the second world war
	LIDAR (Light Detection And Ranging)	
GNSS (Global Navigation Satellite Systems)	GNSS is a space-based, radio-navigation system that provides worldwide, all-weather navigation data.	1980

since workers must be trained to operate conventional surveying equipment properly.

After the Second World War, the development of LIDAR (Light Detection and Ranging) and of differential radio signals (RADAR, Radio Detection and Ranging) helped to establish automated navigation. Instead of emitting radio waves (RADAR), LiDAR devices use light to detect and range. In other words, the bulk of routine navigation tasks has passed from manual to RADAR/LIDAR based techniques and the automated satellite based systems. For example, in desert or jungle terrains and other remote areas, there may be insufficient landmarks to employ alternate forms of navigation, Satellite navigation tools such as GNSS provide a critical means of reducing uncertainty in complex navigation tasks [3]. GNSS is the most global and accurate navigation system ever built. GNSS offers much wider worldwide location information than dependent upon fixed sensors such as RADAR and LIDAR. But GNSS does not work inside buildings or other places where its satellite signals are not visible.

Because Britain first developed its accurate navigation technology, it was possible to govern colonies over 153 times of its own national territory size. In modern times, major countries are competing to secure accurate satellite navigation systems. We find GNSS technology in our commonplace that requires navigational aids or need recordings of geographic locations such as Location Based Services (LBS),[1] smart phones and car navigation system (CNS). The self-driving car is a representative example of utilizing satellite positioning technology, where location accuracy is directly related to human life and safety. In recent years, location-based services for indoor mobile devices are becoming more and more widespread due to their growing service range. In the context of indoor applications, where GPS signals are not available, localization approach relies on inertial sensors (e.g., smart phones or miniature indoor drones). For human tracking, miniature inertial sensors integrated into clothes or shoes can capture full-body human motion. In the domain of miniature indoor drones, inertial sensors are commonly used in combination with cameras for flight stabilization [4].

5.3 Satellite Navigation

5.3.1 History of Satellite Navigation

The Global Positioning System (GPS) comprises three different segments: a constellation of radio navigation satellites, a ground control unit which manages satellite operation and users with specialized receivers. United States Department of Defense (DoD) initiated the GPS system to accommodate defense positioning needs and as a by-product, to serve the civilian navigational community [5]. The Global Positioning System (GPS) and Global Navigation Satellite Systems (GNSS) are often used interchangeably. In reality, they are not equivalent. GNSS is a generic term for a system that measures position using radio waves from satellites. As a satellite navigation system, various types of GNSS are actively providing services globally. GPS is the first satellite navigation system as well as one of the GNSS system to offer world-wide satellite positioning service. Representative GNSS systems include Global Positioning System (GPS) in the United States, GLONASS (Global Orbiting Navigation Satellite System) in Russia, and Galileo in Europe.

The United States government initially launched the first generation of GPS satellites exclusively as a military navigational tool on February 22, 1978. On September 1, 1983, a Korean airplane crashed over the Soviet Union due to Russia air force attack after it lose its way into restricted airspace due to navigational errors. Ironically, the disaster that killed 269 passengers was an opportunity to spread the GPS system built by the US military to the private sector. At the time the aircraft was operated depending on the inertial navigation system (INS). This is a device that estimates the speed and position of the aircraft by measuring the acceleration

[1] Location-based service (LBS) refers to wireless content services such as nearby restaurants or traffic congestion warning that provide specific information based on a user's location.

from the initial position information. The pilots, while relying on the INS, were navigating by looking the map, sea and land alternately. When the failure of the INS device was analyzed as a cause of Korean Air's invasion of the Soviet airspace, the US President Ronald Reagan declared that he would open the GPS to the private sector. The second generation of GPS satellites became fully operational in 1995, when a complete 24-satellite constellation was in orbit, a degraded signal was available for civilian use. In May of 2000, both military and civilians receive the fully functional (with some exceptions) military-quality signals [6].

Russia has its own satellite navigation system (GLONASS) while the Chinese have BeiDou and the Europeans have Galileo. The European Space Agency's Galileo system was brought into orbit in 2005 and projected to provide global coverage by 2020. The Galileo positioning system is intended to comprise a constellation of thirty navigational satellites to be implemented by the European Union (EU). The Galileo positioning system is funded by EU countries as well as a number of other non-EU countries including Israel, South Korea, Morocco, Saudi Arabia, India, and the Ukraine. The ESA asserts that Galileo will be "interoperable" with GPS. This imply the future prospect of GNSS receivers that are able to effectively roam between GPS and Galileo in order to improve both accuracy and continuous satellite signal reception [7].

5.3.2 Satellite Navigation Principle

The positioning technology using the satellite altogether operates by the same fundamental principles. It calculates position by establishing the distance relative to reference satellites with a known position. In this case the distance is calculated from the travel time of radio waves transmitted at the speed of light (300,000 km/s) from the satellites. GNSS satellites transmit their exact position and onboard clock time to Earth [8]. The GNSS uses a network of geostationary satellites to calculate the position of a ground receiver over time. Each GNSS satellite contains an atomic clock that provides a stable time and frequency reference signal which is the foundation for the GNSS broadcast signal. Because of their precision, small size, and operational capability in zero-gravity environments of space, chip-scale atomic clocks are now used ubiquitously in positioning satellites [7]. Atomic clocks of GNSS satellites are known as the most precise time measurement instruments so far. Nevertheless, in order to maintain this precision, they are regularly adjusted or synchronized by utilizing data verified in ground stations around the globe.

5.3.3 Three Fundamental Segments of Satellite Navigation

There are three fundamental components necessary for a GNSS to work (Fig. 5.1): a network of satellites with built-in atomic clocks, ground stations that control the space satellite network and receivers carried by ground users;

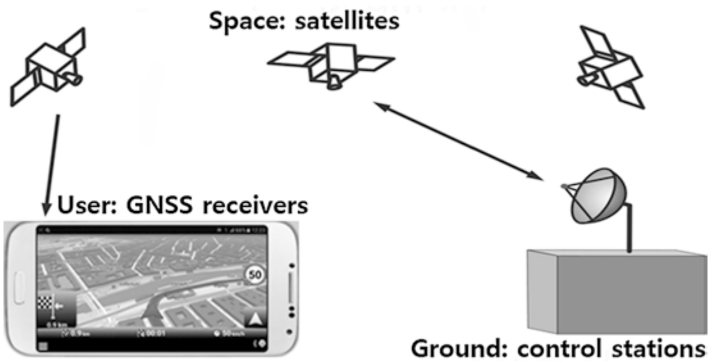


Fig. 5.1 Three fundamental components of the GNSS

Space Segment The number of operating satellites orbiting 20,180 km above the earth surface can vary within a few satellites at any given time, due to old satellites being retired and new satellites being launched to replace them. The operational satellites circle the Earth twice a day in a very precise orbit and are manufactured to stay in the space about 10 years. The nominal specifications of the GPS satellites are as follows [9]: mass (1~2 tones), size (5 m or so), power (solar panels + batteries), atomic clocks.

Ground Control Segment Several ground stations monitor the satellite signals, and assess the health of the satellites by transmitting orbital corrections and clock updates. The ground control segment then uses these signals to estimate and predict the satellite orbits and clock errors, and this information is uploaded to the satellites. For example, the satellites operating at a different orbit can be maneuvered to optimize satellite geometry and to keep the satellites to within a certain tolerance of their nominal orbital parameters [9].

User Segment: GNSS Receivers It is common equipment that ordinary citizens face in everyday life. This segment includes the navigation system in a car (Car Navigation System), the GNSS device in a smart phone or location sensor equipped in drones. GNSS receiver varies significantly from model to model (e.g. cost, size, signal frequency etc.), but most share several common features. Most can track from 8 to 20 satellites simultaneously and can provide time and frequency signals derived from an average of all satellites in view. Most offer a 1 pulse per second (pps) electrical output [10].

5.3.4 Triangulating Three GNSS Satellites

The Satellite Navigation Systems is designed to allow at least four satellites to be visible (line-of-sight contact) in radio communication range and in any location on the earth surface. A satellite will be return to its initial starting position above the

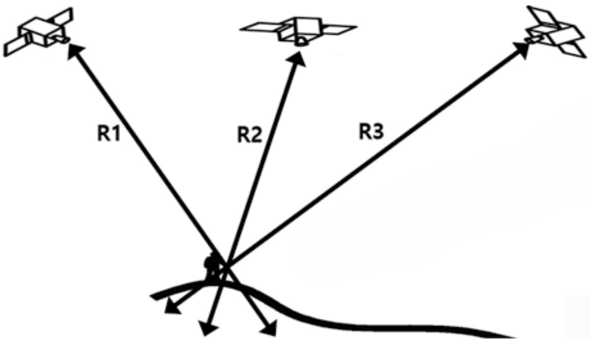


Fig. 5.2 Schematic representation of theoretical principle involved in GNSS navigation

Table 5.2 Comparison of almanac versus ephemeris

	Almanac	Ephemeris
Number of satellites providing orbit information	Orbital parameters for all the GPS satellites	Orbital parameter for single satellite
Precision	Not very precise	Very precise
Valid time period	Valid for a period of up to 90 days	Valid for about 30 min
Main applications	Used to speed up time to first fix by 15 s	Real time satellite coordinate computation by broadcasting orbital parameter of each satellite every 30 s

earth's surface after approximately 24 h [8]. Signals are transmitted and received by the satellite using microwaves. To derive accurate location data, several long-known and reliable technologies are combined with GNSS receivers. The theoretical principle involved in GNSS navigation is dead reckoning (Fig. 5.2). It estimates current location by applying simple calculations for moving speed (using odometer) and direction (using a traditional compass) from a last known location. For example, a hiker can determine their position roughly by observing speed using an odometer, and detecting direction using a traditional compass [7]. Satellite Navigation Systems employ simple calculations for moving speed and direction from a last known satellites orbiting location above the Earth.

The satellites broadcast two types of data, Almanac and Ephemeris (Table 5.2). Almanac data is coarse orbital parameters for all the GPS satellites. The almanac is used to identify the locations of the other satellites in the GNSS constellation. Each satellite broadcasts almanac data for all the GPS satellites. This Almanac data is not very precise and is considered valid for up to several months. Ephemeris data by comparison is very precise orbital and clock correction for each satellite and is necessary for precise positioning. Each satellite broadcasts only its own Ephemeris data (reported satellite orbital location). This data is only considered valid for about 30 min. The Ephemeris data is broadcast by each satellite every 30 s [11]. These satellites continuously broadcast their position and a timing signal. The radio signals transmitted by the GPS satellites in space take about 67 milliseconds to reach a receiver on Earth. The signals travel at a constant speed, as electromagnetic signals travel through space at the speed of light (c = 300,000 km/s). Their travel time determines the exact distance between the satellites and the ground receiver.

GNSS receivers are able to identify their location when three GNSS satellites triangulate and measure the distance to the receiver. The position is the point where all three of the spheres intersect. To establish position, all that is required is a receiver operated by an accurate clock. Based on the measured travel time of the radio waves the position of the receiver is calculated. The receiver compares the signals from several satellites to find the difference between the time satellites sent the signal and the time the signal was received. That information allows the GNSS receiver to calculate how far away the satellite is, and determine the location of the GNSS user. If the earth surface is perfectly flat, you can determine its position with only two satellite signals. However, since the real world is three-dimensional space, three or more satellites are required to determine the position. A calculation from three satellites will give the longitude and latitude of the receiver. A calculation from four satellites will also give altitude [8].

5.4 GNSS Errors and Biases

Certain atmospheric factors and other sources of error can affect the accuracy of GNSS receivers. Even if most of the sources of error are unavoidable, it is important for the user to be aware of the ones that he can influence and be prepared to take steps to reduce their impact. Table 5.3 shows the extent of horizontal position errors caused by different sources [12, 13].

5.4.1 GNSS Satellite Errors

The greatest source of GNSS measurement error is associated with the position of the satellite in the space when taking the measurement (Fig. 5.3). The spread of the satellites in the sky is called the Positional Dilution of Precision (PDOP). A good PDOP is obtained when the satellites are widely distributed at wide angles relative to each other. On the contrary, if all visible satellites are close to one another, the anticipated position error will be higher. Although, for example, every GNSS satellite is provided with four highly accurate atomic clocks, a time error of only 10 nanosecond (one billionth of a second) is enough to produce a positioning error in a distance error of about 3 m on the ground [8].

Table 5.3 GNSS error causes (typical ranges)

	Error cause sources	Typical error range (m) without DGPS (Differential GPS)
GNSS satellite	Satellite geometry Positional Dilution of Precision (PDOP)	1~5 m
		The strength of the current satellite configuration
		The number of visible satellites spread evenly throughout the sky,
	Ephemeris data	1.5 m
		Nominal errors due to inaccuracies in broadcasting orbital parameter for single satellite
	Satellite clocks	1.5 m
		Difference between satellite time and true GNSS time
	S/A (selective availability)	Errors due to the intentional orbital degradation (S/A, 0~70 m)
Natural phenomenon	Effect of the ionosphere	0~30 m
		Delay in signal transmission due to free electron density in the ionosphere
		The electron density in the ionosphere is changing by solar radiation.
	Effect of the troposphere	0~30 m
		Delay in signal transmission due to wet and dry components in the region of the atmosphere extending up to 80 km above the earth
	Multipath reception	0~1 m
		GNSS multipath is caused by the reception of signals arrived not only directly from satellites, but also reflected or diffracted from the local objects.
Errors in the measurement range of receiver	Effect of the receiver	0~10 m
		Difference between receiver time and true GNSS time/short occupation period
	Signal arrival C/A: Coarse	±3 m
		Inaccuracies of code measurements due to receiver noise
	Signal arrival P(Y): Precise	±0.3 m
		Inaccuracies of carrier measurements due to receiver noise
Total horizontal error		28 m (When SA is turned off)
		100 m (When SA is turned on)

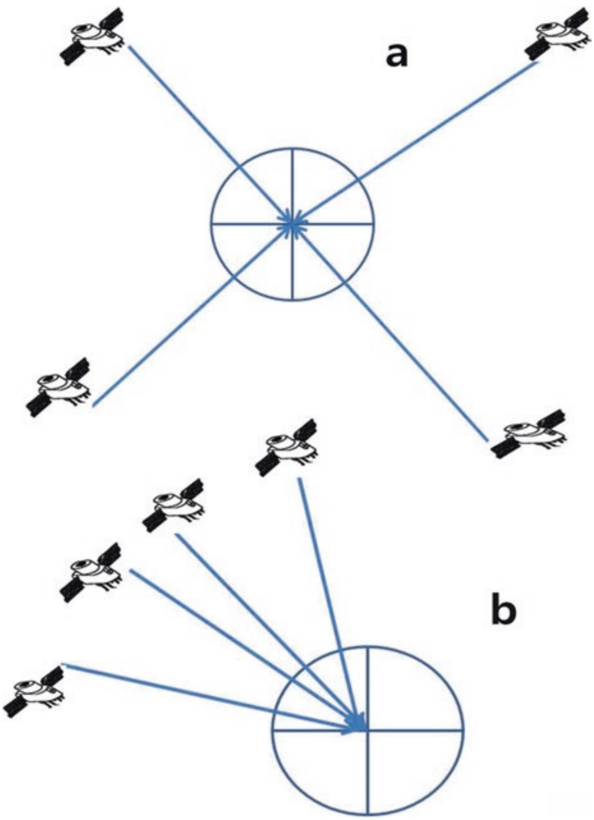


Fig. 5.3 The spread of the satellites: Positional Dilution of Precision (PDOP). (**a**) Using satellites well spread out in the sky will provide a good PDOP. (**b**) All visible satellites close to one another will provide a bad PDOP

5.4.2 Selective Availability

Selective Availability was intended to deny enemy military forces the ability to use the GPS signals to direct their own operations. All satellites of the GPS are operated by the U.S. military. At the outset, signals broadcast by GPS satellites were not anticipated to be available to civilian receivers. The signals open for civilian receivers actually contained degraded information, but the more accurate information was encoded and available only to military receivers [7]. An intentional interference of U.S. military were unable to provide normal positioning service for a significant period of time and have various negative effects on ground GPS receiver operations [14]. On May 1, 2000, the Selective Availability was stopped by order of President Bill Clinton. Since then, the military has employed other techniques for disabling GPS function in a regional basis. This allows the U.S. military to reject enemy contact to GPS signals in the outbreak of war while still providing reliable signals to the civilian community [7].

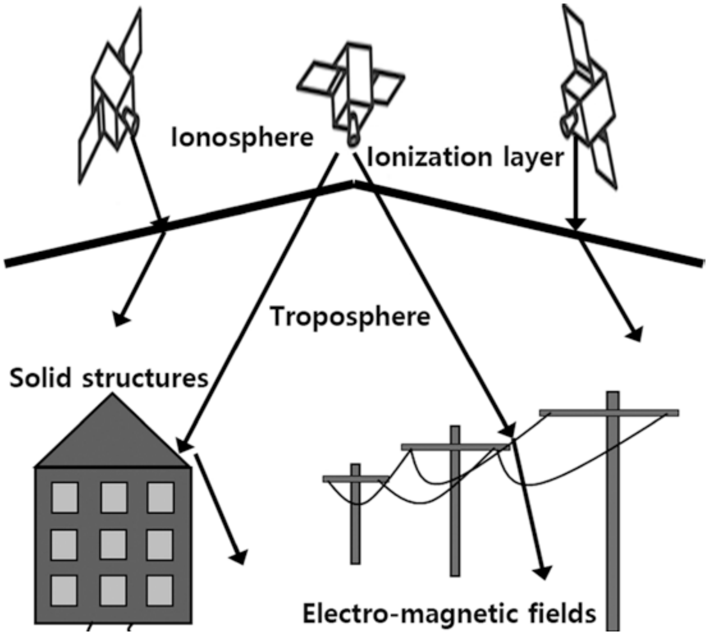


Fig. 5.4 Natural phenomenon as GNSS error causes

5.4.3 Natural Phenomenon

The satellite signal is supposed to reach the earth surface through space of the vacuum state at the speed of light. Atmospheric delay causes the satellite signal to slow as it passes through the ionosphere and troposphere (Fig. 5.4). Therefore, the speed of the satellite signal is not always constant. If the speed of the satellite signal is out of the normal range, the ground receiver will generate an error in the **calculated** position.

Effect of the Ionosphere The ionosphere is an atmospheric layer situated from about 60 km to 1000 km altitude above the earth surface. The gas molecules in the ionosphere are heavily ionized. The ionization is mainly caused by solar radiation (only during the day). The level of ionization differs from time and location, and is strongest during the day and at the equator. If a GNSS radio signal is transmitted through the ionosphere, its signal intensity is reduced down more heavily at lower frequencies. Signal broadcast time increases depending on the strength of ionization [8].

Effect of the Troposphere The troposphere is the lowest layer of Earth atmosphere, and is also where weather phenomenon take place. The bottom of the troposphere is at Earth surface. The troposphere extends upward to about 10 km above the Earth surface. In the troposphere, the temperature decreases at a rate of about

6 °C per km. This vertical distribution of temperature means that the atmosphere is unstable and convection current is likely to occur. When the air is saturated with water vapor, clouds, rain, snow, and hail are formed. This weather phenomenon occurs only in the troposphere. The cause of the error here is the varying density of gas molecules and the air humidity distorts the speed of satellite signals. The GPS system uses a model that calculates an average amount of delay to correct for this type of error.

Signal Multipath Interference The GNSS satellite signal is distorted due to signal multipath interference before arriving at the receiver. The GNSS satellite signal is reflected from the infrastructure (e.g. buildings) and particular landform (mountains) that are located around the ground GNSS receiver. These objects can block the reception of the signal, causing position errors or possibly no position reading at all. This increases the travel time of the signal and creates errors of distance estimation between the GNSS satellite in space and the ground GNSS receiver. This highlights the importance for the users to be located in the most open area as possible before taking the measurement [12]. The ground GNSS receiver typically will not work indoors, underwater or underground. The effect of multipath can be partially compensated by appropriately selecting the measurement position, increasing the measurement time, or by using a high-performance antenna.

5.5 GNSS Signal Components

The GNSS satellite signals are transmitted to the User Segment (ground receiver) at two carrier signals with the L1 channel (frequency = 1575.42 Mhz; wavelength = 19.0 cm), and the L2 channel (frequency = 1227.60 Mhz; wavelength = 24.4 cm). A summary of the signal components is given in Table 5.4. The military signal PPS (Precise Positioning Service) is accessible only to authorized government agencies and the civilian signal SPS (Standard Positioning Service) can be freely used by ordinary citizens. The C/A (Civilian Access code, coarse acquisition) code can be found on the L1 channel. Most receivers use the C/A code broadcast on the L1 frequency as their time and frequency reference. The P ("precise") code is identical on both the L1 and L2 channel. Whereas C/A is a rough code appropriate for initially locking onto the signal, the P code is better for more precise positioning.

Table 5.4 GPS signal components

Carrier	Freq.	Wavelength	Modulation	Frequency
L1	1575.42 MHz	19 cm	C/A code (coarse acquisition)	1.023 MHz
			P code (precise)	10.23 MHz
			Message	50 Hz
L2	1227.60 MHz	24 cm	P code	10.23 MHz
			Message	50 Hz

Table 5.5 Comparison of the code versus carrier measurements

Characteristics	Code phase measurement	Carrier phase measurement
Carrier frequencies	L1 pseudo random code (C/A or P)	L1 & L2
Number of channels	10	36 (12 × 3)
Code modulation	C/A on L1	C/A on L1, P on L1 & L2
Wavelength	293 m	19 cm
Position accuracy	3–5 m accuracy	Sub-meter accuracy (survey grade).
Strict data collection requirements	Not necessary	Require a clear view to the satellites in order to maintain a constant lock with at least 4 satellites
Post-processing	Not necessary	Required

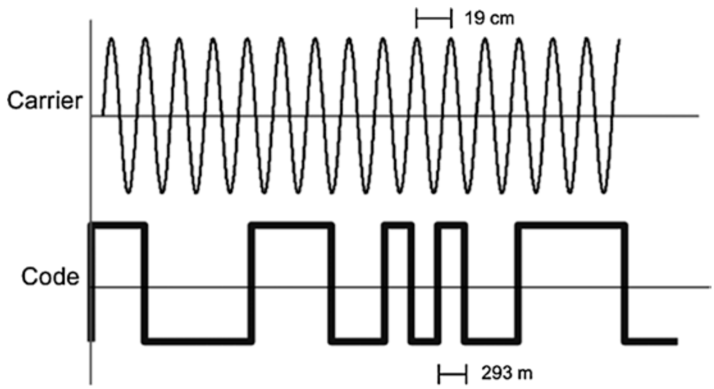


Fig. 5.5 Comparison of the code versus carrier measurements

GPS receivers carried by ordinary users must wait a certain time (at least 18–36 s) to determine the first position (this time is referred to as the Time to First Fix: TTFF). It is difficult to receive satellite signals in central business district areas where super-high-rise buildings block straight sight to the sky. It may take a considerable amount of time to calculate the first position coordinates [8]. This slow start-up in estimating the first position is a system-inherent limitation of GNSS radio signal delivered from GNSS satellites at a height of 20,180 km above the Earth surface. The slow start-up cannot be overcome with improved ground GNSS receiver technology. GNSS receivers are classified as either being single frequency, meaning they receive L1 signals only, or dual frequency, meaning they receive both L1 and L2 signals. Dual frequency receivers may provide access to C/A code data, P code data or both [5].

There are two types of GPS observations: pseudo-range (also called code observation, code phase) and carrier-phase (Table 5.5 and Fig. 5.5). The term pseudo-range is so called because this measurement is contaminated by ground receiver clock errors and do not show the original signal. In pseudo-range, position accuracy is based on measurement which has not corrected synchronization errors between the satellite transmitter clock and the local receiver clock. Pseudo-ranges are used in most applications to obtain sub-meter accuracy. Code phase processing means GPS measurements based on the pseudo random code (C/A or P) as opposed to the carrier of that code (1–5 m accuracy). Code phase is one processing technique that gathers data via a C/A (coarse acquisition) code receiver. After differential correction, this processing technique results in 1–5 m accuracy. There are two types of pseudo-random code. A pseudo-random noise C/A code of 1.023 MHz is modulated on the L1 carrier and a pseudo-random noise P code of 10.23 MHz is modulated on both the L1 and L2 carriers [5]. Each satellite has a unique pseudo-random code. The C/A code is the basis for civilian GPS use. The second pseudo-random code is called the P (Precise) code. This code is intended for military users and can be encrypted. The carrier phase is another processing technique that gathers data using a carrier phase receiver. Carrier phase processing means GPS measurements based on the L1 or L2 carrier signal (sub-meter accuracy). Carrier phase receivers are inherently more accurate than pseudo-range receivers due to the much finer resolution (carrier wavelengths: 19 cm, higher frequency) as compared to the Code-Phase (code wavelengths: 293 m) [5]. The carrier phase receivers used in surveying and geodesy require more involved post-processing and stricter data collection requirements. Carrier phase receivers (survey grade) require a clear view toward the satellites in order to maintain a constant lock with at least 4 satellites, while C/A code receivers (navigation grade) do not need to maintain a constant lock with the satellites to calculate positions.

5.6 GNSS Error Correction

It is possible to divide GNSS receivers into three categories; Single Point Positioning (e.g. recreation), Differential GPS (navigation) and geodetic survey grade receivers. Single Point Positioning (SPP) receiver provides the Standard Positioning Service (SPS) with errors and biases caused by the inherent limitation of GNSS radio signal delivered from GNSS satellites, at a height of 20,180 km above the earth surface. Differential GPS (DGPS) receivers can overcome some of the limitations of SPP GPS by applying corrections, based on a receiver performing measurements at a known point (a reference station). The accuracy achievable from DGPS can range from a few meters down to few decimeters, depending on the quality of the receiver and the DGPS technique used. Geodetic survey grade receivers are designed to achieve consistent network accuracy in the static or real-time mode. Geodetic survey grade receivers employ sophisticated signal processing techniques to measure the phase of the L2 signal. This level of sophistication is a major reason why geodetic survey grade receivers are more expensive than receivers used for SPP and DGPS [15].

5.6.1 DGPS (Differential GPS)

A summary of the positional accuracy according to survey techniques is given in Table 5.6. The civilian GPS signal, referred to as the Standard Positioning Service (SPS) is generally gauged at 25–35 m accuracy in point positioning (when Selective Availability is off). Many civilian applications require better accuracy than what basic SPS provides. An augmentation technique commonly known as the Differential Global Positioning System (DGPS) is used to remove satellite and atmospheric errors, by utilizing GPS receivers performing measurements at a known point (a reference station). The principle behind DGPS is to use the reference location of the base receiver to correct for the error position of the unknown rover position. With DGPS receivers, position accuracy is improved, going from 30 m to better than 10 m. Through the carrier wave of the GPS signal it is possible to increase this accuracy level to ±3 cm (Precision DGPS; PDGPS). Differential GPS positioning requires two GPS receivers. The differential GPS uses a static GPS system at one station (master) while another GPS system (rover) is moved from one station to the next until all stations have been occupied (Fig. 5.6). One unit is placed on a location with known coordinates (ie. a geodetic benchmark), and the other GPS is used at positions to be determined. The GPS located at the known coordinates or benchmark is referred to as the base station or control station. The GPS used to determine the unknown location is referred to as the remote or field station. The GPS readings at the base station are compared to the coordinates of the benchmark and this difference is applied to the remote station. Normally, the base station should be within

Table 5.6 Comparison of positional accuracy according to survey techniques

Technology	What it does	Accuracy
Standard Positioning Service (SPS)	Standalone GPS	30 m
Precise Positioning System (PPS)	Standalone GPS It is reserved for military use and authorized civilian users.	20 m
A-GPS smart phone	A-GPS is an augmentation technique which uses the same satellites as GPS, but besides that, it also uses Cellular Network as references. The reference network tracks the receiver and the satellites. The GPS receiver, installed on the smart phone, performs its First Fix using assistance data provided by Cellular Network.	10 m
DGPS	Differential Global Positioning System improves location accuracy based on a receiver performing measurements at a known point (a reference station). The DGPS correction signal loses approximately 1 m of accuracy for every 150 km. Shadowing from buildings, tunnels, and plants causes temporary losses of signal.	1–5 m
RTK	Real Time Kinematic satellite navigation is based on the use of carrier phase measurements where a single reference station provides real-time corrections.	1–2 cm
SBAS	Satellite Based Augmentation System	1 m

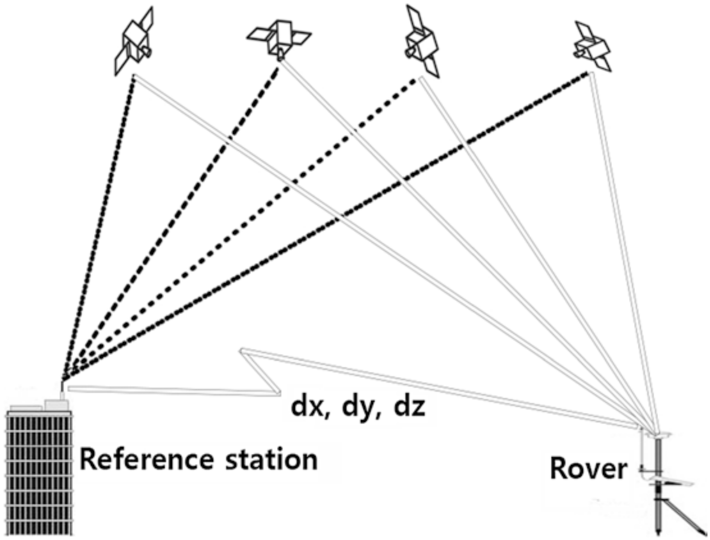


Fig. 5.6 Schematic representation of theoretical principle involved in DGPS (Differential GPS)

Table 5.7 Comparison of RTK GPS versus Differential GPS

	RTK	DGPS
Radio transmissions from a base station	Yes	Yes
GPS signal components	Carrier-base dual frequency phase data)	Code-base (pseudo-range corrections)
Location of base station	Own base station in 10 km range	Further range than RTK (~300 km)
Satellites to initialize	5 Satellites	4 Satellites
Waiting timing to initialize	1 min	Immediately
Accuracy	Centimeter accuracy in 3 dimensions	Sub-meter accuracy in horizontal position
Applications	Survey	Navigation

300 km of the second receiver. This differential correction can be done in real-time, with a radio-link between the base receiver and the remote, or by post-processing the data files collected by both receivers during a similar experiment [16].

5.6.2 *Kinematic Positioning and RTK*

Real-time differential GPS based on pseudo-range is more accurate than stand-alone (or autonomous) GPS (S-GPS), but not as accurate as carrier-phase GPS surveys (Table 5.7). Carrier phase GPS positioning is now increasingly used for many surveying and precise navigation applications on land, at sea and in the air. Over the last decade a number of distinct GPS techniques address different requirements such as static or kinematic positioning (or both), real-time or post-processed mode of operation, short-range or long-range applications, and so on [17]. Carrier phase GPS kinematic positioning are usually used in low dynamic situations requiring high accuracy (such as in geodetic survey). Carrier phase relative surveying techniques, except OTF (on the fly) and RTK, require post-processing of the observed data to determine the relative baseline differences.

The quality of the carrier phase kinematic GPS solution, as always, depends on the geometry of the satellite constellation and on the number of satellites. The more satellites observed, the stronger the solution. For kinematic purposes, a known base station must be much closer to the rover than that of differential GPS, to guarantee centimeter level accuracy. Depending on satellite configuration and atmospheric conditions, this distance could be 20 km, which requires several receivers for several hundred kilometers target (while pseudo-ranges real-time differential GPS would require 300 km between the known base station and rover).

Real-Time Kinematic (RTK) GPS surveys are performed with a data transfer link between a reference GPS unit (base station) and rover units. The field survey is conducted like a kinematic survey, except data from the base station is transmitted to the rover units through a data radio or through an Internet connection. The data provided by a cellular link, enable the rover unit to compute its position in real time. The maximum range from a reference station at which a standard RTK rover can operate successfully (i.e. resolve ambiguities) is usually quoted as about 10 km. This assumes favorable atmospheric conditions that the rover is receiving standard RTK data from the station. RTK does not require post-processing of the data to obtain a position solution. RTK techniques offer outcomes with very little delay and therefore this allows for real-time surveying in the field [18]. Satellite measurements collected in the field can be stored, and then combined in a computer for Post-Processed Kinematic (PPK) positioning. The continuous kinematic and stop-and-go kinematic surveying techniques are used to improve productivity in open areas where many points need to be located. At least 5 satellites are required to initialize and resolve the carrier phase ambiguities. The post-processed kinematic survey method provides the surveyor with a technique for high production survey measurements and can be used in areas with minimal satellite obstructions [18]. Generally, millimeter resolution is possible with this technique, whereas the non-post-processing RTK can only achieve a solution of a few centimeters.

5.6.3 Principle of A-GPS

With the introduction of GPS on smartphones, the location data were widely spread as common commodity among consumer and business markets, offering a universally available map service indoor and outdoor. This was an extraordinary shift towards the democratization of GPS, coupled with explosive growth of the smartphone. Today, general users can achieve even cm-level accuracy on their smartphone.

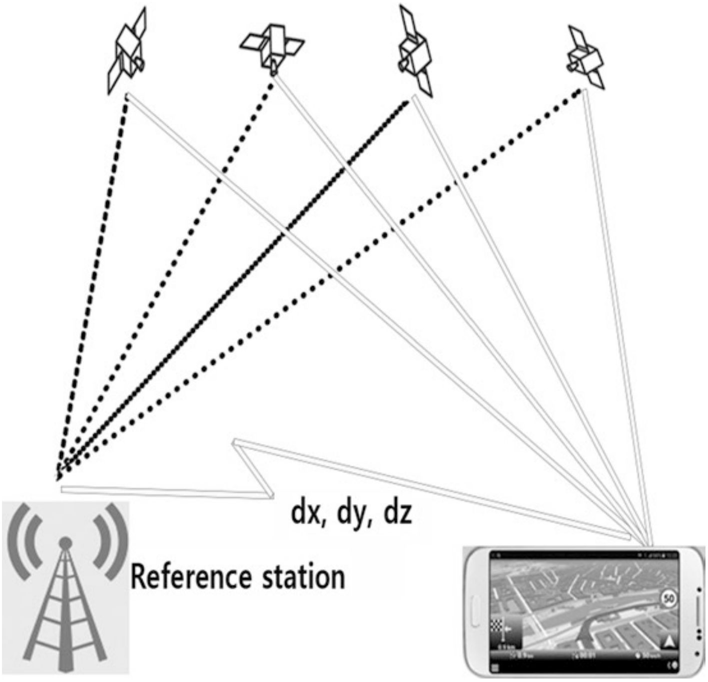


Fig. 5.7 Schematic representation of theoretical principle involved in A-GPS

Standalone GPS (S-GPS) receiver estimates its First Fixing position directly from GPS satellites in its line of sight without assistance data coming from cellular network. S-GPS is not adequate to mobile devices because satellite signals are too weak and obstacles such as buildings and dense tree cover prevent a direct view of the satellite. It takes several minutes for the standalone receiver to establish contact with the satellite and calculate its position. This is unacceptable for the typical mobile phone consumer, who is used to work in a few seconds [19]. A-GPS was initially introduced as mobile communication standards to significantly reduce the Time To First Fix (TTFF) of cell phones.

Most GPS-enabled cell phones employ a technology known as Assisted GPS (A-GPS). A-GPS is a positioning system which utilizes the same satellites as GNSS, but besides that, it also uses cellular network for typical mobile phone as a reference network (Fig. 5.7). A comparison of S-GPS versus A-GPS is given in Table 5.8. The cell towers of cellular reference network plays a role of the Base Station or Control Station in case of AGPS. Assisted GPS mode (A-GPS) allows the GPS receiver of cell phones to perform its Time To First Fix (TTFF) using assistance data provided by Cellular Network. Cellular network positioning triangulates the GPS receiver of cell phones based on nearby cell phone towers. Phone companies have precise location information for their cell towers and known coordinates of cell towers that can be used to approximate the GPS receiver location of cell phones. A-GPS location accuracy is dependent on overlapping signals from either access points or cellular towers. Therefore A-GPS is more accurate in urban settings because obstacles such

Table 5.8 Comparison of S-GPS versus A-GPS

Feature	Standalone GPS	A-GPS
Line of sight requirement	Required	Not required
	The GPS receiver estimates its position directly from GPS satellites in its line of sight.	To perform its First Fix using assistance data provided by Cellular Network.
The initial receiver position	A ground GPS receiver uses satellite signals to determine the initial receiver position.	The initial receiver position is estimated from cell ID techniques.
Access to cellular network	Not required	Required
	To perform its First Fixing activity without assistance data coming from cellular network.	To perform its First Fix using assistance data provided by cellular network.
TTFF: The time-to-first-fix	Slow	Faster
	First Fix is considerably slower in a target where the satellites signals are corrupted by the multipath propagation.	TTFF is considerably reduced since a GPS receiver is assisted with data provided by a cellular telephone network.
Battery power requirement	Serious	Little
		The GPS server aids the cell phone user in calculating the position. It saves time and battery power.
Indoor application	Impossible	It can be used in multi-story building, high-rise building, valleys, inside office buildings, and even in underground parking garages.

as buildings and dense tree cover do not prevent a direct view of the satellite [20]. Network-based location technology depends on current wireless networks to obtain information about user position. In these systems, several receiver stations measure the signals transmitted from wireless users and relay this information to a central site for processing to calculate the users location. A hybrid-positioning system merges both the signals transmitted from wireless users and network information to generate the positioning estimate [21].

A number of indoor positioning systems have been developed based on terrestrial beacons and use cellular network signals, WiFi signals, Bluetooth, infrared, ultrasound or other radio frequencies [22]. Positional accuracy of these techniques depends on the density of base stations and the reliability of time of arrival measurements [23]. A-GPS architectures increase the capability of a stand-alone GPS receiver to conserve battery power, track more satellites indoor, and increase sensitivity over a conventional GPS architecture. The Time To First Fix (TTFF) of cell phones reduced by A-GPS architectures allows various adventure application to smartphone user, from waypoint navigation to locating a friend using SMS (short message service and MPTP (Mobile Phone Telematics Protocol) to exchange location information. For example, AGPS enables tracking of closest taxi cab, or calculating package delivery arrival timing by exchanging location and route messages among various A-GPS service users. GPS Essentials is one of the most useful and innovative App for finding locations, routes, Maps, finding directions, roads and many more interesting features (Fig. 5.8).

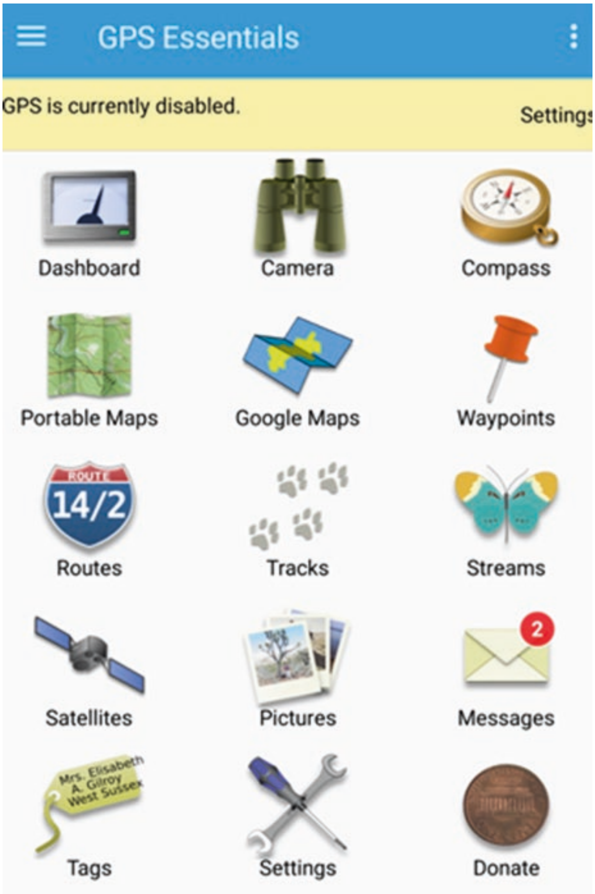


Fig. 5.8 Example of A-GPS App exchanging location messages among various A-GPS service users (GPS Essentials)

5.6.4 Ground Based Augmentation Systems (GBAS)

Many countries operate their own systems that provide data to correct errors in satellite signals on the ground such as NDGPS (Nationwide Differential Global Positioning System) as shown in Table 5.9. The GBAS is referred as various terms by application situations or countries; LADGPS (Local-Area Differential GPS), NDGPS (Nationwide Differential Global Positioning System), LAAS (Local Area Augmentation System), Ground-based DGPS services and Local DGPS. For example, multiple GPS reference receivers and their associated antennas are established at a fixed location with known coordinates, typically located within the airport boundary. The correction data is transmitted to the user's GPS receiver utilizing various communication methods (internet, satellite communication, etc). GBAS is a safety navigation and landing system within the airport boundary to offer pseudo-range correction data [14].

Table 5.9 Augmented GNSS classifications

	Hierarchy	Examples
GBAS	Ground-Based Augmentation System	It provides navigation service in the vicinity of the host airport.
LADGPS	Local-Area Differential GPS (extended version of GBAS)	The Nationwide Differential Global Positioning System (NDGPS)
		Local Area Augmentation System (LAAS)
A-GPS	It is subset of the LADGPS.	A-GPS device (like your cellular phone) can download assistance data, such as the position of the satellites via the devices' network connection using LTE or Wi-Fi.
CDGPS	Carrier-Phase Differential GPS (usually a subset of Local-Area DGPS), RTK	Surveying, precision farming (cm level)
SBAS	Space-Based Augmentation System International includes Wide-Area Differential GPS.	WAAS (FAA, USA), EGNOS (ESA, Europe), MSAS (JCAB, Japan), GAGAN (India), SNAS (China)

The Nationwide Differential Global Positioning System (NDGPS) augments the existing satellite system with ground-based radio transmitters, known as reference stations. It is operated by the United States Coast Guard, Department of Transportation and Army Corps of Engineers. Users who receive the ground-based signal from the reference stations in addition to the normal satellite signals will be able to determine their position with an accuracy of 1 to 3 m [24]. Achievable accuracy degrades at an approximate rate of 1 m for each 150 km distance from the broadcast site. Typical user equipment achieves 1–2 m horizontal accuracies in real-time, throughout the coverage area [14].

5.6.5 Satellite Based Augmentation Systems (SBAS)

Satellite Based Augmentation Systems (SBAS) are developed to improve the positioning accuracy by broadcasting differential correction data for GNSS from SBAS geostationary satellites (Fig. 5.9). SBAS geostationary satellites receive signals from terrestrial monitoring stations and transmit that signals to users with GNSS receivers [8]. SBAS monitors ephemeris of each GNSS satellite and notifies the ground GPS receiver of a satellite error if the quality of the received signals remains below the specific threshold (Table 5.10). SBAS passes on correction information concerning the satellite position (ephemeris) and time measurement [8].

Unlike the GNSS satellites, these SBAS geostationary satellites do not have the equipment to generate their own satellite position signals. But main mission of the SBAS geostationary satellites is to relay the signals processed from the ground monitoring stations to ground receiver. Wide Area Differential GPS (WADGPS) system is a general term for solutions used to enhance GPS accuracy over large areas (e.g., North America or Europe). The WADGPS is the U.S. implementation of SBAS (Table 5.11). WAAS (Wide Area Augmentation System, USA), EGNOS

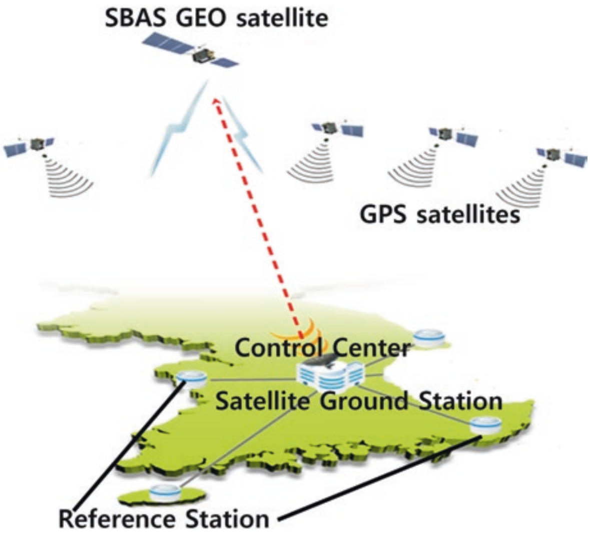


Fig. 5.9 Schematic representation of theoretical principle involved in SBAS navigation
The complex ground segment is composed of several reference stations, ground control centers and 2–3 satellite ground stations. Each system uses its own designation for its stations
Reference stations: There are several reference base stations in the SBAS area, which are networked to each other. The reference base stations receive the GNSS signals. Each base station determines the deviation between the actual and calculated positions relative to the satellites (the pseudo-range). This data is then transmitted to a control center
The control centers: They carry out the evaluation of the correction data from the reference base stations and detect the inaccuracies of all GNSS signals received by each base station. Data concerning the variations are then integrated into a signal and transmitted via distributed satellite ground stations
Satellite ground stations: They broadcast signals to the different geostationary satellites

Table 5.10 Positioning accuracy without and with DGPS/SBAS

Error cause and type	Error without DGPS/SBAS	Error with DGPS/SBAS
Ephemeris data	1.5 m	0.1 m
Satellite clocks	1.5 m	0.1 m
Effect of the ionosphere	0~30 m	0.2 m
Effect of the troposphere	0~30 m	0.2 m
Multipath reception	0~1 m	0.4 m
Effect of the receiver	0~10 m	0.1 m
Total RMS value	28 m (When SA is turned off)	1.0 m

Note: GPS receivers all have a different accuracy level, depending on extra information from the GPS satellites, signal coverage, pass-to-pass (the relative accuracy over a 15 min interval) and year-to-year repeatability etc. This table is roughly derived from the theoretical basis of the DGPS / SBAS technique

(Europe), and MSAS (Japan) are specific implementations of WADGPS. The Satellite Based Augmentation System (SBAS) is an extension of the WADGPS concept. Wide Area Augmentation System (WAAS) is a new satellite-based navigation system built by the U.S. government (FAA, Federal Aviation Administration) for

Table 5.11 Comparison of RTK versus WADGPS

	RTK	WADGPS
Method	Carrier-base	Code/carrier-base
Accuracy	Centimeter	Meter
Coverage	20~30 km	~1000 km
Techniques	Kinematic (RTK/Semi Static)	WAAS Wide Area Augmentation System
	CDGPS (Carrier phase DGPS)	
Applications	Survey	Aviation
Reference type	Single reference	Multi-reference

boating and supplementary navigation for aircraft. It is designed for aircraft landing and has position accuracy as good as 3~7 m. Several countries have implemented their own Satellite-based Augmentation (differential) System. In Asia, it is the Japanese Multi-Functional Satellite Augmentation System (MSAS), while Europe has the Euro Geostationary Navigation Overlay Service (EGNOS). EGNOS covers the majority of the European Union (EU), along with some neighbouring countries and regions. Eventually, GPS users around the world will have access to precise position data using these and other compatible systems [25]. Although designed primarily for aviation applications, WAAS is widely available in many receivers manufactured for various communities such as maritime, automotive, agriculture, and surveying [14]. Other national SBASs include:

USA: Wide Area Augmentation System (WAAS)
Japan: Multi-functional Satellite Augmentation System (MSAS)
India: GPS and GEO Augmented Navigation (GAGAN)
China: Satellite Navigation Augmentation System (SNAS)
South Korea: Wide Area Differential Global Positioning System (WADGPS)
Russia: System for Differential Corrections and Monitoring (SDCM) [26]

WADGPS utilizes a geographically distributed network of reference receivers at precisely known locations throughout the service region, and these reference receivers, continuously monitor all GPS satellites and their propagation environments in real time [27]. WADGPS solutions compare their precisely known location with locations calculated from GPS satellite signals. Any differences between GPS satellite signals and known location coordinates can be used to generate correction data. The SBAS geostationary satellites broadcast their signals from an altitude of around 36,000 km above the equator in the direction of the area of use. The broadcasting frequency of SBAS geostationary satellite's signals is the same as GPS (L1, 1575.42 MHz). It means that no additional investment in ground receiver hardware is needed in order to receive signals from SBAS geostationary satellites [8].

RNSS (Regional Navigation Satellite System) can only be used for navigation in limited areas (e.g. individual countries). RNSS is also a component of GNSS (Global Navigation Satellite System) since it makes possible region-wide navigation and positioning as an axis of GNSS (GPS, GLONASS and GALILEO) [8]. The following regional satellite navigation systems are planned: India (IRNSS, Indian Regional Navigation Satellite System), Japan (QZSS, Quazi Zenith Satellite System). The transition from SBAS to RNSS is quite fluid, since all the regional

GNSS systems like QZSS, IRNSS, WAAS, EGNOS and BEIDOU-1, etc. are compatible with universal SBAS standard (named U-SBAS).

5.7 GNSS and INS Integration

5.7.1 INS (Inertial Navigation Systems)

In navigation, dead reckoning or (dead-reckoning, or deduced reckoning) is the method of calculating up-to-date position by comparing between an initially starting point and moving position based upon the estimated speeds over travel route. Dead reckoning is principally based on step count and azimuth of displacement. The number of steps is calculated using accelerometer, while the azimuth is obtained through the means of an electronic compass. The corresponding term drift is the angle between the heading of the objects and the desired track. These days, satellite navigation using the GNSS have made the dead reckoning old-fashioned [28].

INS (Inertial Navigation Systems) is a self-contained dead reckoning navigation system that does not require help or support from any external signals or inputs. INS provides data on dynamically changing state of the object with a high data rate and the initial condition (position, velocity and attitude) of the platform prior to the start of navigation, based on the measurements obtained from an Inertial Measurement Unit (IMU). Since an INS is self-contained, i.e., it does not rely on any external information sources that can be disturbed or jammed, it is an attractive means of navigation for many applications where 100% coverage and a high continuity-of-service (a high update rate) is needed, e.g. various autonomous systems.

The basic operating principle of inertial navigation is based on Newton's law of motion, which says that an object continues to be in a state of rest or uniform motion, unless acted upon by an external force. The application of any external force generates the acceleration, which is sensed by accelerometers contained in an IMU (Inertial Measurement Unit) [29]. An IMU consists of three accelerometers and three gyros. The accelerometers and gyroscopes are used to track the moving position, velocity, and attitude (orientation) of an object relative to a known start position, velocity, and attitude. Inertial navigation systems have progressed from the crude electromechanical devices that guided missile and the early rockets. The ballistic missile programs of the 1960s required high accuracy at ranges of thousands of kilometers using autonomous navigation systems. So to speak, no man-made signals from outside the vehicle are required to perform the autonomous navigation. If no external man-made signals are required, then an enemy cannot jam them [30]. Inertial navigation systems developed by military agencies became available to non-military users when surveying systems based on the principle of inertial navigation were introduced in the early 1970's. As satellite signals from GNSS are not always available (e.g. high-rise buildings, indoor activities), INS was established as alternative sensors capable of self-controlled and independent dead reckoning navigation. Inertial systems are now standard equipment in military and civilian navigation applications such as drone, aircraft, ships, missiles, and spacecraft.

5.7.2 Comparison of INS versus GNSS

Unlike GNSS, an INS is a self-controlled and independent dead reckoning navigation system which provides position and velocity information through direct measurements from an IMU (Table 5.12). The advantage of INS over GNSS is its independence from external electromagnetic signals, and its ability to operate in environments blocking straight sight to the sky such as indoor and under the tree. This allows INS to provide a continuous navigation solution, with excellent short term accuracy [29]. However, one of the main drawbacks of INS when operated in a stand-alone mode is systematic errors to grow with lapsed time over the track. For longer-duration missions, it is compulsory to provide constant updates to the navigation coordinate such that the errors caused by the inertial system are reset as close to zero as possible [30].

Unlike INS, GNSS alone is capable of providing reliable positioning, with lapsed time along the moving track because it inherently relies on external electromagnetic signals (the radio-frequency signals) from satellites in space [29]. In contrast, GNSS signals are relatively noisy from second to second (e.g. multipath interference and user clock instability etc.) since its signal is transmitted over long distances, but they do not show accumulated drift for longer-duration missions. In contrast to INS's short-term positioning accuracy, satellite-based GNSS position techniques offer relatively consistent accuracy during the longer-duration navigation mission. This fundamental difference in radio navigation and inertial measurements is a clue to integrate the information from each sensor [31].

GNSS, when combined with MEMS inertial devices, can restrict the error growth of inertial measurements over time, while the inertial devices allows the position estimates when there is no GNSS signal reception. Also, the use of inertial components allows the GNSS measurements to be compared against statistical limits and reject those measurements that are beyond the limits [29]. The accuracy achieved by the combined INS/GNSS system should exceed the specified accuracy of GNSS alone, thus enhancing the reliability of the integrated system. The inertial system alone provides the navigation information when the GNSS signal is not available due to signal blockage and antenna shading. Then inertial position and velocity information can reduce the search time required to re-acquire the GNSS signals after interference such as artificial jamming and cycle slip. Such excellent short term continuity of inertial positioning enables direct P(precise) code reacquisition for PPS (Precise Positioning Service) shortly in a jamming environment [31].

Table 5.12 Comparison of GNSS versus INS

	GNSS (radio navigation)	INS
Advantage	Satellite navigation, no cumulative error over time	Standalone navigation system, self-contained (not susceptible to jamming)
	Long-term stability is good.	Continuous navigation information calculation
	High accuracy, consistent accuracy	High frequency and high data rate (100hz)
	Self-initializing	Good dynamic characteristics
	Errors are constrained.	Good short-term stability
		Both translational and rotation angle observation
Disadvantage	It takes considerable time to calculate the navigation information (1hz).	Subject to cumulative errors
	Large error in dynamic environment, limited to the number of visible satellites, since GNSS signal is transmitted over long distances, it is very vulnerable to interference signals such as artificial jamming, cycle slip.	It requires knowledge of gravity field and requires initial conditions.
	Rotation angle calculation error, low data rate	
	Lower attitude accuracy	
	Expensive infrastructure	
Integrated application	In order to minimize the error of the inertial navigation system applying the principle of inertia and acceleration, GNSS with accurate positional accuracy is used since the GNSS location information can estimate the error of INS. Accuracy is highly dependent on GPS while availability, reliability (e.g. rotation angle) and continuity is highly dependent on INS.	

5.7.3 Direct Geo-Referencing Through INS/GNSS Integration

The process of calculating exterior orientation parameters of remote sensing image with airborne integrated GNSS/INS is often referred to as real-time geo-referencing, direct geo-referencing, direct sensor orientation, direct exterior orientation, and direct geo-coding [32]. The term "exterior orientation" of an image refers to its position and orientation related to an exterior coordinate system. The real-time geo-referencing is defined as the direct measurement of the exterior orientation parameters for each image during the flight. The determination of the exterior orientation parameters is a fundamental requirement for the geometric evaluation (such as direct measurements of distances, angles, positions, and areas) of terrestrial and remotely sensed images. Conventionally, this is accomplished by an indirect approach of applying a number of known ground control points (GCPs) and their corresponding image coordinates. Using a mathematical model for the transformation between object and image space, we can calculate the exterior orientation to relate the local image coordinates to the global reference coordinate system.

This can be achieved by direct geo-referencing of the exterior orientation of an imaging sensor using an integrated system comprising a GNSS receiver and an INS component (Table 5.13). Thus, the exterior orientation parameters are observed through the autonomous flight based on defined points in a global coordinate system [32]. GNSS provides the positioning data subject to errors arising from the radio signal transmitted over long distances. Short-term highly-accurate positioning from the INS can be used to correct these errors, while the GNSS data are used to continuously calibrate the INS [32]. Onboard GNSS/INS integration data collection for the direct observation of exterior orientation has rapidly established itself as the standard service offered by aerial companies. In this process, the position and attitude records produced by the navigation processing had been used directly in the geo-correction process. Using fully automated geo-referencing without ground control, the relative distortions caused by aircraft motion are removed. Attitude is obtained from an Inertial Navigation System (INS) or less expensive gyroscopes. Many UAV flight planning software systems such as Pix4D capture now offer such GUI (Graphical User Interface) to reduce or eliminate the need for ground control points.

The implementation of GNSS/INS systems allows precise flight stabilization and enables the user to estimate the expected product accuracy preflight. Such geo-referencing is related to the flight performance and type of flights: manual, assisted or autonomous flight. The drone is capable of carrying a wide variety of sensors; cameras (visible and other spectra), GNSS, INS, radio antennas, laser range finders, radars, and radiation and chemical detectors etc. Depending on the implemented

Table 5.13 Example of direct geo-referencing through INS/GNSS integration (flight log of DJI Inspire 1)

GNSS data		INS data		
Longitude	Latitude	Roll (deg)	Pitch (deg)	Yaw (deg)
128.7264	35.8443	−0.74178	−0.51025	173.7002
128.7264	35.8443	−0.73335	−0.50724	173.6886
128.7264	35.8443	−0.73131	−0.50754	173.6828
128.7264	35.8443	−0.72945	−0.50568	173.6788
128.7264	35.8443	−0.72977	−0.50581	173.6791
128.7264	35.8443	−0.72833	−0.504	173.6795
128.7264	35.8443	−0.72933	−0.50522	173.6812
128.7264	35.8443	−0.72835	−0.50515	173.6856
128.7264	35.8443	−0.73288	−0.50649	173.6779
128.7264	35.8443	−0.73329	−0.50627	173.6735
128.7264	35.8443	−0.73248	−0.50533	173.6744
128.7264	35.8443	−0.72667	−0.50734	173.6726

location sensors and type of image processing, specific UAVs will only be suitable for particular applications [33]. To be able to take images that are not blurred, the camera is mounted on gimbal. This device stabilizes it in three axis directions (pitch, yaw and roll). A camera, for example, should be positioned so that targets are within the frame. This is accomplished by a human pilot flying remotely or by an autopilot flying a series of waypoints. Often, two people must be involved: one to operate the vehicle and one to manage the sensor payload.

The drone receives signals from both GPS and GLONASS navigation satellite systems. The camera is connected with GNSS receiver, so photos that are taken have already coordinates written in EXIF (Exchangeable Image File) format. Hence, there is no need to download flight logs to extract information about geo-location of images. However, from time to time there could be big errors of flight height data (up to several dozen meters), especially when calibration of a drone is not performed before the flight. It is well known that height measured by GNSS is not reliable, so it is usual to obtain the height data from barometric calculations. Thus there could be sometimes problems with height coordinate of centers of pictures. The drone is also equipped with the vision positioning system, which uses two ultrasound sensors and one camera facing downwards to keep the drone stable over the surface. It helps the drone to hover over one spot steadily together with GNSS receiver.

GNSS is not only used for autonomous steering of the drone but also for geo-referencing images. Direct geo-referencing uses geo-location information only from GNSS receiver mounted on UAV. Real Time Kinematics (RTK) GNSS receivers mounted on drone perform direct geo-referencing and eliminate the necessity of using Ground Control Points. Each photo taken from drone has coordinates of its center written in EXIF format (Exchangeable Image File Format) as shown in the Table 5.13. It keeps all metadata of a photo, like camera parameters, settings that were used when the photo was taken and the location information if the camera was connected with GNSS receiver. The coordinates can be also accessed from a log file that is generated after each flight. This direct geo-referencing technique does not require GCP (Ground Control Point), thus, the reliability of ortho-photo as final products is deeply affected by quality of a GNSS receiver.

5.7.4 Accelerometer versus Gyroscope

The gyros provides angular measurements fundamental to an INS (Table 5.14). Thus, the ability of an INS to enable the continuous determination of vehicle position, velocity and attitude, primarily depends on the quality of gyro sensors used [29]. The common types of drones are equipped with flight controller loaded with three or more axis gyros. When the flight is tilted in any direction, it is recognized through the gyro input signal. At the level of the toy drones, at least three-axis gyro to stabilize the aircraft is mounted, and it usually comes with three-axis acceleration sensors for horizontal positioning. Gyro stabilization technology allows the drone

Table 5.14 Comparison of accelerometer versus gyroscope

	Gyroscope	Accelerometer
What it does	Measure angular velocity (rate of rotation, rotational velocity), how fast something is spinning about an axis.	Gauge the orientation of a stationary item with relation to earth surface.
		Can tell it's own tilt relative to the earth surface (2 axes) but not your heading.
		Can't sense it's own rotation, speed or position.
		This can give you the position of the device perpendicular to the earth surface.
Measurement unit	Rotations per minute (RPM), or degrees per second (°/s).	Measure in meters per second squared (m/s^2) or in G-forces (g).
		g is the acceleration due to gravity or 9.81 m/s^2
Roll, pitch, yaw measurement	Roll, pitch, yaw	Roll and pitch can be measured with accelerometer since they are angular measurement on the vertical plane, with respect to the local level frame.
	Yaw can be measured with gyroscope since it is angular measurement on the horizontal plane.	
Application example	Heading indicator of the drone	Detecting portrait/landscape mode in smartphones

Magnetometers are simply a compass. It gives you the orientation with respect to magnetic north and magnetic south of the earth's magnetic fields. Magnetometer measures the heading based on earth's magnetic field and can tell it's own heading if you hold it parallel to the ground

to fly smoothly even in strong winds and gusts (Fig. 5.10). Even if you do not send the control signal separately, gyro stabilization technology let the drone keep itself automatically leveling. Flight controller adjusts the speed of the motor to correct the balance when the drone is tilted. Even if no steering signals are detected, the aircraft can control itself with the value of the gyro sensor to maintain balancing at all times. This is the fundamental structure of gyro stabilization mode that allows us to picture aerial views at stable platform.

A gyro is a spinning wheel (mass) that obeys the Laws of Physics. Due to the conservation of angular momentum, the spinning wheel will try to maintain its orientation, as it is mechanically isolated from the outer casing of the instrument [34]. MEMS (Micro-electro-mechanical systems) gyros offer smaller size, weight, less power consumption and a lower cost than other gyro technologies. The MEMS gyros and inertial systems provide performance ideal for consumer grade applications such as digital cameras, smartphones, video game controllers, airbag deployments and other electronic stability control systems.

Acceleration (acceleration = force/mass) is measured in meters per second squared, m/s^2. An accelerometer is a device that measures proper acceleration; proper acceleration is not the same as coordinate acceleration (rate of change of velocity). For example, an accelerometer at rest on the surface of the Earth will measure an acceleration due to Earth's gravity, straight upwards (by definition) of $g \approx 9.81$ m/s [35]. The acceleration sensor measures the tilt, based on the ground

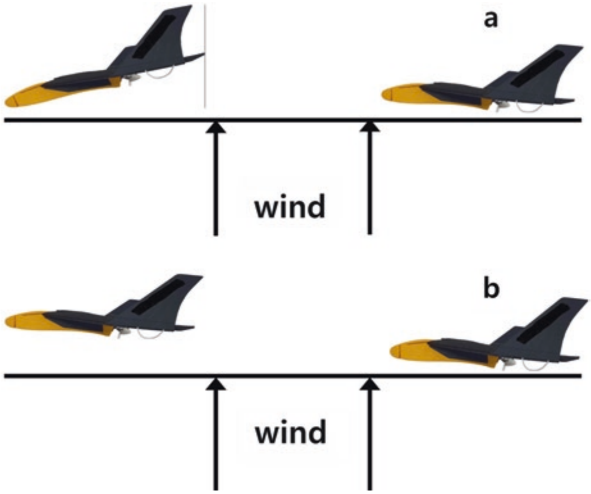


Fig. 5.10 Schematic representation of theoretical principle involved in gyro stabilization, Gyroscope holds a specific heading regardless of conditions (torque variations, cross-wind). (**a**) without gyroscope, (**b**) with head lock gyroscope (or Head Hold)

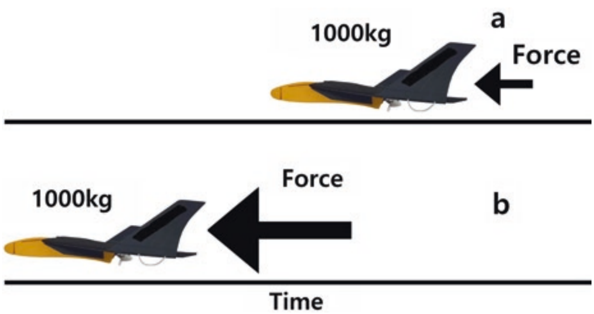


Fig. 5.11 Schematic representation of theoretical principle involved in accelerometer, (**a**) less force, less acceleration, (**b**) more force, more acceleration, Acceleration depends on force. The aircrafts above have the same mass. If we apply different amounts of force, the acceleration of objects (with the same mass) will increase as force increases

surface (Fig. 5.11). The most common use of accelerometers in consumer products is to know whether it's being held in portrait or landscape mode. The 3-axis acceleration sensor keeps the drone body horizontal even when the wind is blowing. If this function is not available, pushing the steering stick forward will tilt forward and eventually the drone will be turn over.

We cannot calculate the value of yaw using the accelerometer only. For calculating it we need data from gyroscope and magnetometer. A magnetometer is an instrument that measures magnetism—or direction of the magnetic field at a point in space. Magnetometer gives the value of magnetic field intensity along the 3-axes of the magnetometer. Since the direction of earth's magnetic field is close to constant, we can use the magnetometer data to calculate the roll, pitch, yaw angles absolutely

[35]. Azimuth represents an absolute heading, with respect to true north while yaw is a measurement of angle moved relative to the first starting point. Thus, if aircraft turns from its current orientation (30) with respect to true north to 124, your yaw is 94, while your current azimuth is 124. The biggest disadvantage of the gyro sensor is that there is no reference point at the start. Azimuth can only be calculated using a magnetic sensor, while yaw can be calculated using a gyro sensor.

The high-grade flight controller is equipped with an air pressure sensor, a magnetic sensor, a GPS, and an ultrasonic sensor. The orientation sensor is a combination between the magnetic field sensor, and gravity sensors. It tells you the angle of the drone relative to the ground (pitch and roll) and the direction (compass). The magnetic sensor is used to detect the azimuth while the ultrasonic sensor is operated to maintain the constant position at low altitude. At high altitude, various sensors such as an air pressure sensor are used to keep the flying height constant. Another way to improve the navigation performance during GNSS signal outages is to include additional sensors. Odometers can provide absolute information about velocity. A commonly used sensor in vehicle applications is a speedometer that has been used to limit INS error drift.

The Pololu AltIMU-10 v5 is an inertial measurement unit (IMU) and altimeter that features the 3-axis gyro and 3-axis accelerometer and 3-axis magnetometer and adds a digital barometer. The nine independent rotation, acceleration, and magnetic readings provide all the data needed to make an attitude and heading reference system [36]. The gyro can be used to very accurately track rotation on a short timescale, while the accelerometer and compass can help compensate for gyro drift over time by providing an absolute frame of reference.

Specifications of Pololu AltIMU-10 v5

Dimensions: 25 mm × 13 mm × 3 mm
Weight without header pins: 0.8 g
Output format:
Gyro: one 16-bit reading per axis
Accelerometer: one 16-bit reading per axis
Magnetometer: one 16-bit reading per axis
Barometer: 24-bit pressure reading

Sensitivity Range

Gyro: ±125, ±245, ±500, ±1000, or ±2000°/s
Accelerometer: ±2, ±4, ±8, or ±16 g
Magnetometer: ±4, ±8, ±12, or ±16 gauss[2]
Barometer: 260–1260 mbar

As the advances in electronic and manufacture techniques, small-size and electronic compasses are available to aid INS by providing absolute heading information. Here, an IMU includes three gyroscopes and three accelerometers. Three

[2] The gauss, abbreviated as G or Gs, is the measurement unit of magnetic flux density.

Table 5.15 Example of accelerometer and gyroscope integration (DJI Inspire 1 flight log file)

Accelerometer xSpeed (m/s²)	Accelerometer ySpeed (m/s²)	Accelerometer zSpeed (m/s²)	Gyroscope X angular velocity (°/s)	Gyroscope Y angular velocity (°/s)	Gyroscope Z angular velocity (°/s)
−0.00423	−0.00189	0.039399	−0.00225	−0.00237	−0.00036
−0.0035	−0.00517	0.041949	−0.00225	−0.00237	−0.00036
−0.0026	−0.00343	0.043813	−0.00226	−0.00237	−0.00036
0.007485	−0.00232	0.042995	−0.00226	−0.00237	−0.00036
0.006288	−0.00877	0.042545	−0.00226	−0.00237	−0.00036
0.008842	−0.01938	0.038794	−0.00226	−0.00237	−0.00035
0.008141	−0.02584	0.040834	−0.00225	−0.00237	−0.00035
0.009043	−0.02774	0.04444	−0.00225	−0.00237	−0.00035
0.007671	−0.02597	0.042325	−0.00225	−0.00236	−0.00034

gyroscopes provide measurements of vehicle turn rates or attitude of vehicle about three separate axes as reference inertial space frame, while three accelerometers provide the components of acceleration which the vehicle experiences along these axes (Table 5.15). Thereafter, the attitude and heading information is utilized to resolve the accelerometer measurements into the reference frame [37].

5.8 Conclusion

The key to operating UAVs safely is to develop reliable navigation and control technologies suitable for UAV applications. Currently, the most widely used navigation technologies for the UAVs are GNSS receivers and INS device. INS offers a complete set of navigation parameters, including position, velocity and attitude, with a high data rate within short period of time in environments blocking straight sight to the sky such as indoor and under the tree since it is stand-alone and independent working device. The data redundancy by INS will helps identify any measurement outliers especially where GNSS satellite signals can be obscured, such as in tall building, valleys or under tree canopies. However, the main drawback of INS's short-term positioning accuracy is the rapid growth of systematic errors with time. In contrast, satellite-based GNSS navigation technique can offer relatively consistent accuracy because it inherently relies on external electromagnetic signals (the radio-frequency signals) from satellites in space. Integrated GNSS/INS navigation have been successfully embedded into UAV platform [38]. The next generation GNSS such as GPS III signals will provide three times better accuracy than any current GPS satellites. The greatest source of GNSS measurement error is associated with the visibility of the satellite in the space when taking the measurement. Within 10 years, there may be as many as 80 GNSS satellites from GPS, GLONASS, Galileo and SBAS [15]. The UAV operator must make an informed decision when choosing the appropriate navigation methodology to be used in a particular project. The competition between USA and Russia to occupy the global leadership in military navigation was the driving force of the first satellite navigation era. The location data demand to obtain technological competitiveness in the global market such as a self-driving flying car is leading to the second location sensing era. Popularized with the rapid development of location sensor and drone platform technology, location data will affect deeply our life style. In the near future, location-based service (LBS) will become a necessity to utilize AI instruments such as self-driving air taxi in daily life of the general public. For instance, a user's location data will be used to call on-line unmanned Uber air taxi.

References

1. Andrejevic M, Burdon M (2015) Defining the sensor society. Telev New Media 16(1):19–36
2. Briney A (2018) A brief history of the age of exploration. ThoughtCo. https://www.thoughtco.com/age-of-exploration-1435006. Accessed 30 Sept 2018
3. Johnson C, Shea C, Holloway C (2008) The role of trust and interaction in GPS related accidents: a human factors safety assessment of the global positioning system (GPS). In: 26th annual conference of the international systems safety society Vancouver, Canada, August 25–29 2008
4. Höflinger F, Müller J, Törk M, Reindl LM, Burgard W (2012) A wireless micro inertial measurement unit (IMU). In: Instrumentation and Measurement Technology Conference (I2MTC), 2012 IEEE International. IEEE, pp 2578–2583
5. Erickson C (1992) Investigations of C/A code and carrier measurements and techniques for rapid static GPS surveys. University of Calgary University of Calgary, Ottawa
6. Wolf PSA, Jacobs WJ (2010) GPS technology and human psychological research: a methodological proposal. J Methods Meas Soc Sci 1(1):1–7
7. Brown TM, McCabe SA, Wellford CF (2007) Global positioning system (GPS) technology for community supervision: lessons learned, vol 219376. Noblis and U.S. Department of Justice
8. Zogg J (2010) GPS: essentials of satellite navigation (Compendium). u-blox AG
9. Blewitt G (1997) Basics of the GPS technique: observation equations. In: Geodetic applications of GPS. Swedish land survey. p 46
10. Lombardi MA, Nelson LM, Novick AN, Zhang VS (2001) Time and frequency measurements using the global positioning system. Cal Lab: Int J Metrol 8(3):26–33
11. Zhang J, Li B, Dempster AG, Rizos C (2010) Evaluation of high sensitivity GPS receivers. In: 2010 international symposium on GPS/GNSS, Taipei, Taiwan, October 26–28, 2010
12. Ebener S, Naville F (2016) GPS field guide, Geneva
13. NOAA (2017) GPS accuracy. NOAA, USA. https://www.gps.gov/systems/gps/performance/accuracy/. Accessed 30 Sept 2018
14. Service NTI (2012) 2012 federal radionavigation plan national technical information service, Springfield, Virginia. Department of Defense, Department of Homeland Security, and Department of Transportation, Springfield, Virginia 22161, USA
15. Huang Y-S, Huang Y-W, Chiang K-W (2007) The benefits of future GNSS. Coordinates
16. Wong DC, Bui K, Nguyen LH, Smith G, Ton TT (2003) Integration of differential global positioning system with ultrawideband synthetic aperture radar for forward imaging. In: AeroSense 2003, Orlando, Florida, United States. SPIE, p 10. https://doi.org/10.1117/12.488581
17. Rizos C, Han S (1998) Status and trends for high precision GPS kinematic positioning. In: Proceedings of the 9th Australasian remote sensing and photogrammetry conference, Sydney, Citeseer, p 18

18. Survey Advisory Board and the Public Land Survey Office (2004) GPS guidebook – standards and guidelines for land surveying using global positioning system methods. State of Washington Department of Natural Resources, Washington
19. Ericsson S (2007) GPS and A-GPS: white paper. Sony Ericsson, Sweden
20. Menke K (2014) How accurate is the GPS on my smart phone? (part 2). Community health maps. US National Library of Medicine
21. Ficco M, Russo S (2009) A hybrid positioning system for technology-independent location-aware computing. Softw Pract Exp 39(13):1095–1125. https://doi.org/10.1002/SPE.919
22. Ramos H (2010) A MS-assisted GPS system for-low power location-based mobile applications technical report. Microsoft
23. Zandbergen PA (2009) Accuracy of iPhone locations: a comparison of assisted GPS, WiFi and cellular positioning. Trans GIS 13:5–25
24. Chamberlain JA, Burns PL (1999) Final programmatic environmental assessment: nationwide differential global positioning system. US Federal Highway Administration, Washington, DC
25. Garmin (2018) What is WAAS? Garmin. https://www8.garmin.com/aboutGPS/waas.html. Accessed 30 Sept 2018
26. European GNSS Agency (2016) What is SBAS? https://www.gsa.europa.eu/european-gnss/what-gnss/what-sbas. Accessed 30 Sept 2018
27. Jan S-S, Lu S-C (2010) Implementation and evaluation of the WADGPS system in the Taipei flight information region. Sensors (Basel, Switzerland) 10(4):2995–3022. https://doi.org/10.3390/s100402995
28. Wikipedia (2018) Dead reckoning. Wikipedia
29. Godha S (2006) Performance evaluation of low cost MEMS-based IMU integrated with GPS for land vehicle navigation application. University of Calgary, Calgary, Alberta
30. Schmidt GT (2010) INS/GPS technology trends. Massachusetts Institute of Technology, Lexington
31. Schmidt GT, Phillips RE (2010) INS/GPS integration architectures. Massachusetts Institute of Technology, Lexington
32. Sanchez RD, Hothem LD (2001) Positional accuracy of airborne integrated global positioning and inertial navigation systems for mapping in Glen Canyon, Arizona. In: SCAR Working Group on Geodesy and Geographic Information, St Petersburg, Russia. The Scientific Committee on Antarctic Research, US Department of the Interior, US Geological Survey, pp 50–56
33. Eisenbeiß H (2009) UAV photogrammetry. University of Technology Dresden, Zurich
34. Pilotfriend company (2018) Gyroscopic systems and instruments. http://www.pilotfriend.com/training/flight_training/fxd_wing/gyro.htm. Accessed 30 Sept 2018
35. Roboclub (2018) Introduction to IMU. Roboclub. http://students.iitk.ac.in/roboclub/lectures/IMU.pdf. Accessed 30 Sept 2018
36. Pololu Robotics and Electronics (2018) AltIMU-10 v5 Brochure. Pololu Corporation. https://www.pololu.com/product/2739. Accessed 30 Sept 2018
37. Vinh NQ (2017) INS/GPS integration system using street return algorithm and compass sensor. Proced Comput Sci 103:475–482. https://doi.org/10.1016/j.procs.2017.01.030
38. Wang J, Garratt M, Lambert A, Wang JJ, Han S, Sinclair D (2008) Integration of GPS/INS/vision sensors to navigate unmanned aerial vehicles. The international archives of the photogrammetry. Remote Sens Spat Inf Sci 37(part B1):963–969

Chapter 6
Imaging Sensors

Abstract In the previous chapter, we described the location sensor under the CPS spectrum and the integration concept of GPS and INS sensors. It is said that the imagery data obtained by human eye accounts for 90% of total information acquired from various human sensory organs such as ear, nose and tongue. As the animals evolve from lower level (e.g. insects) to higher grade (e.g human), the utilization of visual data becomes higher. Likewise, as the substitution of natural intelligence by artificial intelligence advances, the dependence on imagery data increases. The underlying principle in data acquisition for CPS systems is to select imaging sensor suitable for operational application based on customer requirements and intended information such as training AI (Artificial Intelligence). An imaging sensor is a sensor converting the variable electromagnetic radiation delivered from the target into signals that convey the information. In order to identify the sensing requirements desired by the CPS instruments such as drones and self-driving cars, the pros and cons of various imaging sensors should be identified and utilized properly. Subsequently this chapter presented advantages and values of low-cost drone photography for hyper-localized targets (e.g. structural cracks in the skeleton of a concrete building and human hand gesture in the street crosswalk) in comparison to the existing methods.

6.1 Introduction

Image sensors used in electronic imaging devices include digital cameras, medical imaging equipment, night vision equipment, such as thermal imaging devices, radar, and others. Imaging sensor selection ultimately means meeting remote sensing requirements in the CPS systems design process, as it will make a great impact on product reliability. For any imaging sensor, the main categories of consideration will be the accuracy required, cost, size, reliability necessary, redundancy, energy consumption, and finally, the application at hand. There are a number of considerations in imaging sensor selection in optimising aerial data acquisition: navigation, flight restrictions, acceptable weather conditions, timing of flights during the day or

J.-S. Um, *Drones as Cyber-Physical Systems*,
https://doi.org/10.1007/978-981-13-3741-3_6

season, sun angle, ground spatial resolution, flying height, camera characteristics, ground coverage and image motion determination, which are all closely interrelated. Due to the relatively short history of drone remote sensing, there is no standardized comparison with traditional satellite or manned aircraft about determination of imaging sensor. The purpose of this chapter is to outline advantages and values of drone imaging sensor in comparison to the existing methods in the CPS framework and to introduce the related observation during the ortho-photo generation for hyper-localized target.

6.2 Four Sensor Selection Criteria

1. Spatial (what area and how detailed size)
2. Spectral (what colors – bands, wavelength sensitivity)
3. Temporal (how often, time of day/season/year)
4. Radiometric (how much deeper color depth)

The typical approach for sensor selection still depends on know-how acquired through experience. A wide array of remote sensors had developed to allow measurement of vegetation density, distance, and temperature, each specialised for a particular set of requirements. Given the large number of sensors on the market, the selection of a suitable sensor for a new application is a troublesome task for the person engaged in remote sensing. Although there are many factors to select remote sensor, the spatial, spectral, radiometric and temporal components of an image or set of images are recognized as fundamental (Table 6.1). Additionally, economic aspects and geometrical factors may be considered. These four selection criteria should always be interpreted by careful inter-comparison, as they have complementarity and interchangeability in image processing between standards. For example, if the spatial resolution is improved, larger-scale maps can be produced, but there is always a trade-off because it takes much more time and expense in image processing.

Table 6.1 Specification of representative satellite images based on sensor selection criteria

	Landsat 5 TM	IKONOS
Spatial resolution	30 m × 30 m	1 m × 1 m
Spectral resolution (unit: μm)	7 band	4 band
	1: 0.45–0.52 blue	1: 0.45–0.53 blue
	2: 0.52–0.60 green	2: 0.52–0.61 green
	3: 0.63–0.69 red	3: 0.64–0.72 red
	4: 0.76–0.90 Near IR	4: 0.77–0.88 Near IR
	5: 1.55–1.75 Middle IR	
	6: 10.4–12.5 Thermal IR	
	7: 2.08–2.35 Middle IR	
Temporal resolution	16 days	2 days
Radiometric resolution	8 bit	11 bit

6.3 Spatial Resolution

Spatial resolution refers to the size of the smallest possible feature that can be detected and the detail discernible in an image. It is most commonly expressed as the ground dimensions of an image cell. Only large features are visible in the coarse or low spatial resolution while small objects can be detected in fine or high spatial resolution images (Fig. 6.1). During an eye-sight check-up, the vision checklist is used to measure how well you see diverse sizes of the object in the same distance. That could be the example of investigating the spatial resolution of the human eye. Depending on how you look at it, the human eye can see 56 cm at 25 m. This means that human eye as remote sensor can perceive a depth difference of 0.1 cm at 1 m, 9 cm at 10 m, and 56 cm at 25 m. For instance, because the drone image is taken at very low altitude, it has a very fine spatial resolution.

Because commercial satellite imageries are taken at very high altitudes, they provide images with spatial resolutions ranging from a few meters to several km (Table 6.2). It is general that high spatial resolution imagery covers a narrow surface area. Until recently, the best commercially available pixel resolution from satellite imagery was 50 cm, but the US Government relaxed that restriction on 21 February 2015, and satellite companies can now legally distribute photos at about 25-cm resolution [1].

A spatial resolution changes as a reciprocal function (give and take) of several factors, including the platform height, the size of the sensor and the focal length of the lens. Cameras can be mounted on a variety of platforms including drone, ground-based stages, helicopters, aircraft, and spacecraft. The distance between

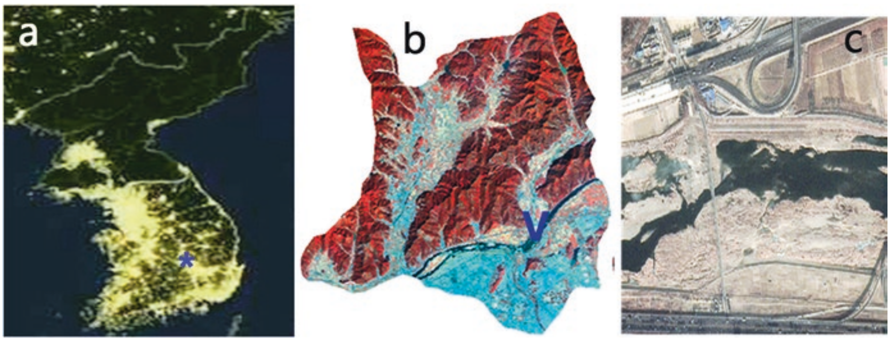


Fig. 6.1 A satellite imagery showing the level of information that is clearly distinguished according to different spatial resolution, (**a**) DMSP-OLS Nighttime satellite imagery (roughly 1 km spatial resolution) of Korean Peninsula, (**b**) Landsat Thematic Mapper scene (30 m spatial resolution) showing North district, Daegu metropolitan city, South Korea. Mountain and rivers are clearly recognizable. The magnified portion of site marked with * at the DMSP-OLS Nighttime satellite imagery (**a**), (**c**) IKONOS imagery (1 m spatial resolution), the magnified portion of site marked with V at the Thematic Mapper imagery (**b**), Smaller buildings and narrower streets are recognizable in the IKONOS image

Table 6.2 Spatial resolution of major remote sensing satellite imagery and corresponding mapping scale

Satellite	Spatial resolution (m)	Mapping scale
GeoEye-1	0.41 (0.31)	1/600 ~ 1/1200
GeoEye-2		
IKONOS	1 & 4	1/1200 ~ 1/2400
Quick Bird	0.82 & 3.2	1/1200 ~ 1/2400
KOMPSAT-3	0.7	1/1200 ~ 1/2400
IRS	5.8 & 22	1/2400 ~ 1/12,000
SPOT4	10 & 20	1/12,000 ~ 1/24,000
LANDSAT 5-8	30	1/24,000 ~ 1/50,000

the ground object and the remote platform has a crucial influence on the detail of information that can be collected. The camera at high altitudes will observe a larger area on the earth than at lower altitudes, but it does not see detailed features of the target (i.e. smaller scale). There is a big difference between satellite images and air-photos. The satellite sensors far away from their targets typically view a larger area (whole province or country), but couldn't distinguish individual houses. Sensors onboard aircraft flying over a city or town would be able to see individual buildings and cars, but would be viewing a much smaller area than the satellite sensor would [2].

6.3.1 Spatial Resolution, Pixel Size, and Scale

Remote sensing image of a digital format is composed of a matrix of picture elements, or pixels, which are the smallest units of an image. The pixel is commonly known as a raster, grid, cell or the square units. The spatial resolution and pixel size are often used interchangeably. In reality, they are not equivalent [3]. The spatial resolution is a measure of the smallest object that can be resolved by the sensor. An image sampled at a small pixel size does not necessarily have a high spatial resolution. It is difficult, however, to analytically determine the spatial resolution for the off-the-shelf UAV camera because the choice depends on many factors, including the sensor parameters, imaging optics (proper focusing), ISO range, atmospheric scattering, target motion and the human perception of image quality. However, it is often expressed that the resolution of a camera sensor used in the drone (e.g. CMOS built-in Zenmuse X3) is a function of the number of pixels and their size relative to the projected image. Therefore, it is often assumed that the smallest resolvable feature in any camera is equal to pixel size [4]. A small pixel size results in higher spatial resolution (higher spatial sampling).

If an imagery with a spatial resolution of 30 m is displayed with a surface area of 30 m per pixel, in this case, the spatial resolution and the pixel size have the same meaning [2]. However, by changing the computer monitor resolution, it is possible to display an image with a pixel size different from the original spatial resolution given from the sensor. The zoom application in the display monitor does not increase spatial resolution of the original imagery. Satellite imagery posters of the Earth have the reduced number of pixels to represent larger areas within the limited paper space such as A3, although the original pixel size of the sensor remains the same. It is often the case that spatial resolution and scale are used as the same concept.

Spatial resolution, as the term itself implies, depends on the sensor because the sensor is capable of detecting the ground object in terms of size. The scale is a way of indicating how the ground distance is reduced on the map or in the photograph (Map Distance/Ground Distance), so it has nothing to do with the capabilities of the sensor. By utilizing remotely sensed imageries acquired from various sensors, it is possible to generate various scaled maps required by the user. When scanning aerial photographs, the user can specify the grid size of the image file, but the grid size determined by scanning process can not represent spatial resolution since user could not change capability of the sensor.

6.4 Spectral Resolution

The principle of remote sensing is based on the measurement of electromagnetic energy. The spectral resolution of a remote sensing system can be described as its ability to distinguish ground target in terms of measured wavelengths (Figs. 6.2 and 6.3). It is a specific wavelength range detected by a remote sensing instrument in the electromagnetic spectrum. This is typically defined in micrometers (Table 6.3). The sun emits various types of radiation and the human eye is only sensitive to the visible light portion in the electromagnetic spectrum of sunlight. Spectral resolution of human eyes as remote sensor is 0.4–0.7 μm since it can detect part of the visible spectrum. The human eye is insensitive to other solar radiation spectra, such as near infrared (NIR) and shortwave infrared (SWIR).

The visual systems of most animals are sensitive to visible wavelengths. Visible light (between 0.4 and 0.7 μm) is only one of many forms of electromagnetic energy.

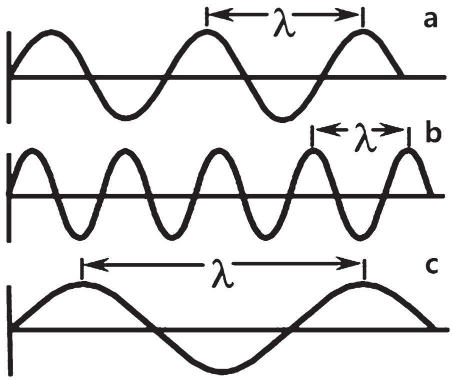


Fig. 6.2 Schematic representation of the inverse relationship involved in wavelength & frequency, (**a**) Near infrared (**b**) Red, (**c**) Microwave

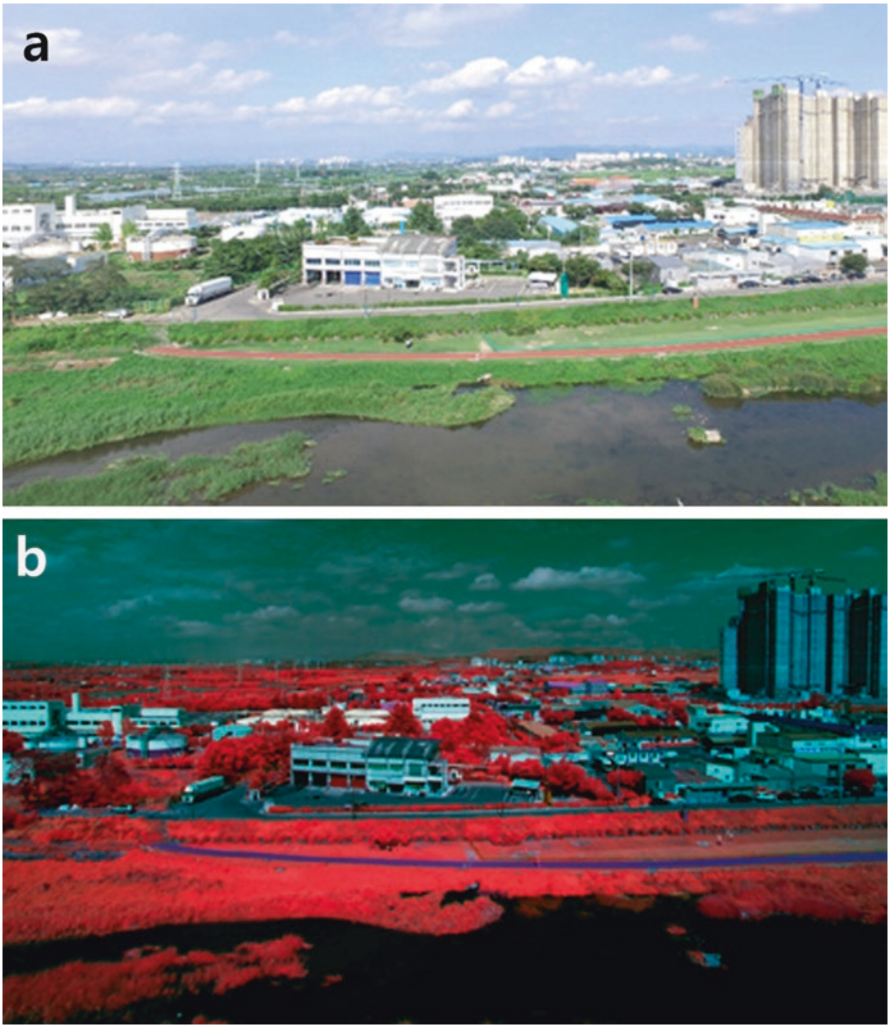


Fig. 6.3 Comparison of visible versus near-infrared imagery, (**a**) visible imagery containing information identical to the normal human perceptual range, (**b**) multi-spectral images including infrared. These are not images in the usual sense because the information represented is not directly visible to the human eye. Since the human eye cannot see infrared radiation, those wavelengths are displayed as a false color image. Green vegetation is displayed as reddish color, urban areas such as building are light blue-gray and clear or deep water is black

The sun is the most important source of electromagnetic energy on Earth. Remote sensing uses the radiant energy that is reflected and emitted from Earth at various wavelengths of the electromagnetic spectrum. The spectral signatures produced by wavelength-dependent sensor provide the key to discriminating different ground features in remote sensing image. Objects with significantly differentiated spectral characteristics such as water and vegetation, can be distinguished in a wide range of spectral signals, for instance, the visible and near infrared [5]. On the other hand,

Table 6.3 Spectral resolution of Landsat satellite imagery

Landsat 5	Landsat 7	Landsat 8
Band 1 Visible (0.45-0.52 μm) 30 m Band 2 Visible (0.52-0.60 μm) 30 m Band 3 Visible (0.63-0.69 μm) 30 m Band 4 Near-Infrared (0.76-0.90 μm) 30 m Band 5 Near-Infrared (1.5-1.75 μm) 30 m Band 6 Thermal (10.40-12.50 μm) 120 m Band 7 Mid-Infrared (2.08-2.35 μm) 30 m	Band 1 Visible (0.45-0.52 μm) 30 m Band 2 Visible (0.52-0.60 μm) 30 m Band 3 Visible (0.63-0.69 μm) 30 m Band 4 Near-Infrared (0.7-0.90 μm) 30 m Band 5 Near-Infrared (1.5-1.75 μm) 30 m Band 6 Thermal (10.40-12.50 μm) 60 m Low Gain/High Gain Band 7 Mid-Infrared (2.08-2.35 μm) 30 m Band 8 Panchromatic(PAN) (0.52-0.90 μm) 15 m	Nine spectral bands, including a pan band: Band 1 Visible (0.43-0.45 μm) 30 m Band 2 Visible (0.450-0.51 μm) 30 m Band 3 Visible (0.53-0.59 μm) 30 m Band 4 Red (0.64-0.67 μm) 30 m Band 5 Near-Infrared (0.85-0.8 μm) 30 m Band 6 SWIR (Short Wavelength Infrared) (1.57-1.65 μm) 30 m Band 7 SWIR 2 (2.1-2.29 μm) 30 m Band 8 Panchromatic (0.50-0.68 μm) 15 m Band 9 Cirus (1.36-1.38 μm) 30 m Thermal Infrared Sensor (TIRS) Band 10 TIRS 1 (10.6-1.19 μm) 10 m Band 1 TIRS 2 (1.5-12.51 μm) 10 m

less distinctive features in terms of spectral signatures, such as the extent of river water turbidity cannot be distinguished from a wide range of spectral signals. In order to detect such an object, a sensor having a finer spectral range is required.

Thus, we would require a sensor with higher spectral resolution. Two essential concepts of spectral resolution are described as the number of wavelength intervals ("bands") that are measured or narrow wavelength ranges (fine wavelength intervals) within a particular channel or band. Remote sensing image can be presented as a single very broad wavelength band (panchromatic), a few broad bands (multi-spectral), or many narrow wavelength bands (hyper-spectral), respectively. Black and white photography records the overall reflectance in wavelengths covering the entire visible portion of the electromagnetic spectrum. Its spectral resolution is fairly coarse, as the various wavelengths of the visible spectrum are not individually distinguished. Some satellite remote sensing systems record a single very broad band (referred to as a panchromatic band) to provide a synoptic overview of the scene, commonly at a higher spatial resolution than other sensors on board. SPOT satellites include a panchromatic band with a spectral range of 0.51–0.73 μm (green and red wavelength ranges) while NASA's Landsat 7 satellite includes a panchromatic band (a wider spectral range of 0.52–0.90 μm (green, red, and near infrared), with a spatial resolution of 15 m (on the contrary, 30-m for the multispectral bands).

In color photography, the sensor is also sensitive to the reflected energy over the visible portion of the spectrum. But it has a higher spectral resolution than that of black and white photography, as this is usually done by analyzing the spectrum of colors into three channels (red, green and blue). The remote sensing imagery gathered and stored from a narrow wavelength range is called as a channel, also sometimes referred to as a band. Spectral bandwidth is the width of an individual spectral channel with a narrow wavelength range in the remotely sensed imagery. As the spectral bandwidth narrows, the sensing ability for ground objects is improved. Each individual channel is sensitive to the reflected energy at the blue (short wavelengths), green (medium wavelengths), and red (long wavelengths) of the visible spectrum (Fig. 6.4). Red, blue, and green are the base colors of the visible light spectrum. This is called as basic color because we cannot create these colors by combining other colors. However, other colors such as yellow can be created by combining blue, green, and red at a certain ratio [5]. The longest visible wavelength is red and the shortest is violet. Sunlight includes electromagnetic waves of various wavelengths such as visible, ultraviolet and near-infrared portions of the spectrum.

For this reason, there are various electromagnetic waves around us, although they are invisible to human eyes. However, these electromagnetic waves can be detected by sensors of remote sensing instruments referred to as multi-spectral sensors. Multispectral images contain information outside the normal human perceptual range: this includes infrared, ultraviolet, X-ray or radar data (Table 6.4). An improved segmentation of objects can be achieved by combining an image captured on a visible light spectrum with an image taken in the thermal infrared (IR) spectrum. The visible light image is good for capturing color intensities while a thermal image, detects heat sources, such as warm bodies of people. Infrared region covers

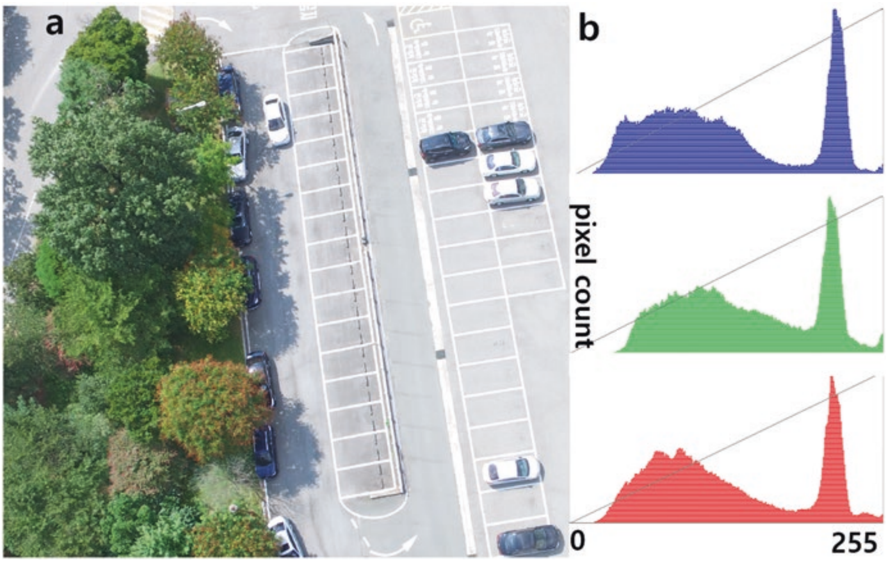


Fig. 6.4 Color digital image and RGB histogram, (**a**) color digital image (RGB combined channel) (**b**) RGB histogram

Table 6.4 Wavelength bands detected by remote sensing instruments

Band	Wavelength	Remarks
Ultraviolet (UV)	3 nm to 0.4 mm	Incoming UV radiation is absorbed by ozone in the upper atmosphere and atmospheric scattering is severe. So it is not employed in Remote Sensing.
Visible	0.4–0.7 μm	Violet: 0.4–0.446 μm
		Blue: 0.446–0.500 μm
		Green: 0.500–0.578 μm
		Yellow: 0.578–0.592 μm
		Orange: 0.592–0.620 μm
		Red: 0.620–0.7 μm
NIR- SWIR	0.7–3 μm	This is primarily reflected solar radiation and contains no information about thermal properties of materials.
		Commonly divided into the following regions:
		Near Infra Red (NIR) between 0.7 and 1.1 μm
		Middle Infra Red (MIR) between 1.3 and 1.6 μm .
		Short Wave Infra Red (SWIR) between 2 and 2.5 μm
Thermal IR	3–5 mm	Thermal infrared energy is emitted from all objects that have a temperature greater than absolute zero.
	8–14 mm	
Microwave	0.3–300 cm	These longer wavelengths can penetrate clouds and fog. Imagery may be acquired in the active or passive mode.
Radar	0.3–300 cm	Active mode of microwave remote sensing

an electromagnetic wave range of approximately 0.7–100 μm. It covers more than 100 times as wide as the visible portion. Infrared regions are divided into two categories according to their radiation properties: the reflected IR, and the emitted or thermal IR. Radiation in the reflected IR region has characteristics similar to that of the visible portion in remote sensing. The reflected IR has a wavelength range of approximately 0.7–3.0 μm which is slightly longer than visible light. The thermal IR region has properties that are different from visible and reflected IR portions because this energy is essentially the radiation that is emitted from the Earth's surface in the form of heat. The thermal IR region is located at approximately 3.0–100 μm wavelengths [5].

Spectral response curves characterize the reflectance patterns of a feature or target over a variety of wavelength range. The spectral reflectance of different ground targets can be measured in the laboratory or in the field, providing reference data that can be used to interpret images. Figure 6.5 shows contrasting spectral reflectance curves for three very common natural materials: dry soil, green vegetation, and water. The reflectance of dry soil rises uniformly through the visible and near infrared wavelength ranges, peaking in the middle infrared range. Reflectance pattern of green vegetation is relatively low in the visible range, but is higher for green light than for red or blue, producing the green color we see. The most noticeable feature of the vegetation spectrum is the dramatic rise in reflectance across the visible-near infrared boundary, and the high near infrared reflectance. Deep clear water bodies effectively absorb all wavelengths longer than the visible range, which results in very low reflectivity for infrared radiation [6].

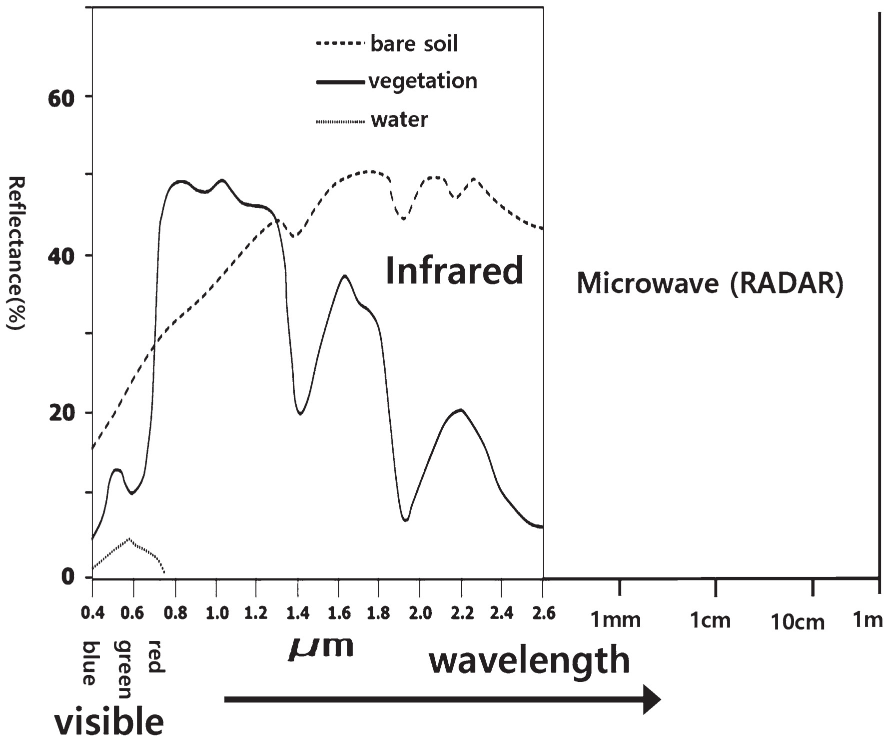


Fig. 6.5 Spectral response curves characterizing the reflectance patterns of a representative feature over a variety of wavelength range

There are two types of remote sensing: the optical (passive) and the microwave (active) system. Passive remote sensing uses the radiation emitted or reflected by an object when the sun is illuminating the Earth. In the passive remote sensing, observations can only take place when EMR (electromagnetic radiation) is naturally available. The reflected energy (visible, NIR near-infrared, MIR middle infrared or SWIR spectrum) is not available at night since the sun as naturally occurring energy source is not existing. However, energy that is naturally emitted (such as thermal infrared) from the target objects can be detected day or night. Thermal radiation (TIR) does not behave similarly to the visible light since it is emitted radiation from target objects. In the thermal radiation of the FIR (far-infrared) spectrum, the pedestrians, animals and automotive vehicles in use appear very clear at night since they show a relatively higher temperature than the surrounding environment although the sun is not available.

The sensor in active remote sensing transmits its own energy (e.g. a microwave radio signal) towards a target and detects the backscattered radiation. The biggest advantage of active sensor is that it can obtain remote sensing data anytime, regardless of the time of day or season (independent from weather and solar illumination effects). Radar (RAdio Detection And Ranging) remote sensing uses a backscattered signal of microwave electromagnetic radiation to discriminate different targets. The time delay between the transmitted and reflected signals determines the distance (or range) to the target. Surveying & mapping professionals have been using both photogrammetry and LiDAR for survey purposes for a long time (Table 6.5). LiDAR is inherently more accurate and more expensive than photogrammetry. Photogrammetry is more visually appealing since photogrammetry's point cloud (known points in a coordinate system) has a RGB value for each point. But LiDAR point clouds colorized with ortho-photos never look natural as the photogrammetry point cloud. But of the two, LiDAR is the only technology that can penetrate a tree canopy to create high resolution DTM (Digital Terrain Model) or map complex structures application to require extreme vertical accuracy at night [7].

Advanced multi-spectral sensors called hyper-spectral sensors, detect hundreds of very narrow spectral bands throughout the visible, near infrared, and mid-infrared portions of the electromagnetic spectrum. The distinction between hyper and multispectral is sometimes based on an arbitrary "number of bands" or on the type of measurement, depending on what is appropriate to the purpose [8]. The hyperspectral imaging measures continuous (e.g. 400–1100 nm in steps of 0.1 nm) spectral range, as opposed to multispectral imaging which measures spaced (e.g. 400–1100 nm in steps of 20 nm) spectral bands [8]. A sensor with only 20 bands can also be hyper-spectral when it covers the range from 500 to 700 nm with 20 bands each 10 nm wide. But a sensor with 20 discrete bands covering the VIS, NIR, SWIR, MWIR, and LWIR would be considered multispectral [9]. Certain objects leave

Table 6.5 Comparison of LiDAR versus Photogrammetry

	LiDAR	Photogrammetry
Energy source	Active	Passive
Measurement tool	Light, lasers	Photographs
Cost	Expensive	Cheap
Visually appealing	No	Yes
Type of sensor	The main parameter of aerial laser scanning is the point density, which is expressed as the point number per square meter.	Frame or line scanning
Method to measure elevation	Only a single ray	Derive elevation by triangulating two different images of the same area
Imaging capability	Often image is not available.	High quality spatial and radiometric resolution image
Vertical accuracy	When extreme vertical accuracy (e.g. 10–15 cm) is required, LiDAR is better.	Dependent on flight altitude and the camera's focal length
End-lap and side-lap	Do not consider overlap. It does not provide overlapped imagery.	Overlap is required.
Independence from weather and solar illumination	It is less influenced by weather such as cloud conditions, seasons, and sun.	Shooting only on a clear day

unique 'fingerprints' in the hyper-spectral electromagnetic spectrum. For example, a hyper-spectral signature for river water helps water quality surveyor find source of water pollutants such as a specific textile manufacturing factory.

6.5 Radiometric Resolution

The radiometric resolution of remote sensors describes its ability to subdivide the energy received by a sensor into a number of discrete levels (recorded as integer values). The radiometric resolution means the sensitivity of a sensor to the electromagnetic energy received from targets. The very high radiometric resolution facilitates fine discrimination between different targets based on their numerical EMR (Electromagnetic Radiation) values in each of the narrow bands (Fig. 6.6). Human eye can discriminate about 30 shades of B/W (black and white image), thus its radiometric resolution is 30 for B/W image and 100 or so for colors. All modern imaging systems use some form of electronic sensor. An image from an electronic sensor array consists of a two-dimensional rectangular grid of numerical values that represent different radiometric levels.

The radiometric resolution is expressed in a range of grey tones, with black representing a digital number of 0 and, white representing the maximum value (for example, 255 in 8-bit data). This range corresponds to the number of bits used for coding numbers in binary format. Each bit records an exponent of a selected power 2 (e.g. 1 bit = 2). The maximum number of brightness levels available depends on the number of bits used in representing the energy recorded. Thus, if a sensor used 8 bits to record the data, there would be $2^8 = 256$ digital values available, ranging from 0 to 255. However, if only 4 bits were used, then only $2^4 = 16$ values ranging from 0 to 15 would be available. By comparing a 2-bit image with an 8-bit image, we can see that there is a large difference in the level of detail discernible depending on their radiometric resolutions [5].

Normal sensors have a gray scale of 6–8 bits. It is known that a gray scale of 10 bits or more is required to interpret the detailed features such as a shadow of a building. Many current satellite systems quantize data into 256 levels (8 bits of data in a binary encoding system). Landsat 7 has a radiometric resolution of 8 bits, IRS has 6 bits, and IKONOS has a radiometric resolution of 11 bits. The thermal infrared bands of the ASTER sensor are quantized into 4096 levels (12 bits). The narrower the band width of a specific spectral wavelength, the more detailed features within the specified electromagnetic wavelength can be detected. The radiometric resolution is increased as the ability to refining the physical quantity in a specific spectral wavelength is expanded. This can be said that the radiometric resolution is the performance of a sensor that differentiates the distribution range of numerical EMR values within narrow wavelengths.

The radiometric resolution of the Landsat 8 satellite is 12 bits, which is better than the 8 bits of Landsat 7, so that more precise radiant energy values can be recorded. As shown in Fig. 6.6a, pixel values in 8-bit data of Landsat 7 are defined

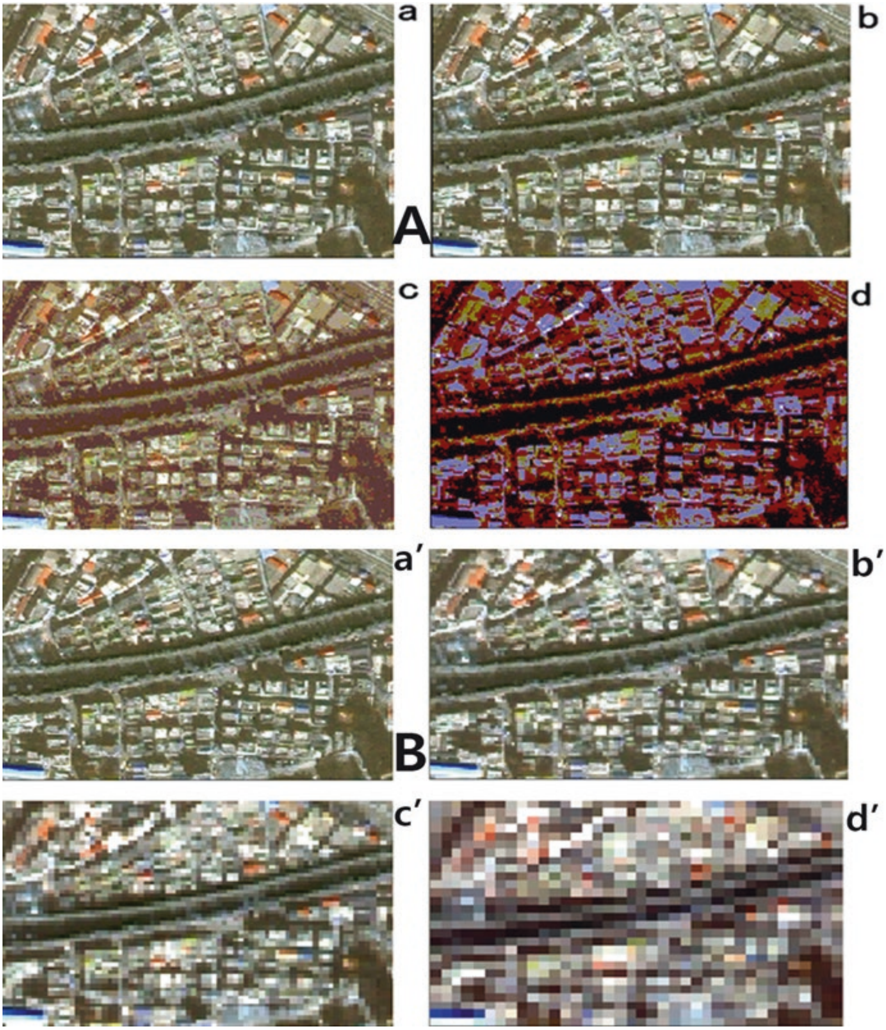


Fig. 6.6 Comparison of radiometric resolution versus spatial resolution. (**A**) Ground object definition changing according to radiometric resolution, a: higher radiometric resolution (16 bit), b: imagery (8 bit) degrading radiometric resolution from a imagery, c: imagery (4 bit) degrading radiometric resolution from b imagery, d: imagery (2 bit) degrading radiometric resolution from c imagery, (**B**) Ground object definition changing according to spatial resolution, a': higher (finer) spatial resolution (1 m), b': imagery (2 m) degrading spatial resolution from a' imagery, c': imagery (4 m) degrading spatial resolution from b' imagery, d': imagery (8 m) degrading spatial resolution from c' imagery

as minimum 0 to maximum 255 within a particular wavelength band. The maximum value of the Landsat 8 OLI sensor is 65,536 (256 * 256). This is because the 12 bit raw data of Landsat 8 OLI sensor is converted to 16 bits and distributed in comparison with the previous 8 bit Landsat imagery. The maximum value of Landsat 8 OLI sensor (20427) in Fig. 6.6b means that they have a radiometric resolution converted to a 16bit. When analog image is scanned, the gray level of the image can be specified by the user, but the radiometric resolution is not determined in this process. Likewise, the radiometric resolution cannot be improved by the operation using the software later on. The radiometric resolution of the image depends on the ability of the sensor, thus that radiometric resolution of image taken by the Landsat 8 OLI sensor is still 12 bits (not a 16bit). Since the radiometric resolution is defined as the number of signals that can be distinguished, it becomes an important factor in identifying spatial objects.

Six bits (64 levels), 8 bits (256 levels) and 10 bits (1024 levels) are mainly used to express the degree or amount of information detected by each wavelength band. As a result, the higher the radiometric resolution, the higher degree to which the characteristics of ground objects can be determined. It can be said that designating the subdivision range of color displayed on a computer monitor such as 32 bits or 256 colors (that is, 8 bits) is a process that applies a concept similar to radiometric resolution. In the case of 4 bits, the monitor color tone can be divided into 16 kinds and displayed while in the case of 8 bits, it is possible to display the different color levels corresponding to 256. It is one of the most important performance indicators that any remote sensor must measure the signal from the ground target with enough precision to record details in the spectrum. In remote sensing, the ratio of the output signal (response amount) from an object on the surface of the earth and the output signal caused by other factors than those from the ground object surface is called S/N ratio (signal to noise ratio). The S/N is dependent on the detector sensitivity, the spectral bandwidth, and the intensity of the light reflected or emitted from the surface being measured. The higher the S/N ratio means the better the radiometric resolution. The same terminology is used in various electronic devices, such as a telephone, a camera, a radio, and a television, and this is one of the most important performance indicators of IT equipment.

6.6 Temporal Resolution

In addition to the spatial, spectral, and radiometric resolution, the concept of temporal resolution is also important in a remote sensing system. The temporal resolution refers to how often the imagery data can be acquired for a specific area (Figs. 6.7 and 6.8). The actual temporal resolution of a sensor depends on a variety of factors, including the platform/sensor capabilities, the swath overlap, the orbit and altitude of the satellite and latitude. Remote sensors in recent satellites have a function to acquire images by tilting to the left and right, and thus the temporal resolution is greatly improved. Most surface-monitoring satellites are in low-Earth orbits (between 650 and 850 km above the surface) that pass close to the Earth's poles. For example, the repeat interval of the individual Landsat satellites is 16 days (Table 6.6). Placing duplicate satellites in offset orbits (as in the SPOT series) is one strategy for reducing the repeat interval. Satellites such as SPOT and IKONOS also have

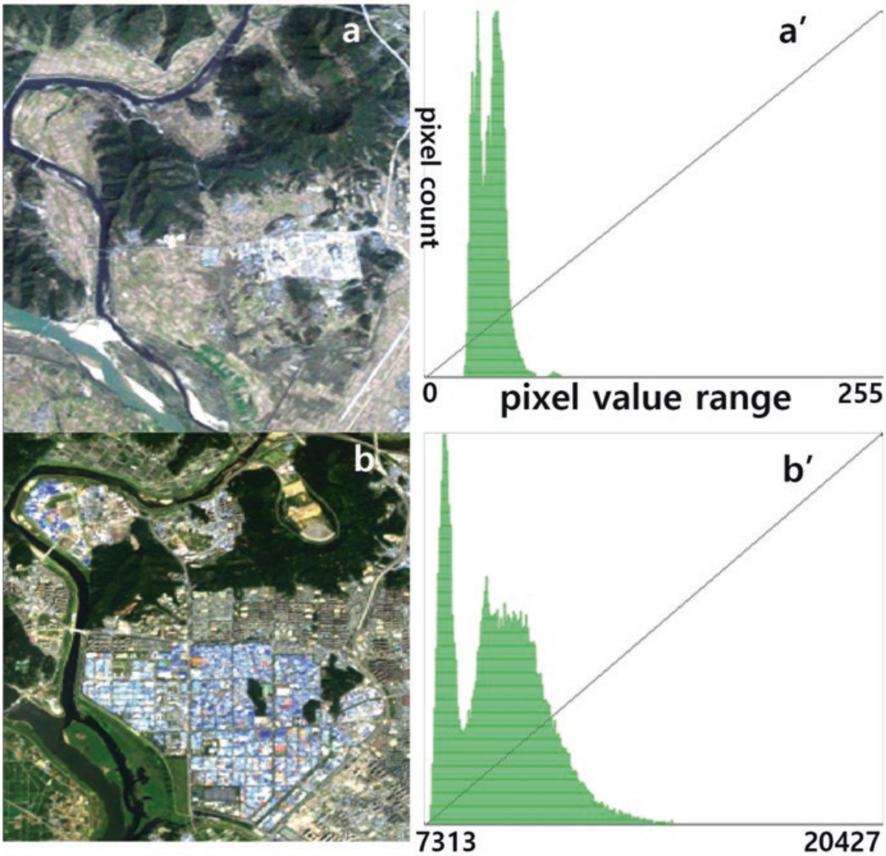


Fig. 6.7 Spatial and spectral variations occurring before and after Sung-su industrial complex construction, Daegu, South Korea, (**a**) October, 1985 (Landsat-5), (**b**) September 2014 (Landsat-8)

sensors that can be pointed off to the side of the orbital track, so they can image the same areas within a few days, well below the orbital repeat interval [10].

The typical satellite has significant limitations in temporal resolution because it acquires an image depending on the sunlight and cannot acquire images properly at night or in bad weather. The actual number of images that can be acquired in a particular area is determined by several variables such as cloud coverage, solar angle, and revisit cycle of the satellite. On the other hand, the satellite using micro wavelength (e.g. ERS-1) emits energy by itself, so the imagery can be collected at all times and temporal resolution is very high.

The surface environment of the Earth is dynamic, with change occurring on time scales ranging from seconds to decades or longer. The seasonal cycle of plant growth that affects both natural ecosystems and crops is an important example. The ability to collect the same area imagery at different periods of time is one of the most important elements for applying remote sensing data. Spectral characteristics

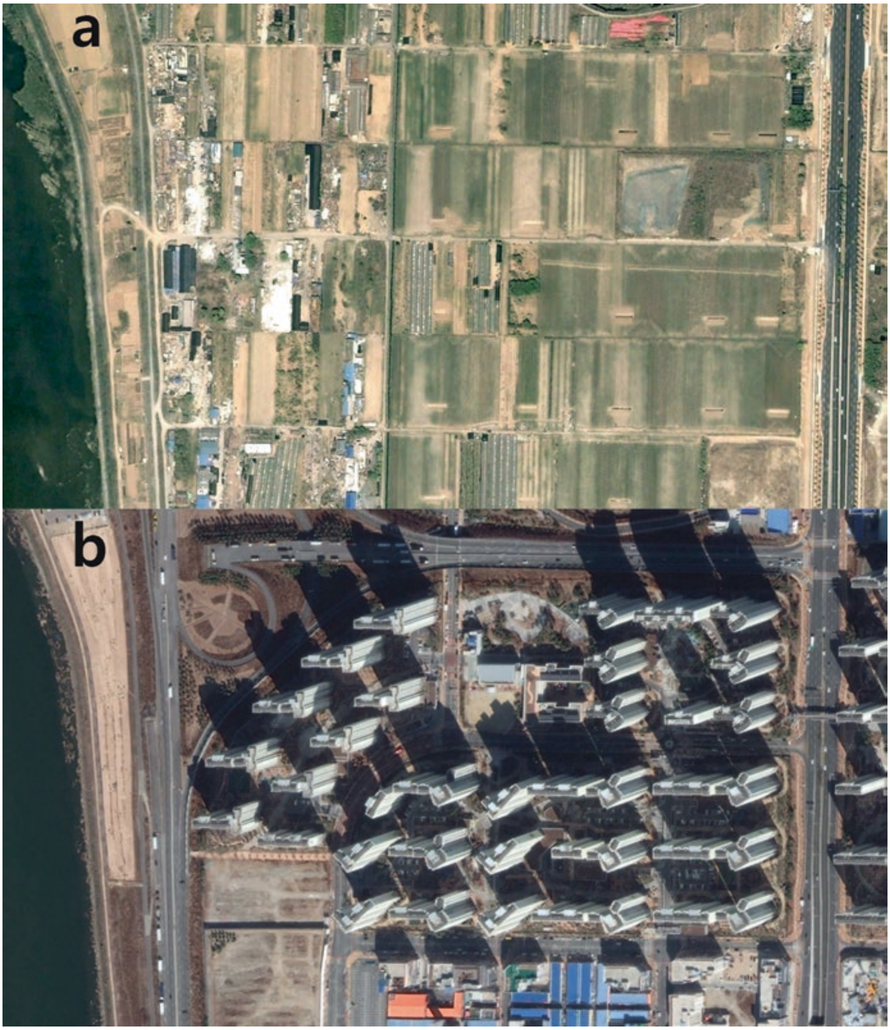


Fig. 6.8 Satellite imagery before and after Isia polis apartment construction (Daegu, South Korea), (**a**) IKONOS (April, 2007), (**b**) IKONOS (February, 2017)

Table 6.6 Temporal resolution of major remote sensing satellites

Sensor	Temporal resolution (days)
Landsat 8	16
GeoEye-1	10
IKONOS	1 ~ 3
Quick Bird	1 ~ 4
IRS	3 (with steering)
	25
SPOT	26

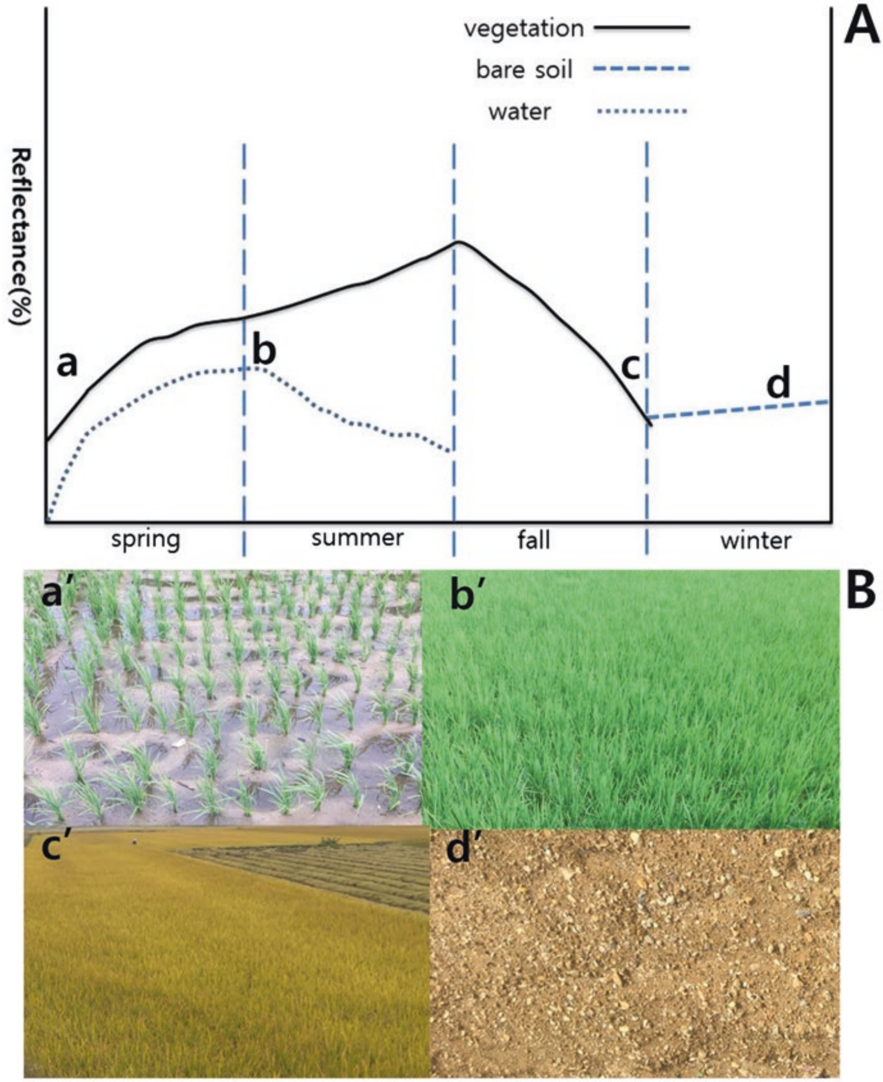


Fig. 6.9 Seasonal spectral response characteristics (near-infrared imagery) of paddy fields and ground photos (South Korea), (**a**) The reflectance characteristics of the ground surfaces (vegetation, soil and water) fluctuating according to the **season**al growth pattern of rice plant in the near infrared imagery, (**B**) Seasonal sequence of ground photos for paddy field, a': spring, b': summer, c': fall, d': winter

of features may change over time and these changes can be detected by collecting and comparing multi-temporal imagery. Thus the image interpretation process can be improved by using remotely sensed imageries taken at different times, whether they are naturally occurring (such as changes in natural vegetation cover or flooding) or induced by humans (such as urban development or deforestation).

Temporal resolution is the most important resolution in applications monitoring the natural environment that changes as often as the weather phenomenon. As the climate is changing in many regions of the earth, the appearance of the ground surface varies with the different seasons. Crops have a unique cultivation cycle, depending on the terrain and climate. Multi-temporal imagery analysis provides information about ground condition changing over time. Information about these changes can be used to identify the process that affects crop growth. Different spectral and spatial variations occurring during the growing season of a crop may not be identified on a single time image (one image on a particular day), but can be identified on multiple date images. Application areas for analyzing rice crop productivity, or calculating the cultivation area of rice paddies will require several seasonal images such as seeding time and harvest time. Figure 6.9 shows the spectral response characteristics (near-infrared images) of vegetation, soil and water in paddy fields. They appear differently season by season according to the growth and cultivation pattern of rice plants. The rice plant showed a distinct difference in the spectral response of near-infrared from the initial transplanting of the rice seedling to harvest. In winter, bare soils of the paddy field mainly affect the spectral characteristics since there is no growing rice. It indicates a strong water response in spring just after transplanting of rice seedling, while the spectral characteristics of typical healthy vegetation is observed in summer when rice is strongly grown. In this regard, the analysis should be appropriately performed according to the season. Analysis using data obtained in different times can easily distinguish paddy fields, showing wetland characteristics in spring and spectral characteristics similar to other crops in autumn.

6.7 Drone Imagery as a Survey Tool for Hyper-Localized Targets[1]

6.7.1 Drone versus Traditional Remote Sensing

Since World War I, aerial photography has evolved in two directions, larger sensor formats for accurate mapping and smaller sensor formats for reconnaissance practice. The former became standardized with large, geometrically precise cameras designed for cartographic measurements (Tables 6.7 and 6.8). The science of photogrammetry was developed for transforming air-photos into accurate maps [11]. Traditional aerial photography using the past film camera is generally collected using a large-format camera (a standard square sensor format, 9″× 9″ film or 230 × 230 mm) mounted on the underside of a fixed-wing aircraft. Photographs were taken sequentially at set intervals, often with a significant amount of overlap

[1] This chapter was revised from author’s PhD thesis as shown in the following; J.S. Um, 1997, Evaluating operational potential of video strip mapping in monitoring reinstatement of a pipeline route. University of Aberdeen, Aberdeen, UK

Table 6.7 Comparison of sensor characteristics based on sensor selection criteria

	Landsat imagery	Conventional aerial photography	Drone
Spatial resolution	30 m × 30 m	Better than satellite imagery	Adjustable to user requirement
Spectral resolution	Visible, NIR, Thermal (7 Band)	Visible, NIR, (3 or 4 Band)	Adjustable to user requirement Visible, NIR, Thermal, hyper-spectral
Radiometric resolution (sampling frequency)	usually 8 bit	usually 8 bit	usually 8 bit
Radiometric resolution (imaging condition)	Sensitive to atmospheric scattering, absorption, reflection, etc.	Better than satellite imagery	Better than satellite imagery and manned aerial photograph
Temporal resolution	16 days	About 2 ~ 3 months per year in temperate climate	Better than satellite imagery and aerial photograph

Table 6.8 Remotely sensed imagery utilized in map production.

	Scale	Remotely sensed imagery utilized
Hyper- large scale	Larger than 1/500	Drone imagery
Large scale	Larger than 1/5000	Manned aerial photography
Medium scale	1/10,000–1/100,000	Manned aerial photography/satellite imagery
Small scale	Smaller than 1/100,000	Satellite imagery

(standard end-lap: 60%, side-lap: 30%) to create a stereoscopic view. For digital cameras there is no standard sensor format. The market is divided into large format cameras (as the Intergraph DMC, Leica ADS40 and Vexcel UltraCam), medium format cameras and small format cameras. Most of these cameras have a rectangular image format, where the larger dimension is in the across-flight direction to minimize the number of required flight lines for photo flights. With the advent of digital aerial photography cameras, significantly more vendors are launching products to the market.

It is necessary to understand the difference between traditional analog and digital camera when purchasing a new camera or contracting with a professional aerial photography company [12]. These cameras operate in the same spectral range as conventional analog film including visible and near-infrared, panchromatic, color-infrared, or multiband photography. With the advent of airborne drone imagery in the mid-2010s, another system became available to the environmental manager for remote evaluation of ground targets. With several hundreds of US dollar, the drone can acquire similar or even higher resolution imagery compared to a standard manned aircraft system. Many remote sensing specialists accustomed to interpreting aerial photography or analysing satellite images now had a 'moving window' to view hyper-local representative sections (building safety inspection, urban stream monitoring etc). UAV photography can provide high spatial details needed by scientists and is not constrained by satellite orbital times or flight schedules of manned fixed-wing aircraft [13]. Various Unmanned Aerial Vehicle (UAV) companies are introducing affordable options for individuals to collect sub-meter aerial imagery directly. These new developments will allow for common access to massive amounts of hyper-spatial resolution imagery at affordable rates over the coming decade. Hyper-spatial resolution imagery introduces the capability of mapping land use and land cover (LULC) of the earth surface with a high level of detail that has led to many new applications.

The flight height of the platform is very different between the satellite and UAV imagery. Thus ground coverage of a single scene is completely different between the satellite and UAV imagery. For this reason, the pre-processing and image interpretation procedure is completely different between the satellite and UAV imagery (Table 6.9). Satellite imagery is processed at various levels ranging from Level 0 to Level 4. Level 0 products are raw data at full instrument resolution. At higher levels, the data are converted into more useful parameters and formats as shown in Table 6.10.

Currently one of the most widely used methods for geometric correction of UAV imagery is based on Structure from-Motion (SfM) algorithms. These algorithms provide the opportunity to create accurate 3D models from image structures without prior information about the location at the time of image acquisition, or about the camera parameters. With the SfM method, the 3D scene geometry and camera motion are reconstructed from a sequence of 2D images which are taken by a camera that moves around the scene. The Sfm algorithm detects common 16 feature

Table 6.9 Comparison of satellite imagery versus UAV imagery

Division		UAV imagery	Satellite imagery
Data characteristics	Flight height of the platform	Adjustable to user requirement	705 km (Landsat 8)
	Ground coverage of single scene	Adjustable to user requirement	170 km × 185 km (Landsat 8)
	Image mosaicking	Necessary	Not necessary
Pre-processing	Data distributed for operational user	Raw data	Pre-processed data at ground receiving station: level 0 to 4 data (NASA)
	Radiometric correction	Not necessary	Necessary
	Ground control	Not always required due to utilizing SfM	Required
Interpretation	Supervised classification	Deep learning (through many layers, hierarchically) still prototype	Shallow machine learning (usually 4–6 multiple layers)
	Visual/manual interpretation	Inadequate (too much time consuming task)	Established as standard

Table 6.10 Data processing levels of Satellite [14]

Data level	Description (NASA-EOSDIS definition)
Level 0	Reconstructed, unprocessed instrument and payload data at full resolution, with any and all communications artifacts (e.g., synchronization frames, communications headers, duplicate data) removed.
Level 1A	Reconstructed, unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters (e.g., platform ephemeris) computed and appended but not applied to Level 0 data.
Level 1B	Level 1A data that have been processed to sensor units (not all instruments have Level 1B source data).
Level 2	Derived geophysical variables at the same resolution and location as Level 1 source data.
Level 3	Variables mapped on uniform space-time grid scales, usually with some completeness and consistency.
Level 4	Model output or results from analyses of lower-level data (e.g., variables derived from multiple measurements).

points in multiple images and uses them to reconstruct the movement of those points throughout the image sequence. With this information the locations of those points can be calculated and visualized as a 3D point cloud [15].

Supervised machine learning has been commonly used for classifying satellite imagery. The shallow or superficial machine learning typically depends on radiometric values of training samples used for classifying the satellite imagery. Hyper-localized target segmentation in super-high resolution images acquired by unmanned aerial vehicles (UAVs) is a challenging task since it requires much more complicated algorithm capable of classifying spatially fine-grained data [16]. Deep learning methods derive their own features (convolution and sub-sampling) directly from the raw data and perform multiple levels of representation for the underlying structure or distribution in the data. Deep learning uses multiple hidden layers and pooling techniques; shallow learning typically only uses one hidden layer according to the user operation having some prior knowledge. The emphasis in shallow learning is on superficial feature detection while in deep learning the emphasis is on defining the most distinctive topology and optimizing hyper-parameters correctly. Automatically classifying hyper-localized UAV imagery with millimeter or centimeter spatial resolution has been dreams of remote sensing experts [17]. It is expected that this dream will come true soon.

6.7.2 Small Sensor Size of Drone Camera

The drawback of conventional small format cameras (36 mm by 24 mm) is that they are still big, bulky, heavy, and fragile when this camera is mounted on the drone. The large sensor size means that each additional payload either increases the size

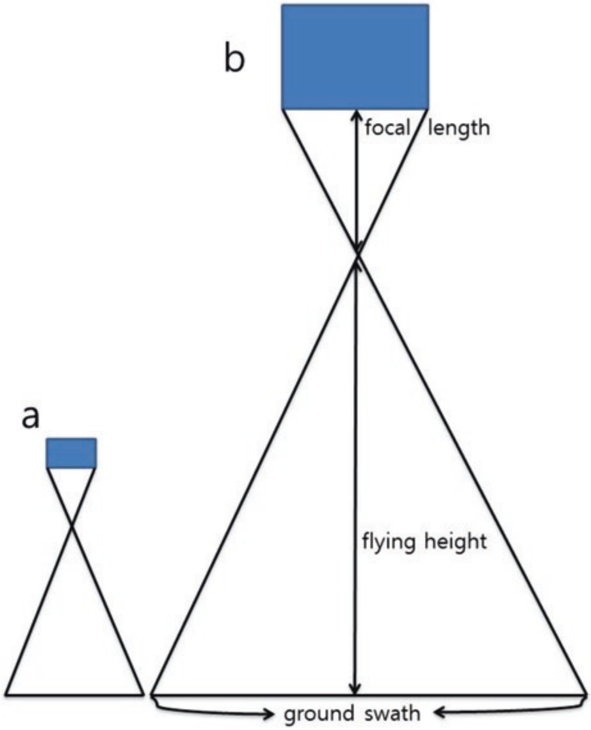


Fig. 6.10 Schematic representation of reciprocal relationship between sensor size and flying height versus ground swath in vertical aerial photograph, (**a**) drone imagery taken with small sensor size at low flight altitude, (**b**) traditional manned aerial photography taken with large sensor size at high flight altitude

and cost of the optics needed or decreases flight time. Most obvious impact of a bigger camera sensor is that it not only will the sensor take up more space in the drone flying part, but it will also need a bigger lens to house an image over it. Stabilizing a larger camera module is also more difficult. With traditional large sensor size (e.g. manned aerial photography), there is much recording of redundant information in hyper-localized target due to wide coverage angle (Fig. 6.10). Traditional large sensors are basically designed for specific wide-area ground targets. They do little to address the monitoring requirements of hyper-localized target in the landscape. Hyper-localized target monitoring represents a potential application for remote sensing which is largely unfulfilled. For drones, larger, heavier cameras also require larger and heavier gimbaling mechanisms. That is why drone manufacturers generally stick with very small sensors. They want to keep devices pocketable and not deal with the bulk of larger lenses.

As sensor technology improves, we're seeing much better performance of smaller sensors [18]. Sensor size is one of the key imaging parameters, along with focal length of the lens, since it is the core component in defining the ground sample dis-

Table 6.11 Examples of small format UAV camera [19]

Camera	Megapixels	Sensor size (mm)	Max focal length (mm)	Compatibility
DJI Zenmuse X3	12.0	6.17 x 4.55	14	Inspire 1
DJI Zenmuse X5	16.0	17.3 x 13	16	Inspire 1
DJI Zenmuse X5S	20.1	13 x 17.3	16	Inspire 2
DJI Zenmuse X4S	20.1	13.2 x 8.8	20.1	Inspire 2
GoPro Hero 4 Silver	12	5.9 x 4.5 mm	30 mm	3D Robotics

tance (GSD: the pixel size in the real world). The small sensor size is an attractive option for those concerned with covering hyper-localized target, or surveying in remote areas, as its light weight can significantly increase flight time (Table 6.11). There are "popular" sensors designed for many compact cameras and phones. Typical compact cameras such as the Canon IXUS 255 HS and the Samsung Galaxy camera use 1/2.3-inch sensors (6.17 x 4.55 mm) [18]. The small sensor size has been the camera of choice for many consumer-level UAV manufacturers (e.g. 3D Robotics, www.3dr.com). Further, the popular DJI Inspire series comes with a built-in camera of very similar specifications to those designed for many compact cameras and phones (DJI Zenmuse X3 of Inspire 1: 6.17 x 4.55 mm sensor size).

The ground sample distance (GSD) is a term to describe the pixel size measured on the ground. For example in an image with 5 cm GSD, a pixel corresponds to 5 cm on the ground. The value depends mainly on the camera sensor resolution, focal length and flying height. The 'ground sample distance' can be improved by reducing ground coverage (by using longer focal length) or by a lower level flight. In drone, improving the ground sample distance is more simple than with other manned airborne sensors, by using the narrow angle-of-view (Fig. 6.10). In fact, to ensure adequate ground coverage for hyper-localized target (e.g. around 10 m width), the sensors with wide-angle of view would require quite heavy optics in terms of focal length and exposure time and a much lower altitude flight specifications than in the case of drone. The reduced ground coverage would also increase the data acquisition cost proportionately for photography. It is not feasible for manned airborne sensors to be used practically for this type of hyper-localized target (e.g. around 10 m width), in terms of flying height, FOV, and cost. Although large format photography has better spatial resolution in terms of absolute value, it is unsuitable for this type of hyper-localized target due to the inappropriateness of the imaging system in terms of wide angle-of-view, cost and low tolerance of image motion [20].

Another important element is the required optimal swath width. Field of View (FOV) differences provided by various remote sensors will find application at different scales. The view-angle of the imaging device must first be carefully considered when trying to obtain remotely sensed data of a long, narrow target. Wide-angle imagery, such as conventional manned aerial photography, generally covers a larger area of land surface than a smaller format system operated at the same altitude and with the same focal length lens as shown in Fig. 6.10. Any single-scene image collected via such systems covers a wide area of surrounding features in addition to the hyper-localized target. Such an image will, therefore, include a considerable redundancy of information which is not needed for hyper-localized target monitoring. Such wide-area coverage also disturbs the information content of the image by increasing spectral variance, through displaying unnecessary thematic ground classes. This can complicate analysis when doing digital image processing at a later stage [20].

The information content in a remote sensing application depends on the coverage angle of the imaging system if same flight specification (focal length and flying height) is applied. The coverage-angle of the imaging device must first be carefully considered when trying to obtain remotely sensed data of a long, narrow target. Field of View (FOV) differences provided by various remote sensing sensors will find application at different scales [21]. To cover such a narrow swath, the camera should use a zoom lens, which causes some deterioration in photo image quality. Even if it is available, it is not an easy matter to change focal length of a photographic camera while in-flight. On the other hand, a drone camera is almost invariably fitted with a zoom lens operated by remote controller in the ground. In the context of swath/coverage angle, this offers a greater possibility of selecting swath and changing it in-flight if required. This observation demonstrates that drone remote sensing with such narrow angular coverage (requiring a narrow swath) is the system which can be applied in a fairly cost-effective manner to hyper-localized target by covering the necessary ground target precisely.

Aerial drone imagery is a technology that fills a niche that conventional manned aerial photographs cannot meet. Drone remote sensing offers a number of unusual characteristics different from the traditional large format sensors which can be highly advantageous for imaging and monitoring hyper large-scale and hyper-localized target. The characteristics of the ground target are considerably different from the conventional target on which traditional remote sensing has focused. It is necessary to acquire the remotely sensed image from an extremely low altitude, with a narrow angle of view along hyper-localized target [22]. Drone remote sensing can be applied in a fairly cost-effective manner to hyper-localized target monitoring because angular coverage of the camera built in consumer grade drone such as Inspire 1 is much narrower than for conventional photographic cameras.

6.7.3 Low-Height Drone Photography (LHDP)

There are regulations in each country of the world that cover how low an aircraft can lawfully fly. Flying below these heights can be a violation of the regulations, although there are exceptional situations where low flying is permitted.[2] The regula-

[2] These situations include, but are not limited to: flying in the course of taking off, landing or conducting a missed approach, flying in accordance with instructions from an air traffic controller

Table 6.12 Comparison of sensor characteristics for hyper-localized applications

	Satellite imagery	Conventional manned aerial photography	Drone
Cost	Relatively cheap, but, due to limitations in spatial resolution, adequate data cannot be acquired for hyper-localized applications such as building safety inspection.	It is difficult to secure adequate data due to limitations of shooting altitude while the aircraft flight and shooting cost are very expensive.	Hardware purchase cost: Inspire 2 (US$ 4000)
Low-altitude tolerance	No	No	Yes
User friendliness	Intermediate	No	Yes
Image motion tolerability	Yes	No	Yes

tions usually require that pilots fly no lower than 300 m (1000 feet) over built-up areas, or 150 m (500 feet) over any other area (rural area). For instance, Federal Aviation Administration (FAA) is the government agency responsible for aviation safety in United States and its territories. According to the Code of Federal Regulations in the USA (Section 91.119 of the General Operating and Flight Rules), a manned aircraft would not be allowed to fly lower than 150 m (500 feet) over other than congested areas and not less than 300 m (1000 feet) over congested areas of a city, town, or settlement.[3]

In order to monitor hyper-localized target (e.g. urban stream with around 10 m width), it is necessary to acquire the remotely sensed image from an extremely low altitude, with a narrow angle of coverage. This means that low-level flight with small photographic format violates the regulation. Low-level flight also causes serious image motion and it should be compensated with a faster shutter speed in very bright conditions. Over the last 20 years or so, the majority of remote sensing has been used to support global, national, or large area applications. As a consequence, those charged with more target specific requirements, such as the building safety inspection, have benefited far less from the fruits of that conventional research. The high cost of photo acquisition, particularly for a scattered hyper-localized target, is a significant disadvantage of the manned photographic survey method. With drone remote sensing, the scattered hyper-localized target may be recorded all on the same day. Additionally, drone remote sensing is much less expensive than most other remote sensing systems (Table 6.12). Due to such low-cost data acquisition, this

undertaking certain kinds of specialised aerial work, for example, power line inspection, geographical survey work, aerial firefighting, agricultural spraying.

[3] 91.119 – Minimum safe altitudes: General. [Doc. No. 18334, 54 FR 34294, Aug. 18, 1989, as amended by Amdt. 91-311, 75 FR 5223, Feb. 1, 2010] Except when necessary for takeoff or landing, no person may operate an aircraft such altitudes. A helicopter may be operated at less than the minimums over congested areas and other than congested areas, provided each person operating the helicopter complies with any routes or altitudes specifically prescribed for helicopters by FAA

technology may have a particular value in highly changeable areas, such as rooftop temperature and the monitoring agricultural crop harvests, where year-to-year, day to day, hourly and seasonal changes are common. Large-scale changes for various ground targets could be monitored, thus, monthly or seasonal survey results could be updated on a site-specific basis.

Airborne drone monitoring programs, aided by the use of conventional sampling, can complement the present field survey in an optimal way. This method will provide information efficiently, that is both scientifically justifiable and practically understandable by the customer [23]. The high cost of aerial photo acquisition, particularly for a scattered target such as an urban stream with around 10 m width is a significant disadvantage of the conventional manned photographic survey method. With airborne drone survey, the long linear extent of corridor targets such as the urban stream could be recorded all on the same day. The time and cost of post-processing are virtually eliminated by providing instantaneous real-time imagery, much more quickly than with the field survey. It is much less expensive than in-situ survey systems [24].

Monitoring is fundamental to any development projects both to assess adherence to national regulation and to support management options. Monitoring can be considered at a pre- or post-decision project stage. Pre-monitoring, called baseline monitoring, measures the initial state prior to implementation of a proposal. Post-decision monitoring includes monitoring activities undertaken to determine the impacts or changes to the environment caused by the proposal once it has been implemented (environmental effects monitoring) [25–27]. Environmental monitoring to communicate information about the environment and human activities is emerging as a global trend and applicable to all types of organization (e.g. government or private companies). It equally covers activities undertaken to ensure that environmental components are not altered by human activity beyond a specific standard or regulation level (compliance monitoring) [27].

Especially in development projects requiring the EIA (Environmental Impact Assessment), impacts of projects need to be monitored on a regular basis during the entire project life cycle. The comprehensive EIA is accomplished by gathering information about socio-economic, biological and physical setting, to evaluate potential interactions between the environment and the activities associated with development projects. Developers are obliged to monitor the significant environmental effects of the implementation of plans and programs in order, inter alia, to identify at an early stage unforeseen adverse effects, and to be able to undertake appropriate remedial action. This baseline assessment establishes the current environmental conditions of the site and its surroundings. The environmental inventory is intended to describe the condition of the site on which the project is to be built as well as its environmental characteristics, including key ecological interactions, sufficiently precise, clear and transparent to enable individuals to ascertain their rights and obligations.

Utilizing area-wide spatial information in the EIA process is one of priority issues to assure and improve public communication and participation. The main intentions introducing drone imagery is to communicate information about the environment and human activities. The drone image can be especially useful to highlight emerging significant environmental impacts during monitoring programs. Further drone imagery could provide evidential information for EIA performance, such as regulatory compliance, mitigation performance, validation of impact-prediction and verification of residual effects [25]. Drone imagery could be used to verify predicted impacts and confirming the effectiveness of mitigation measures (e.g., auditing of compliance with environmental legislation and with site specific environmental protection plans) since it is presented as a permanent record at the various timing of construction (pre-construction, during construction, or post-construction as applicable).

The funding and number of personnel that were available to do ground monitoring 10 years ago are now generally unaffordable, while the cost of drone remote sensing data is getting much cheaper, and it is more powerful in terms of information content than before. The collection of field data via drone remote sensing is, therefore, proposed as a practical, cost-effective alternative. Drone imagery provides a permanent visual record for the pre-construction and post-construction phases of any project (e.g. building, bridge, road etc). It is particularly useful for assessing a variety of spatial and temporal characteristics of various development activities [23].

6.7.4 Low-Height Drone Photography as an Alternative for In-situ Survey

Fundamental advantage of using UAVs is that they are not burdened with the physiological limitations and economic expenses of human pilots. Most of the UAV systems on the market are less expensive and have lower operating costs than manned aircrafts. UAVs are increasingly seen as an attractive low-cost alternative or a supplement to in-situ terrestrial photogrammetry due to their low cost, flexibility, availability and readiness for duty [28]. In addition, UAVs can be operated in hazardous or temporarily inaccessible locations. Major advantages of LHDP (low-height drone photography) compared to manned aircraft systems are that UAVs can be used in high risk situations without endangering a human life and inaccessible areas, at low altitude and at flight profiles close to the objects where manned systems cannot be flown. These regions are for example, natural disaster sites, e.g. mountainous and volcanic areas, flood plains, earthquake and desert areas and scenes of accidents. In areas where access is difficult and where no manned aircraft is available or even no flight permission is given, LHDPs are sometimes the only practical alternative [28]. They also, if properly used, increase the safety of people conducting measurements, because an operator can stay out of a dangerous zone.

The "primary advantage of LHDP is the ability to bridge the scale gap between field-based observations and manned airborne or satellite observations. For low-height applications, it was usual that in-situ terrestrial survey has to be implemented

Table 6.13 Comparison of UAV imagery versus field survey point photo

	UAV remote sensing	In-situ survey
Data acquisition area	Area-wide information in a short time	Fragmented information only for survey sites
Objectivity of information	There is little controversy involving the subjectivity of the investigator since the remote sensing data is presented as permanent record.	Since the position of the investigator changes from time to time, subjectivity may be involved depending on the sample location.
Accessibility of survey points	There is no obstacle because it is approached through low-altitude flight considering spatial variables over survey point	There is always a restriction to accessibility, due to safety and time-consuming task such as water-body and mountains.
Position accuracy	The position of the real world is accurately displayed because it is collected at the vertical vantage point available at map and ortho-photo.	It is performed from horizontal perspective, so it has considerable limitations in matching the survey results to real world position in terms of map coordinates.
Expenses	Cheap	Expensive
Change detection	It is easy to acquire data in a timely when an investigator needs to acquire data.	The results presented by tables and figures have significant limitations in performing change-detection because it is impossible to quantitatively analyze the various variables such as the natural environment and human environment.

as alternative arrangement (Table 6.13) since remote sensing projects are quite often not feasible due to the expenses for manned aircrafts. LHDP can be seen as supplement or replacement to terrestrial in-situ survey in many fields of applications. In the case of combination of terrestrial in-situ survey and UAV photogrammetry, it is even possible to use the same camera system and having the same distance to the object, which simplifies the combined data processing [28]. With the advent of hyper-spatial resolution imagery of drones, many objects and shapes that have not been seen in satellite images and manned aerial photograph have become apparent. The images taken by the drone can identify people or road lanes that have not been distinguished from high resolution satellite images or aerial photographs. As the spatial resolution of the image is improved, the identification range of the object is also widened. Remote sensing applications have focused on more than medium scale environments such as ocean, atmosphere, forest, and water resources.

However, the emergence of drones has expanded the scope of remote sensing, which requires detailed information such as building inspection, power-line monitoring and individual tree analysis. It is now possible to observe urban facilities, such as buildings and traffic facilities, that can be identified at a high resolution of less than 10 cm. LHDP shorten the time of performing surveys (from several days to few hours) that have to be spent in a field. New products such as colorful overview maps and detailed CAD models of buildings can be delivered to the customer just after drone flight. Much of the data acquired by current field surveys is expected to be replaced or complemented by unmanned aerial imagery that allows intensive investigation of specific locations [29]. Furthermore, much of the remote sensing area that used manned aircraft images or high-resolution satellite imagery in the past is likely to be replaced by drones.

6.7.5 Decreasing Cost of Hyper or Multi-spectral Sensors

Visible wavelength sensor (e.g., RGB sensor) usually only provide information on a very limited number of bands and/or spectral ranges. It might not work for very detailed land mosaic components that characterize hyper-localized targets, such as a solar-powered house rooftop or a building safety inspection target. To tackle this issue, hyper-spectral sensors, commonly used on satellites or manned aircraft a few years ago are getting redesigned to be lighter and smaller. Thus, UAV is now more suitable to bring the sensor with a wider spectral range and narrower bands [29, 30].

New sensors with multi-spectral sensitivity are rapidly emerging into UAV platform, making high-resolution infrared sensors not only smaller and more lightweight, but also less expensive (Fig. 6.11). Decreasing costs for sophisticated infrared sensors makes UAV platform accessible from a growing number of innovative new applications. Hyper-spectral sensors also are decreasing in size, weight, and cost to increase the availability of these technologies [31]. UAV carrying advanced hyper or multi-spectral sensor proliferate in various applications, in the air, on the ground and at sea [32, 33].

Thermal infrared sensing is becoming far more sophisticated today than simply detecting warm objects. This approach continues to detect and classify humans and animals from the warmth of their skin, as well as land vehicles, aircraft, and industrial sites from their hot engine exhaust. Further blending visible sensors with thermal infrared can detect humans, animals, and vehicles quickly against a cool background [31, 34]. Hyperspectral sensors usually generate huge amounts of data since they retrieve spectra sets composed of hundreds of bands across considerable spatial resolution images. It is expected that the technological development of upcoming years can bring smaller and more affordable devices, turning hyperspectral-based sensing into a mainstream approach for agriculture, forestry and related areas [30].

Satellite and aerial imaging are generally referred to as passive, because they measure radiation from an external source (i.e. sunlight). LiDAR (light detection and ranging) and RADAR (Radio Detection and Ranging) are considered active, as they are not dependent on sunlight, but rather emit their own radiation. LiDAR uses a laser to produce and emit pulses of light, and measures the time it takes for a reflection of this pulse to return. LiDAR is a remote sensing method that uses a laser to measure distances. When learning about LiDAR, one is likely to encounter terms

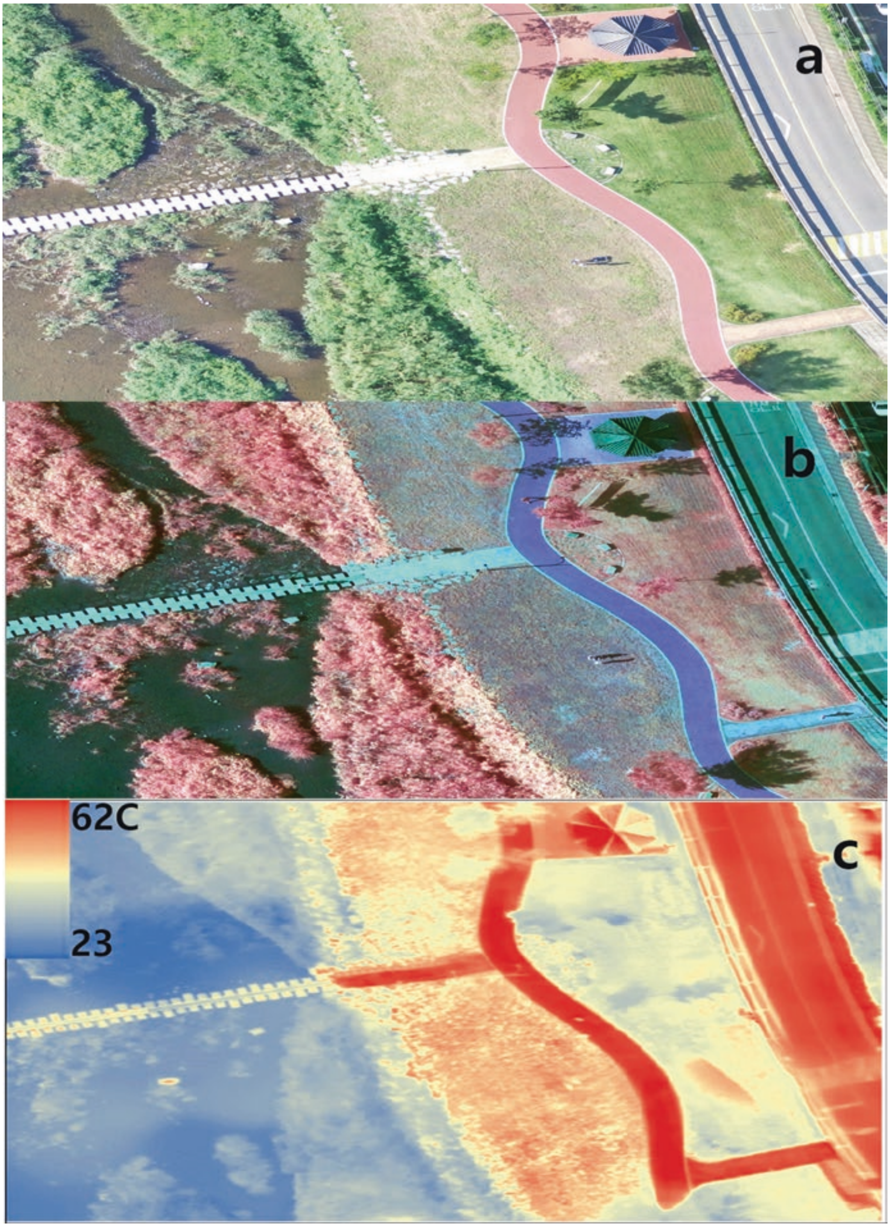


Fig. 6.11 Example of multi-spectral imagery taken at UAV platform, (**a**) visible imagery, (**b**) near-infrared imagery, (**c**) thermal infrared imagery

like airborne or terrestrial LiDAR, or aerial or terrestrial laser scanning. A LiDAR device itself can be mounted on an airplane, helicopter, drone, car or tripod. In the typical case, the LiDAR device is mounted on board an airplane and the system scans [35]. At present, extremely compact laser scanners became commercially available. UAV-based laser scanning (ULS) is a new segment complementing the existing applications for lidar technology, such as airborne, mobile, and terrestrial laser scanning. UAV-based laser scanning (ULS) provides extremely flexible and cost effective operation possibilities, delivering comprehensive and accurate data in combination with ease of operation and low cost [36]. It shows high potential for various applications.

The laser emits millions of such pulses of light and when the pulse hits a target, signals representing the target are reflected back to the laser scanner. They record a highly precise 3D-point cloud which can be used to estimate the 3D structure of the target area (digital elevation model). This technology provides real-time and autonomous 3D-point clouds data on the fly and ground. LiDAR provides the most accurate data on 3D structure of any remote sensing technique [35]. The performance of UAV-based laser scanning has shown remarkable results during the last decade, including ground surface scanning at night, electrical powerline, carbon storage and vegetation roughness scanning as well as texture scanning of various ground objects (e.g. bridges, buildings, daylight mining area, etc.) [37]. Future LiDAR datasets will likely include multispectral properties and improved spatial and temporal coverage and resolutions. REDD+ (Reducing Emissions from Deforestation and Degradation) is a UN framework designed to support financially as an incentive for the protection of carbon contained in forests. LiDAR has been increasingly used for mapping above-ground forest biomass and for estimating forest carbon stock, since it has capability to penetrate the forest canopy and determine the three-dimensional structure of the target [38].

6.7.6 Sunrise Calendar Temporal Resolution

Change-detection' means to identify and locate changes in imagery of the same geographic area obtained at different times. The information is extracted by comparing two or more images of an area that were acquired on separate occasions. This approach is frequently taken to monitor area-wide Earth features by satellite remote sensing (such as deforestation monitoring, detection of crop-yield change and land-use changes, such as urban fringe change due to urban development). Traditionally, such change-detection has been conducted by manual interpretation of aerial photography. A problem associated with using historical remotely sensed data for change-detection is that the data are usually of non-anniversary dates, with variations in sun angle and in atmospheric and ground moisture conditions.

A key advantage of unmanned platforms in change detection is a constant availability. Manned missions can be limited by human endurance factors, whereas unmanned aerial vehicles (UAVs) can survey the area of interest for 24 h or more (Fig. 6.12). The change-detection study assumes that the multi-temporal imageries have been collected under similar conditions (e.g., the camera is pointing vertically downward and lens distortion has a negligible effect). The effect of atmospheric

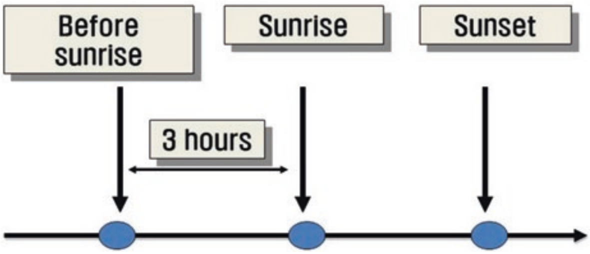


Fig. 6.12 Schematic representation of theoretical principle involved in sunrise and sunset calendar temporal resolution

turbulence or other distortions in the images should be negligible. It is also assumed that changes in plant condition are accompanied by corresponding changes in leaf reflectance characteristics. However, any study dealing with several images should also consider the problems of image combination. Elements such as geometric position, atmospheric effects, or radiometric equivalence are very difficult to correlate in several images [39].

In a temperate region such as the UK, South Korea, there are only a few months in the year with the necessary bright light conditions for manned aerial photography. On the whole, the reduced illumination conditions of winter do not favor manned aerial photography. Such weather conditions do not allow the data acquisition with large format cameras integrated into manned aircrafts due to required high flight altitude above ground. However, in cloudy and drizzly weather conditions, the data acquisition with LHDPs is still possible, when the distance to the object permits flying below the clouds [24]. LHDP have particular advantages in terms of temporal resolution. Because the user has a platform, it has the advantage of being able to shoot at any place at any time. It can be dispatched to a disaster site (for example, a fire) that occurs without notice, and a necessary image can be collected. It is particularly advantageous in applications that monitor changing site conditions through day by day, the seasons or during a period of years repeatedly such as traffic congestion and agricultural crop analysis [28].

Even with a wider angle of view, it is difficult to ensure coverage of the hyper-localized target using manned aerial photography from low altitude. It is difficult to send aircraft frequently to the survey area since manned aerial photographs are expensive to shoot. Target navigation problems can be much less troublesome with drone since it is possible to review an image strip in real-time and correct for any gaps in coverage by flying the drones again. Moreover, great advantages of drone imagery in change detection are the real-time capability for fast imagery acquisition, while transmitting the geo-referencing and orientation data (GPS, INS etc) in real time to the ground control station (Fig. 6.13). For hyper-localized target such as house, road and urban stream, it is necessary to fly at very low altitude with longer focal length to achieve a narrow ground swath. This specification requires the use of very fast shutter speeds, such as 1/2000s, to avoid image motion. For example, with the popular drone camera sensor size of 6.4 mm by 4.8 mm, it is possible to cover a 40 m swath from 100 m flying height, without any difficulties in terms of image motion and flight regulation. As a result, the use of airborne drone data would fill an

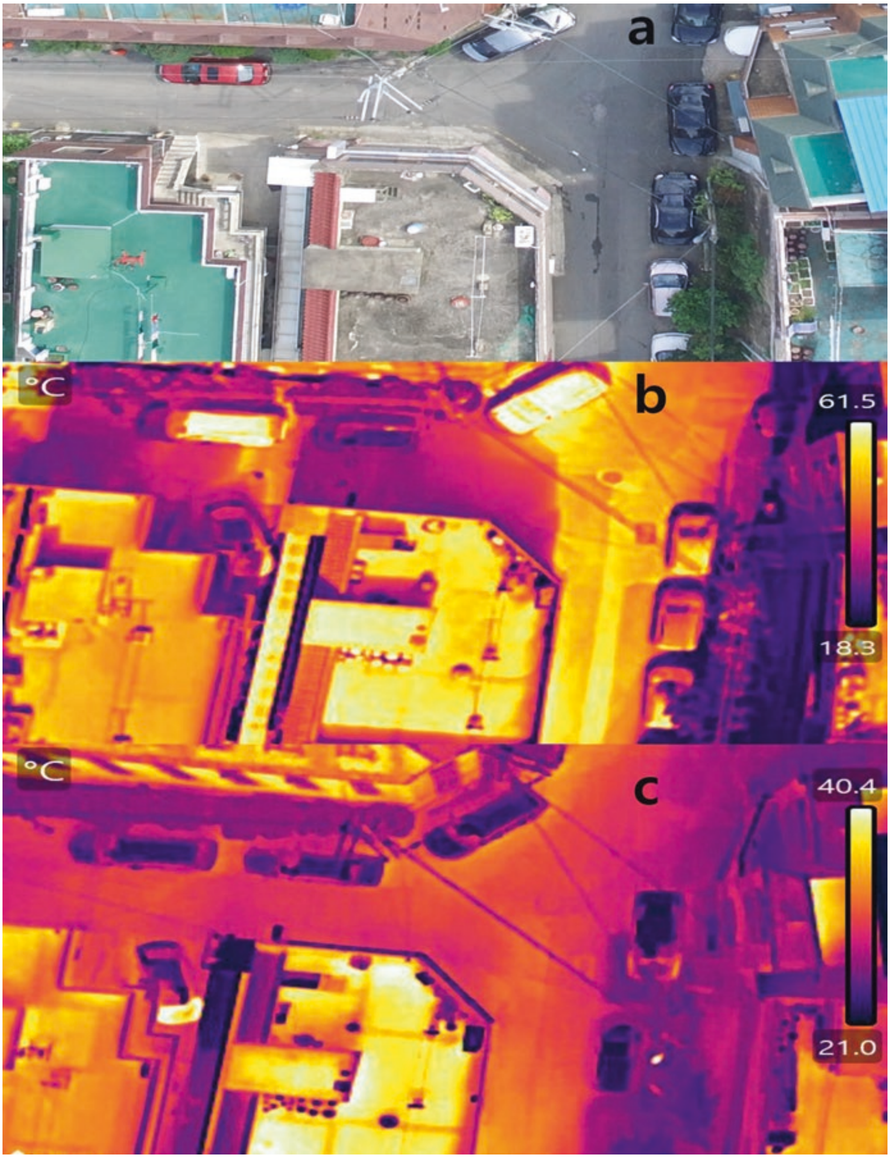


Fig. 6.13 Thermal-infrared imageries taken before and after sunset. (**a**) visible imagery (**b**) thermal imagery taken at 15:00 PM Sept 3, 2017 (**c**) thermal imagery taken at 20:00 PM Sept 3, 2017

existing gap with its ability to detect change of hyper-localized target quickly and under conditions of weather and time that would render manned aerial photography inadvisable. This is a very important attribute of drone imagery for low-level change detection application [20].

Radiometric equivalence is another source of problems in change-detection studies, which arises from differences in illumination conditions among multi-temporal images. Because the mechanism of acquiring remote sensing imagery varies so widely with the systems used, direct comparison of imagery acquired with different systems at different dates can be quite difficult. Radiometric calibration involves direct comparison of the brightness with the amount of radiance received by the sensors, which depends on several complex factors. It is very difficult to calibrate the grey value difference since related environmental factors at the time of image acquisition are too dynamic to control. Without radiometric calibration, it would be difficult to quantify and interpret change in multi-temporal images since there would be no clear baseline to compare spectral reflectance differences between the same ground objects. In particular, remote sensing has been avoided for multitemporal applications because of radiometric calibration problems, real or perceived.

Atmosphere will affect EMR (Electromagnetic Radiation) in three ways (absorption, transmission and scattering). Atmospheric distortion can occur anywhere in information flow (Sun → Surface → Sensor). Atmospheric conditions weaken the intensity of sunlight incident on the sensor and consequently affect the radiometric fidelity of the imagery. Manned aerial photographs are significantly exposed to distortion due to the atmosphere. This is because sensors located at an altitude of 300 m or more are affected by various atmospheric conditions such as clouds and dust in the process of detecting electromagnetic waves reflected from the ground surface. There are many problems in ensuring radiometric fidelity so that change detection can be performed if the weather conditions are not exceptionally clear since the manned aircraft has a fundamental limitation in lowering the shooting altitude. In the case of drones, the distance between the sensor and the ground object is much closer to that of an aerial photograph, and it can take close-up pictures, so it is less affected by the atmosphere. Therefore, it is considered that the drone image guarantees better radiometric fidelity than other remote sensors. Therefore, the high radiometric fidelity means that radiometric equivalence for the change detection is high. UAVs have the advantage of flying closer to the earth surface wherein the influence of the atmosphere is not as significant. For this reason, there is no need for atmospheric corrections as it would be in traditional platforms [30]. Thus, drone imagery has frequently been analyzed to compare relative spectral differences between features with special attention to the absolute radiance or reflectance differences being imaged [40–44].

6.8 Drone Shooting and Related Observation

In designing a drone flight system, many options of sensors (such as no GPS, GPS and DGPS) affect the quality of the data that can be acquired. A successful UAV flight is one where sensors are properly used to accomplish tasks. UAV platforms can be classified according to their integrated location sensors and real-time imaging capability, which influence directly the autonomous flight performance.

High-end sensors, such as DGPS and navigation-grade IMU (Inertial Measurement Unit) have the potential for real-time geo-referencing while low-cost sensors will imply post geo-referencing. Nowadays, the autonomous flight based on defined points in a global coordinate system is a standard approach to collect the nadir drone imagery (Table 6.14). Autonomously flying UAVs provides the overlapped imagery for further photogrammetric processing. However, prior to a successful UAV operation, an extensive mission planning is necessary. This mission planning is dependent on the kind of application and in particular on the specific situation at the flight area. The autonomous flights still have to be performed with a backup pilot in line of sight (LOS) due to security of people and obstacle avoidance in certain emergency situations [28].

The aerial photographs taken by UAV platforms can be classified according to the orientation of the camera axis. The oblique imageries were usually acquired by common UAV users, while traditional nadir images were collected in a number of mapping applications. True vertical photograph is a photograph with the camera axis perfectly vertical and such photographs hardly exist in reality. The near vertical photograph is a photograph with the camera axis nearly vertical. The deviation from the vertical is called a tilt that is usually less than two to three degrees. Gyroscopically controlled mounts provide stability of the camera so that the tilt must not exceed platform-driven tolerance for further photogrammetric processing. The UAV platform operated by rotary wing allows vertical take-off and landing without the need for an available runway. Furthermore, the use of VTOL (vertical take-off and landing) systems permits the image acquisition on a hovering point, while the camera is turning in the vertical and horizontal direction [45]. For the oblique imagery control is mostly done in the manual or assisted flight mode. The oblique photograph is a photograph with the camera axis intentionally tilted between the vertical and horizontal. A high oblique photograph is tilted so much that the horizon is visible on the photograph. A low oblique does not show the horizon. The total area photographed with oblique is much larger than that of vertical photographs. 3D reconstruction for any target can be performed by drone imagery since oblique images can allow the observation of vertical structures (e.g., including transmission line and building footprints) [46–48].

Table 6.14 Example of flight log file (DJI Inspire 1)

Longitude	Latitude	Height (GPS)	Height (barometer)	Number of GPS satellites
128.7264	35.8443	47.0316	49.702	16
128.7264	35.8443	47.2684	49.7039	16
128.7264	35.8443	46.6589	49.7037	16
128.7264	35.8443	47.0159	49.7009	16
128.7264	35.8443	46.523	49.7011	16
128.7264	35.8443	46.4545	49.6984	16
128.7264	35.8443	46.5125	49.699	16
128.7264	35.8443	46.4744	49.7017	16
128.7264	35.8443	46.9396	49.7026	16

The autonomous flight is most suitable for photogrammetric data acquisition, since the planned flight route can be flown without manual operation by ground pilots. The autonomous flight capability for the application requirements can vary among the large spectrum of flight planning software and existing UAVs. The commercial mission planning packages (for instance, Pix4D Capture) usually have a function combining the classical flight planning applied in large-format aerial photography and the close range terrestrial photogrammetry. The software controls UAV while it is flying and collecting images so that the mission can be fully automated, but it is also possible to take over manual control in case of emergency situations (Fig. 6.14). With the commercial mission planning packages, it is possible to choose a mission among several parameters. It allows you to create flight plans for capturing image data and set up the main project parameters like appropriate overlap percentages, flight altitude or flight speed, the flying mode, coordinate system and camera parameters (e.g. viewing angle), the definition of the photographing target area in a graphical interface (Fig. 6.15). The photographing target area can be defined by describing the boundary in a map using a GIS system, as well as in a 3D world viewer like Google Earth, Virtual Earth etc.

The predefined flight path can be exported to Google Earth in the KML data format. This procedure allows one to check the flight path to cause possible collisions in the local environment such as super-high rise building and electric powerline. Pix4D Capture supports flexible flight mission (grid, double grid, polygonal,

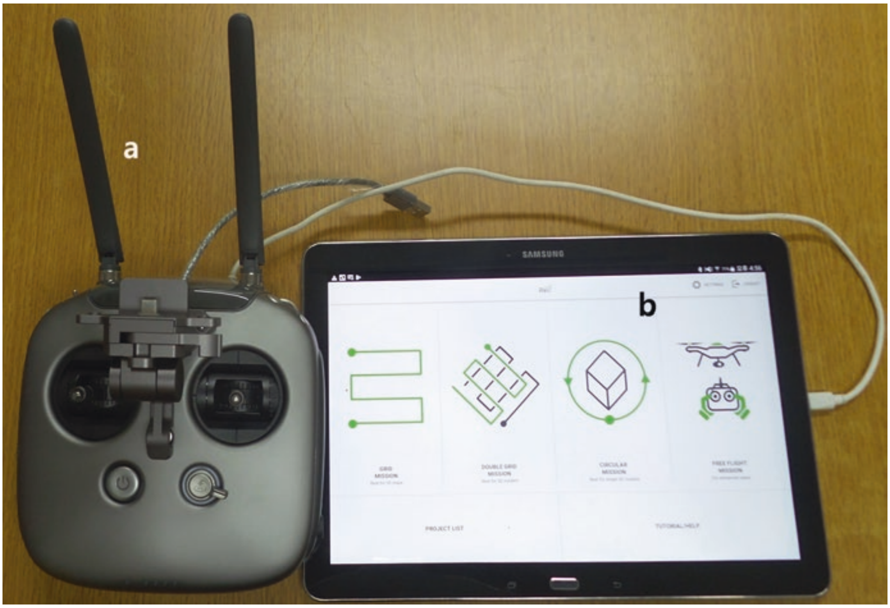


Fig. 6.14 User-interface for flight missions in the commercial UAV mission planning package, (**a**) remote controller, (**b**) flight missions (grid, double grid, polygonal, circular mission) available in Pix4D Capture

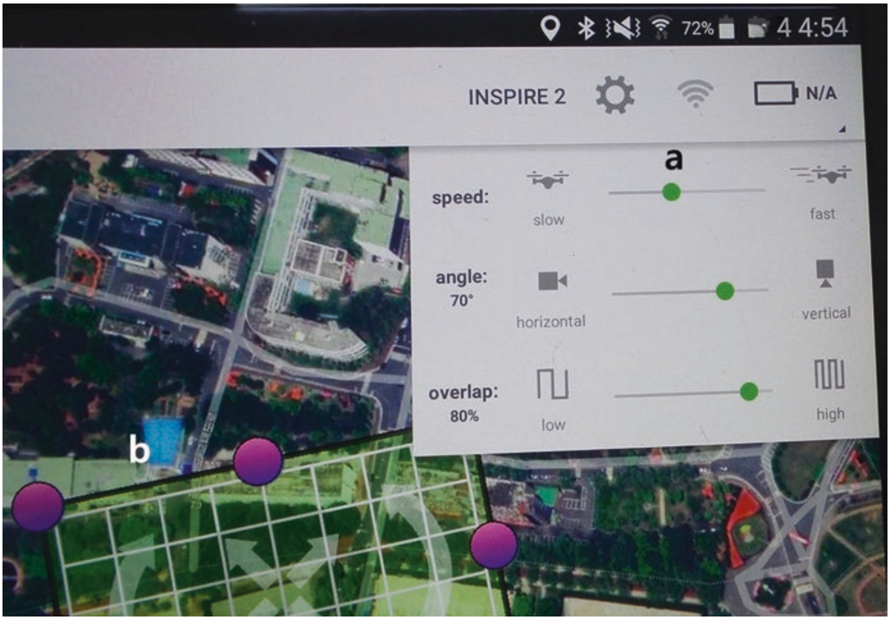


Fig. 6.15 User-interface to select flight parameters in Pix4D Capture, (**a**) Main project parameters (overlap percentage, flight speed, and camera viewing angle), (**b**) predefined flight path overlaid to Google Earth

circular mission) to accommodate diverse project requirements. There is a polygon mission to plan a project over an arbitrary and irregular area. Grid mission allows the drone to perform a flight over a rectangular field while a Double Grid mission to also fly over a rectangle but in both directions (Fig. 6.16).

The photogrammetric block is based on one or more areas of interest defined interactively by the user and consists of an origin point (start point or take-off point), a final point (home point or landing point), and an initial block direction together with the accomplishment of certain photogrammetric constraints. Strong wind disturbs UAV in realizing a perfect, preplanned flight projects. Strong wind disturbs UAV in navigating a pre-planned flight routes in autonomous navigation. In particular, in the case of a light-weight UAV (DJI Inspire 1: 2935 g), the wind causes a profound effect to stable flight. If the UAV were flying at 10 m/s speed, and the wind speed in opposition direction was 10 m/s at that time, then principally the UAV could not go to its own destination and only consumes the battery. Such instable flight will cause holes in imagery overlap and seriously influence the quality of the produced ortho-photos since it does not follow pre-defined flight route for autonomous navigation.

Temperature is the most important factor in the normal operation of a UAV-loaded battery. The flight time of the UAVs depends on battery performance, since propulsion devices such as motors and propellers are driven by the energy powered from battery. Almost all UAVs use a lithium-polymer battery (e.g. DJI Inspire 1).

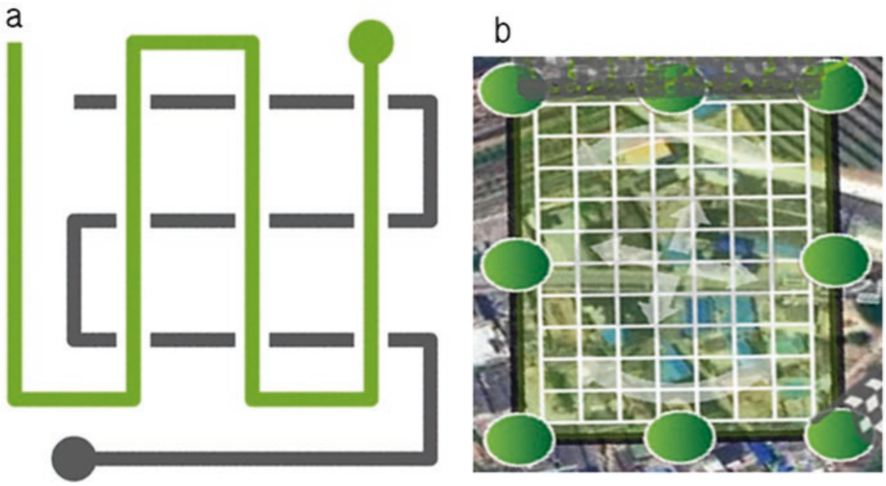


Fig. 6.16 User-interface showing Double Grid mission and a rectangular boundary (Pix4D Capture), (**a**) Double Grid mission to fly in both directions, (**b**) rectangular boundary overlaid to Google Earth

Basically, batteries produce energy through chemical reactions. But they do not react well at above or below the proper temperature range. Batteries will lose much of their capacity when exposed to cold temperature since it adversely affects chemical reactions of battery until the batteries warm up. In below 0 °C weather, the electrons slow down and the battery voltage does not come out properly. Inspire 1 User Manual indicates that the performance of the intelligent Flight Battery is significantly reduced when flying in low temperature environment (those with air temperature below 5 °C) [49].

The sunlight affects the quality of the images that are taken and too bright or dark lightning. If it is sunny, objects in the photos will be well visible but there also will be shadows. On the other hand, when the sun is not shining and it is cloudy, the terrain is uniformly exposed but also dark. A compromise between two approaches must be made to capture appropriate images. Good lighting will reduce grain, and will result in having a high shutter speed which reduces motion blur. Visual aspect of final photogrammetry products can lead to difficulties for software (such as Pix4D mapper or photoscan) to do post-processing aligning the photos.

6.9 Ortho-Photo Generation

6.9.1 Bundle Block Adjustment

A single aerial photograph presents a picture of a portion of the earth's surface. Because the single aerial photograph is limited in an area, groups of photographs are combined into mosaics to provide the area-wide pictorial view of ground coverage. However, certainly to achieve the area-wide visualization, human labor and cost required in the time-consuming mosaicking process would be the serious constraint [50]. A stereopair of the aerial photograph consists of two photos of the same object that allows it to appear in three dimensions by photogrammetric processing. The imagery is commonly collected with a 60% overlap in the flight direction (forward overlap) and 30% to the sides (sidelap) across a flight path with a wide angle lens.

Photogrammetry is the art and a science of performing accurate measurements from 3D photographs generated using overlapped 2D images. It is a tool to generate spatial and descriptive information reconstructing objects by utilizing data acquired from remote-sensor without touching targets. The output of photogrammetry is ortho-photo represented in their true positions in relation to their ground position. There are two general types of photogrammetry; aerial photogrammetry and close-range terrestrial photogrammetry. Ortho-rectification is the process of removing the image distortion induced by the sensor taking perspective view, and relief displacement for the purpose of creating a geometrically correct image. Ortho-photos can therefore be used to make direct measurements of distances, angles, positions, and areas without making additional geometric corrections for relief displacements. As imageries taken from UAV are widely available, the digital ortho-photo has become a very common part of spatial datasets. In order to generate the ortho-photo, various parameters for terrain are needed and they can be derived using either a bundle adjustment using photogrammetry or by fitting the image over some known ground control points (GCP). GCP is a point with known coordinates, that is located in the area of interest and recognizable in the photos. The location of any point in an image is labeled with two coordinates (x, y) since images are only two-dimensional. The location of any point in the real world is defined by three coordinates (x, y, z, latitude, longitude, altitude) since the real world is primarily three-dimensional. 3D models can be generated from either nadir imagery (shot vertically, straight down) or oblique imagery (from an angle to the side), but the most detailed models combine both into a single representation [51]. Overlapping images taken from a different location allow us to determine the 3D location of the point.

This process requires the position and orientation of the camera during the exposure. Bundle Block[4] Adjustment (Fig. 6.17) is a method to directly compute the relations between image coordinates and object coordinates and is a basic tool in the photogrammetric data handling. It is time consuming procedures to determine the photo orientation individually for each photo or model based on control points. All images of a block are connected together using corresponding points, “gluing” them to a mosaic which is then transformed to the GCPs [52]. It is common to place a set of reference markers with known 3D coordinates during collecting camera positions and identify them manually in the images. The photogrammetric block is based on one or more areas of interest defined interactively by the user and consists of an origin point, a final point, and an initial block direction together with the camera orientation parameters. Block adjustment not only links image coordinates with the

[4] All images covering an area and being processed in a block adjustment.

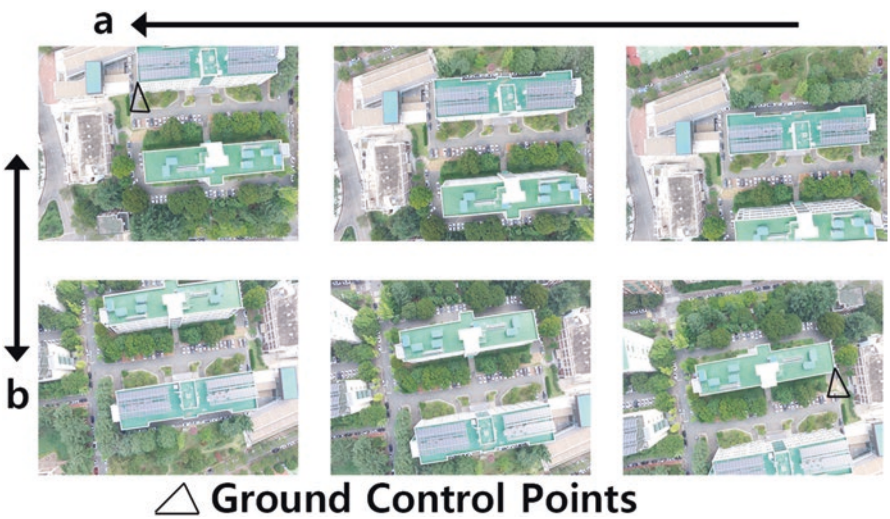


Fig. 6.17 Concept of bundle block adjustment, (**a**) end-lap (overlap between neighboring images), (**b**) side-lap (overlap between neighboring strips) Adding another image taken from a different location allows us to intersect the rays and determine the 3D location of the point where the light came from

real world location, but also connects between overlap images of a mosaic dataset. Bundle block adjustment reduces the cost of field surveying and verifies the accuracy of field observations during the adjustment process [53].

Once, the coordinates acquired by indirect (GCP) or direct (GNSS) geo-referencing are obtained, they can be processed in a bundle block adjustment. This geo-referencing can generally be done indirectly using ground control points, or directly using an on-board sensor system. The indirect geo-referencing can be performed by conventional methods, i.e. total station survey to calculate coordinates for known ground points (Northings, Eastings, and Elevations) and GNSS or acquired from other available sources, like internet map service or old maps. Since an indirect geo-referencing is very time consuming, and also not available in real time, many users would prefer a direct geo-referencing. GNSS measurements in indirect geo-referencing are the most efficient way in terms of accuracy, reliability and time.

Direct geo-referencing is used mainly when high accuracy is not needed, for example, in vegetation survey and carbon monitoring missions. Meter accuracy can be achieved when ordinary, non-RTK receivers are used while it can be improved to a couple of centimeters when RTK is applied. Similarly, the Inertial Navigation System (INS), as well as the Inertial Measurement Unit (IMU) plays an important role in a quality of a direct geo-referencing. Inertial Navigation System (INS) is equipped with motion sensors (accelerometers), rotation sensors (gyroscopes) and magnetometers and is responsible for collecting data about forces acting on the aircraft. There is also a barometer, which determines the actual altitude of UAV over the starting point. They are essential for fixing UAV's position and providing the highest possible accuracy of a final ortho-photo product.

6.9.2 *Self-Calibrating Bundle Adjustment: Structure from Motion*

In order to relate the UAV image to a world coordinate system, knowledge for inner geometry and exterior orientation of the camera is needed. Exterior orientation establishes the position of the camera projection center in the ground coordinate system. This process is to relate image coordinates in the sensor plane (two dimensions based on central projection) to the object point in the ground coordinate system (in three dimensions). They can be achieved by two approaches: classical photogrammetric workflow or computer vision (CV) technique. However, the former approach is mostly applicable to high-level classical airborne photogrammetry since it relies on known camera positions based on field surveying. The use of computer vision software is an alternative technique to create 3D models from photographs that evolved considerably in recent years [13]. To acquire approximate EOE (Exterior Orientation Elements), namely position of camera when the image was taken, the measurements are performed during the flight by on-board equipment. This information greatly reduces computation time needed for image matching. Even UAV equipped with simple C/A (coarse) receiver and low-cost INS system provides data that can be advantageous and useful. The accuracy of this devices and final required accuracy determine how EOE can be further used in bundle block adjustment, either as approximate values or for direct georeferencing. This is called self-calibration or self-calibrating bundle adjustment. The whole process of determining camera parameters and 3D structure is called 'Structure from Motion (Fig. 6.18). This alternative is cost effective and easy, compared to rigorous photogrammetry. The technique also only requires a few control measurements and the processing is automated.

Computer vision software integrates state-of-the-art SfM (Structure from-Motion) algorithms to generate/reconstruct very dense and accurate point clouds from a series of overlapping photographs (Fig. 6.19) [15, 54, 55]. Instead of a single stereo pair, the SfM technique requires a series of overlapping photographs as input to feature extraction and 3D reconstruction algorithms [13]. Even if the coordinates of the photos are not accurate enough for Ground Control, it can be highly beneficial using them in computations. In the first step, when photos are aligned/matched to each other, this information can be applied and serve as additional data, so that the software knows on which pictures it should look for matches and which can be omitted. It can greatly improve performance and reduce time consumed for the process. The image stitching methods treat the world as planar and simply stitch the different images together by finding their relative positions [56].

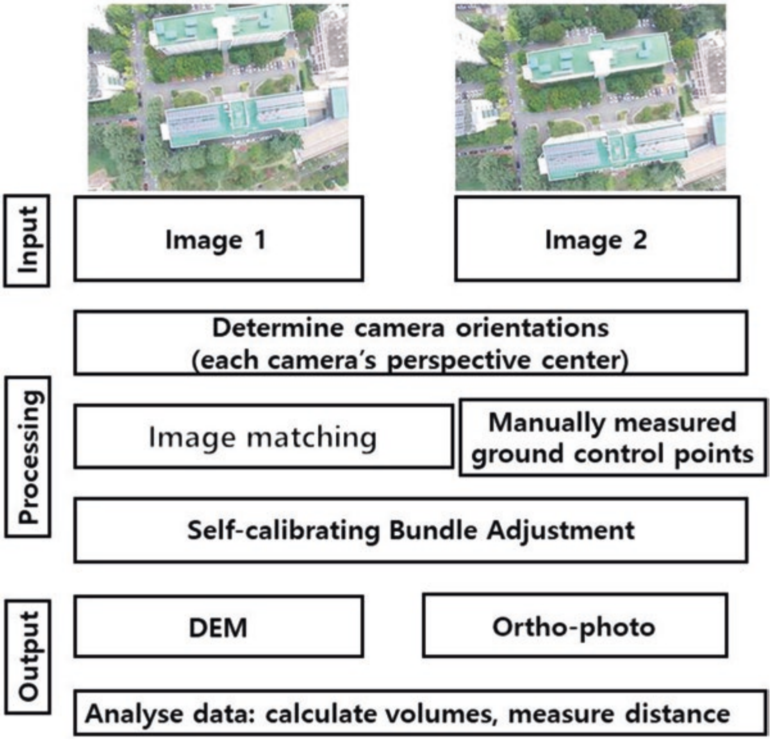


Fig. 6.18 Schematic representation of self-calibrating bundle adjustment through Structure from Motion

Various commercial software packages are available on the market, like Agisoft Photoscan, Pix4D Mapper and also open-source MicMac. They rely on tie point generated automatically based on feature-matching. The difference between classical photogrammetric approach and computer vision technique lies in fact that correspondences between images are computed automatically and the camera positions (Fig. 6.20) together with the scene structure are calculated simultaneously. They are usually obtained in an iterative bundle block adjustment that ensures statistically correct and robust solution. It is required that images are taken with sufficient overlap, so highly redundant number of connections is generated. However, there is also no need of using a metric camera, because its parameters are optimized during camera calibration procedure.

Agisoft PhotoScan is a stand-alone software package created and developed by Russian company founded in 2006. It can integrate vertical, oblique and motion imagery. PhotoScan imagery can both generated in controlled and uncontrolled situations with almost any camera ranging from low cost to highly professional medium-format cameras. It is designed to cope with photogrammetric computer vision projects such as area mapping or 3D object digitization task. Photoscan fol-

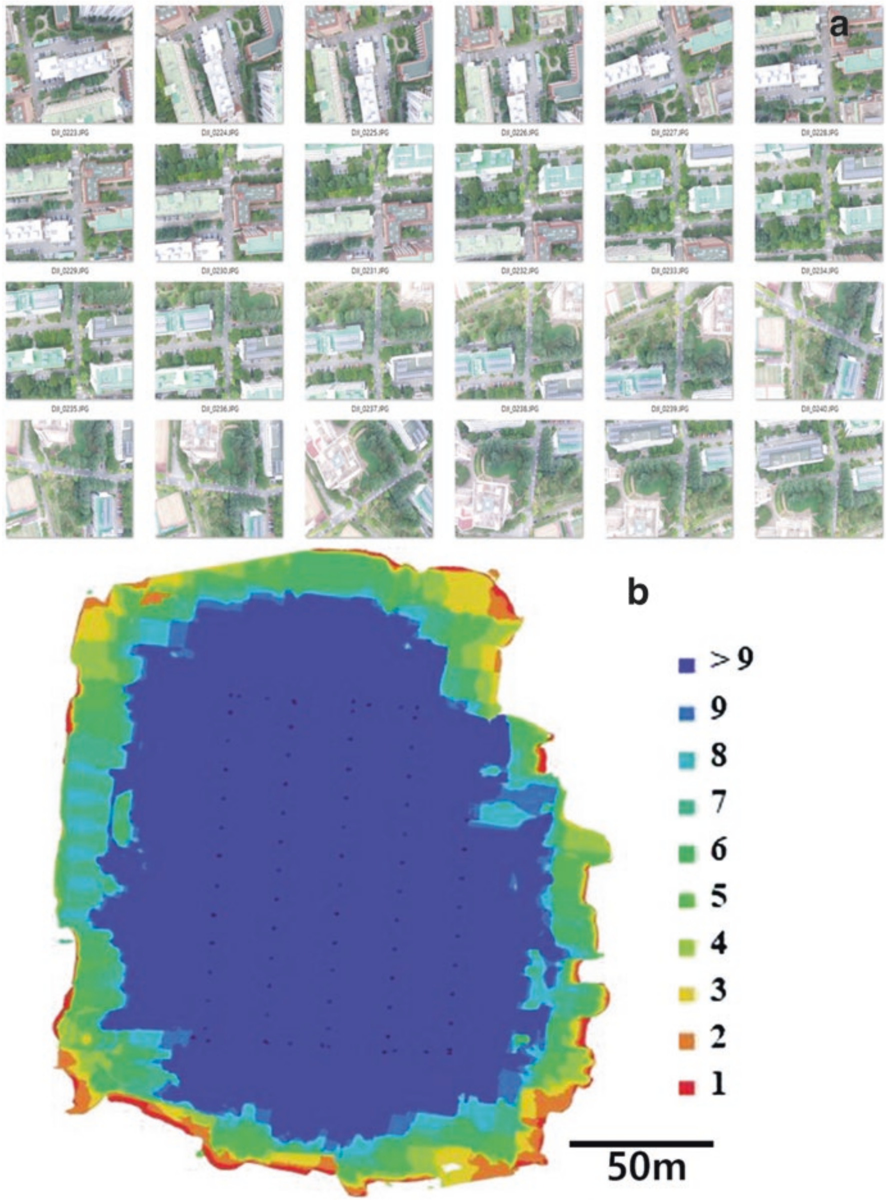


Fig. 6.19 Camera positions estimated using the scene structure of overlapping photographs, (**a**) 70% overlapped image taken from a different location (**b**) Camera locations and image overlap. Estimated camera locations are marked with a black dot. The overlapping of the photographs is displayed in color. The cooler color has a high degree of overlapping while warmer color represents a low degree of overlapping. Number of images (76), Flying altitude (100 m), Ground spatial resolution (3.61 cm/pixel)

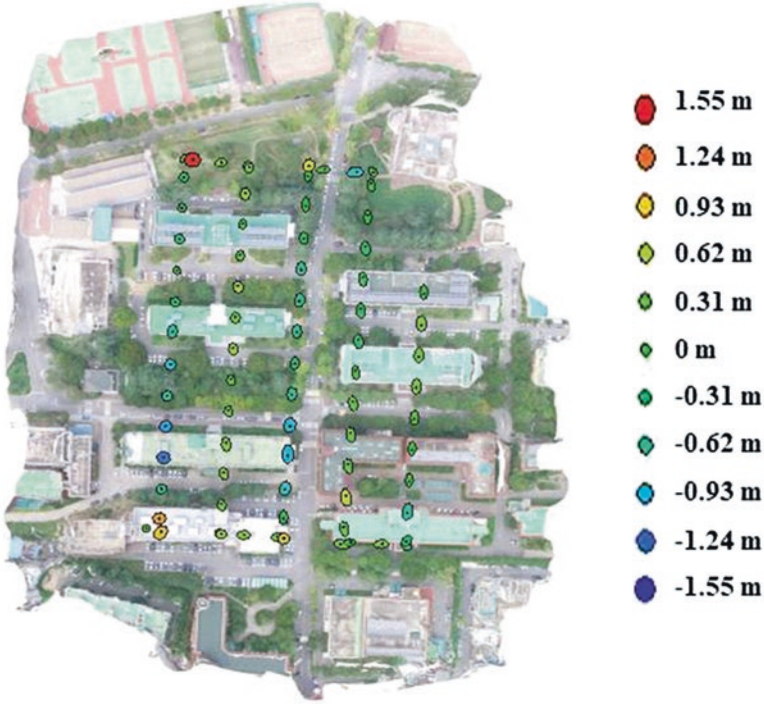


Fig. 6.20 Camera locations and error estimates. Z error is represented by ellipse color while X, Y errors are represented by ellipse shape. The error ellipse more circular, the more improved X, Y accuracy: Estimated camera locations are marked with a black dot. Average camera location error (m): X (0.473813), Y (1.24614), Z (0.51574), **Total (1.42946)**

lows a common SfM workflow through the steps of feature identification, matching and bundle adjustment to reconstruct the camera positions and terrain features as shown below:

1. Loading photos acquired into the PhotoScan software.
2. Inspection of loaded images and removal of unnecessary images
3. Alignment of the photos including the import of GCP

   Agisoft PhotoScan first carries out the automatic process of photo alignment by searching for common points on photographs. This alignment of the photos process starts with feature identification and image matching using the approximate GPS coordinates of the camera stations. Photoscan also performs automatic camera calibration as part of this step.
4. A sparse point cloud created through initial bundle adjustment

   Once photo alignment is completed, the software generates a sparse point cloud with a set of associated camera positions (orientation of each camera station), internal camera parameters, the XYZ/3D coordinates of all image features (tie points). A sparse point cloud is simply such a point cloud with relatively few points. A sparse cloud may be adequate to produce a less detailed 3D model that doesn't need to be precisely georeferenced.

5. A dense point cloud set to high quality

   Agisoft PhotoScan requires this set of camera positions and an optimized sparse point cloud to advance in the process of producing a dense point cloud [51].

6. Next, the software builds a 3D polygonal "mesh" based on the dense point cloud, representing the surface of the object (a net drawn over a three-dimensional object).

   3D point clouds are mostly generated directly from stereo image matching, processing imagery algorithms by overlapping (terrestrial or airborne). This means that it is possible to acquire relevant ortho-mosaic parameters (camera location, overlap percentage, tie point coordinates) at low-cost, from 3D point cloud data [57, 58].

7. Builds texture over the 3D mesh, giving a sense of depth and volume.

   In the final step, the software lays texture taken from the original photographs over the 3D mesh, giving the original flat imagery a sense of depth and volume. The final outcome is a detailed 3D model (Fig. 6.21) that can be used for a variety of quantifiable or specialized analyses [51]. Finally, quality report is generated with information such as project summary, camera calibration details, accuracy of Ground Control Points and Check Points and other processing options. The ortho-mosaic generated from the drone imagery provides a high resolution visual summary of the target from a low altitude vantage point, revealing tiny details. The UAV-SfM approach offers economical alternatives to other traditional methods such as the ground control using Real Time Kinematic (RTK) GPS terrestrial surveys. The UAV-SfM approach plays an efficient role in rapidly producing

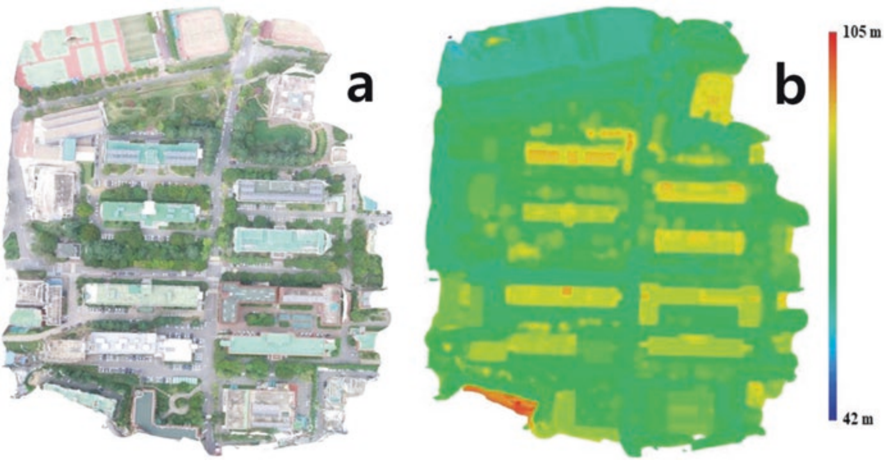


Fig. 6.21 Ortho-rectified imagery and 3D surface map, (**a**) Ortho-photo (**b**) Reconstructed digital elevation model (spatial resolution: 14.5 cm/pixel)

large-scale topography (higher temporal or spatial resolution) or detailed 3D models, practically on demand (high frequency). The spread of low-cost platforms combined with tiny MEMS cameras and GNSS systems offering point cloud coordinates constitutes some of the main characteristics for the success of this UAV-SfM technology [59].

6.10 Conclusion

The advancement and development of UAV imaging sensor technology over the last few years provided a considerable advantage of the current CPS framework in comparison to the traditional manned airborne sensor or in-situ survey for hyper-localized target. The narrow target requires extremely low-level flight and longer zoom lens, which almost inevitably result in serious image motion. Several previous studies based on manned aerial photography have noted the difficulty of obtaining large scale imagery free of image motion. This book emphasizes low-height drone photography (LHDP) based on lightweight and inexpensive smaller sensor (e.g. 10 mm) and platforms operated at relatively low height (100 m or so).

Off-the-shelf and low cost imaging sensor can provide centimeter-level spatial resolution imagery while location accuracy products of sub-meter level could be collected with low cost location sensor. In addition, the user can collect and process, very rapidly, realistic 3D data at a low cost, especially when compared with traditional methods. Computer vision based SfM allows the user to combine the virtual data to the real world, using UAV imageries. Each sensor type is being continually improved by combining infrared, and synthetic aperture radar to provide better spectral resolution in numerous applications.

Unmanned imaging sensors will be an area of both spatial resolution and spectral resolution evolution over the next 10–15 years [60]. The competition between USA and Russia to occupy the global leadership in space exploration was the driving force of the first remote sensing era. The remote sensing demand to obtain technological competitiveness in the global market such as a self-driving flying car is leading to the second remote sensing era. Popularized with the rapid development of location/imaging sensor and network technology, drone remote sensing will affect deeply our life style. In the near future drone remote sensing will become a necessity shooting and sharing aerial photographs in daily life of the general public (like current SMS, short message service).

References

1. Dickerson K (2015) Companies want to launch satellites that can see a phone in your hand from space. Business Insider
2. Bracher A, Sinnhuber BM (2009) An introduction to remote sensing. http://www.iup.uni-bremen.de/~bms/remote_sensing/remote_sensing_chap5.pdf. Accessed 30 Sept 2018

3. Natural Resources Canada (2015) Spatial resolution, pixel size, and scale. Natural Resources Canada. https://www.nrcan.gc.ca/node/9407. Accessed 22 Sept 2018
4. Strüder L, Davis JM, Hartman R, Holl P, Ihle S, Kalok D, Soltau H (2017) Spatial resolution smaller than the pixel size? Yes we can! Microsc Microanal 23(S1):90–91. https://doi.org/10.1017/S1431927617001131
5. A Canada Centre for Remote Sensing (2016) Tutorial: fundamentals of remote sensing. Natural Resources Canada. http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/resource/tutor/fundam/pdf/fundamentals_e.pdf. Accessed 30 Sept 2018
6. Mavi HS, Tupper GJ (2004) Agrometeorology: principles and applications of climate studies in agriculture. CRC Press, Boca Raton
7. Karpowicz J (2016) Figuring out aerial surveying with a Drone instead of arguing about photogrammetry vs LiDAR. Commercial UAV News. Diversified Communications, Free Street, Portland, ME
8. Veys C, Hibbert J, Davis P, Grieve B (2017) An ultra-low-cost active multispectral crop diagnostics device. In: SENSORS, 2017. IEEE, pp 1–3
9. Wikipedia (2018) Hyperspectral imaging. https://en.wikipedia.org/wiki/Hyperspectral_imaging. Accessed 30 Sept 2018
10. Smith RB (2012) Introduction to remote sensing of environment (RSE). MicroImages, Inc. http://www.microimages.com/documentation/Tutorials/introrse.pdf. Accessed 30 Sept 2018
11. Aber JS, Marzolff I, Ries JB (2010) Chapter 1 – introduction to small-format aerial photography. In: Aber JS, Marzolff I, Ries JB (eds) Small-format aerial photography. Elsevier, Amsterdam, pp 1–13. https://doi.org/10.1016/B978-0-444-53260-2.10001-8
12. Neumann KJ (2008) Trends for digital aerial mapping cameras. Int Arch Photogram Rem Sens Spatial Info Sci (ISPRS) 28:551–554
13. Boon MA, Greenfield R, Tesfamichael S (2016) Unmanned aerial vehicle (UAV) photogrammetry produces accurate high-resolution orthophotos, point clouds and surface models for mapping wetlands. S Afr J Geol 5(2):186–200
14. National Aeronautics and Space Administration (2018) Data processing levels. NASA. https://science.nasa.gov/earth-science/earth-science-data/data-processing-levels-for-eosdis-data-products/. Accessed 22 Sept 2018
15. Verhoeven G (2011) Taking computer vision aloft–archaeological three-dimensional reconstructions from aerial photographs with photoscan. Archaeol Prospect 18(1):67–73
16. Nogueira K, dos Santos JA, Cancian L, Borges BD, Silva TS, Morellato LP, Torres RdS (2017) Semantic segmentation of vegetation images acquired by unmanned aerial vehicles using an ensemble of ConvNets. In: Geoscience and remote sensing symposium (IGARSS), 2017 IEEE International, pp 3787–3790
17. Ammour N, Alhichri H, Bazi Y, Benjdira B, Alajlan N, Zuair M (2017) Deep learning approach for car detection in UAV imagery. Remote Sens 9(4):312
18. Crisp S (2013) Camera sensor size: why does it matter and exactly how big are they? New Atlas. GIZMAG PTY LTD 2018
19. Connor JO, Smith M (2016) Selecting cameras for UAV surveys. GIM Int 30:34–37. Geomares Publishing
20. Um J-S (1999) Airborne video as a remote sensor for linear target: academic research and field practice. Korean J Remote Sens 15(2):159–174
21. Um J-S, Wright R (2000) Effect of angular field of view of a video sensor on the image content in a strip target: the example of revegetation monitoring of a pipeline route. Int J Remote Sens 21(4):723–734
22. Um J-S, Wright R (1999) 'Video strip mapping (VSM)'for time-sequential monitoring of revegetation of a pipeline route. Geocarto Int 14(1):24–35
23. Um J-S, Wright R (1998) A comparative evaluation of video remote sensing and field survey for revegetation monitoring of a pipeline route. Sci Total Environ 215(3):189–207
24. Um J-S, Wright R (1996) Pipeline construction and reinstatement monitoring: current practice, limitations and the value of airborne videography. Sci Total Environ 186(3):221–230

25. Ramos TB, Caeiro S, de Melo JJ (2004) Environmental indicator frameworks to design and assess environmental monitoring programs. Impact Assess Project Apprais 22(1):47–62. https://doi.org/10.3152/147154604781766111
26. Caeiro S (2004) Environmental data management in the Sado estuary: weight of evidence to assess sediment quality. Universidade Nova de Lisboa
27. Akanmu A, Anumba C, Messner J (2014) Critical review of approaches to integrating virtual models and the physical construction. Int J Confl Manag 14(4):267–282. https://doi.org/10.1080/15623599.2014.972021
28. Aber JS, Aber SW, Pavri F (2002) Unmanned small format aerial photography from kites acquiring large-scale, high-resolution, multiview-angle imagery. Int Arch Photogramm Remote Sens Spat Inf Sci 34(1):1–6
29. Park S-I, Um J-S (2018) Differentiating carbon sinks versus sources on a university campus using synergistic UAV NIR and visible signatures. Environ Monit Assess 190(11):652. https://doi.org/10.1007/s10661-018-7003-x
30. Adão T, Hruška J, Pádua L, Bessa J, Peres E, Morais R, Sousa JJ (2017) Hyperspectral imaging: a review on UAV-based sensors, data processing and applications for agriculture and forestry. Remote Sens 9(11):1110
31. Keller J (2014) Infrared sensors blending with signal processing to yield new levels of surveillance. Military & Aerospace Electronics
32. Calderón R, Navas-Cortés J, Zarco-Tejada P (2015) Early detection and quantification of verticillium wilt in olive using hyperspectral and thermal imagery over large areas. Remote Sens 7(5):5584
33. Uto K, Seki H, Saito G, Kosugi Y (2013) Characterization of rice paddies by a UAV-mounted miniature hyperspectral sensor system. IEEE J Sel Top Appl Earth Obs Remote Sens 6(2):851–860. https://doi.org/10.1109/JSTARS.2013.2250921
34. Keller J (2012) Advanced military night-vision sensors rely on sensor fusion, networking, and signal processing. Military & Aerospace Electronics
35. Markus Melin ACS, Paul Glover-Kapfer (2017) Remote sensing: lidar. WWF Conservation Technology Series, United Kingdom
36. Lin Y, Hyyppa J, Jaakkola A (2011) Mini-UAV-borne LIDAR for fine-scale mapping. IEEE Geosci Remote Sens Lett 8(3):426–430
37. Agishev R, Comerón A (2018) Assessment of capabilities of lidar systems in day-and night-time under different atmospheric and internal-noise conditions. In: EPJ Web of conferences. EDP Sciences, p 01018
38. Lefsky MA, Cohen WB, Parker GG, Harding DJ (2002) Lidar remote sensing for ecosystem studies lidar, an emerging remote sensing technology that directly measures the three-dimensional distribution of plant canopies, can accurately estimate vegetation structural attributes and should be of particular interest to forest, landscape, and global ecologists. Bioscience 52(1):19–30. https://doi.org/10.1641/0006-3568(2002)052[0019:LRSFES]2.0.CO;2
39. Chuvieco E, Vega JM (1990) Visual versus digital analysis for vegetation mapping: some examples on Central Spain. Geocarto Int 5(3):21–30. https://doi.org/10.1080/10106049009354265
40. Parasuraman R, Cosenzo KA, De Visser E (2009) Adaptive automation for human supervision of multiple uninhabited vehicles: effects on change detection, situation awareness, and mental workload. Mil Psychol 21(2):270–297
41. Cook KL (2017) An evaluation of the effectiveness of low-cost UAVs and structure from motion for geomorphic change detection. Geomorphology 278:195–208
42. Lucieer A, de Jong SM, Turner D (2014) Mapping landslide displacements using structure from motion (SfM) and image correlation of multi-temporal UAV photography. Prog Phys Geogr 38(1):97–116
43. Sui H, Tu J, Song Z, Chen G, Li Q (2014) A novel 3D building damage detection method using multiple overlapping UAV images. Int Arch Photogramm Remote Sens Spat Inf Sci 40(7):173

44. Chen B, Chen Z, Deng L, Duan Y, Zhou J (2016) Building change detection with RGB-D map generated from UAV images. Neurocomputing 208:350–364
45. Eisenbeiß H (2009) UAV photogrammetry. University of Technology Dresden
46. Schenk T (2005) Introduction to photogrammetry. The Ohio State University, Columbus. http://www.mat.uc.pt/~gil/downloads/IntroPhoto.pdf. Accessed 30 Sept 2018
47. Rossi P, Mancini F, Dubbini M, Mazzone F, Capra A (2017) Combining nadir and oblique UAV imagery to reconstruct quarry topography: methodology and feasibility analysis. Eur J Remote Sens 50(1):211–221. https://doi.org/10.1080/22797254.2017.1313097
48. Jiang S, Jiang W, Huang W, Yang L (2017) UAV-based oblique photogrammetry for outdoor data acquisition and offsite visual inspection of transmission line. Remote Sens 9(3):278
49. DJI (2015) Inspire 1 user manual V1.0
50. Um J-S (1997) Evaluating operational potential of video strip mapping in monitoring reinstatement of a pipeline route. University of Aberdeen, Aberdeen
51. Greenwood F (2015) How to make maps with drones. Drones and aerial observation, July, pp 35–47
52. Linder W (2009) Digital photogrammetry. Springer
53. Um J-S, Wright R (1999) Video strip mosaicking: a two-dimensional approach by convergent image bridging. Int J Remote Sens 20(10):2015–2032
54. Westoby MJ, Brasington J, Glasser NF, Hambrey MJ, Reynolds JM (2012) Structure-from-motion' photogrammetry: a low-cost, effective tool for geoscience applications. Geomorphology 179:300–314. https://doi.org/10.1016/j.geomorph.2012.08.021
55. James M, Robson S (2012) Straightforward reconstruction of 3D surfaces and topography with a camera: accuracy and geoscience application. J Geophys Res Earth Surf 117(F3):F03017
56. Vasisht D, Kapetanovic Z, Won J, Jin X, Chandra R, Sinha SN, Kapoor A, Sudarshan M, Stratman S (2017) FarmBeats: an IoT platform for data-driven agriculture. In: 14th USENIX symposium on networked systems design and implementation, Boston, MA, USA, 2017. USENIX Association, pp 515–529
57. Tenedório JA, Rebelo C, Estanqueiro R, Henriques CD, Marques L, Gonçalves JA (2016) New developments in geographical information technology for urban and spatial planning. In: Geospatial research: concepts, methodologies, tools, and applications. IGI Global, pp 1965–1997
58. Marques LFdESC (2017) Augmented valuation of cultural heritage through digital representation based upon geographic information technologies: the case study of Lisbon aqueduct system within an augmented reality environment. Universitat Politècnica de Catalunya, Portugal
59. Nex F, Remondino F (2014) UAV for 3D mapping applications: a review. Appl Geomatics 6(1):1–15
60. Howard C (2012) Unmanned, sensor-laden, and ubiquitous. Military & Aerospace Electronics. Military & Aerospace Electronics

Chapter 7
Valuing Cyber-Physical Bridging Intensity of Drone

Abstract Bi-directional coordination between virtual models and the physical system has the potential to improve the operation of diverse social infrastructures (road, building, energy, factory, etc.) through real-time progress monitoring, information exchange, consistency maintenance tracking, and sustainable real-time documentation practices. Two huge industries (IoT and drone) are expected to be closely linked to each other in the future. IoT technology connects physical things in the real world and virtual things in the cyber environment through sensors and communication technologies. It is a future internet infrastructure technology that can provide various services such as data sharing, remote manipulation, object tracking, etc. through the linkage of objects, data, and people in the physical space and virtual space. The purpose of this chapter is to outline advantages and values of drone in comparison to the existing methods in the cyber-physical bridging intensity framework and to explore the realistic potentials between the autonomous driving versus flying.

7.1 Introduction

The Cyber-Physical systems approach consists of two key elements: a physical to cyber bridging and a cyber to physical bridging [1]. The bridging involves linking the cyber world (e.g., information, communication, and intelligence) with the physical world through sensors/data acquisition technologies and actuators to form a closed loop or feedback system [2]. The physical to cyber bridging is the sensing process using sensors as the technological instrument to collect information about the real life phenomenon. The cyber to physical bridging represents the actuation which shows how the sensed information physically controls real life activities [1]. The actuation process is a concept that existed in the information age. However, connecting the cyber and the physical world through sensors is the concept that emerged as the core technology of the fourth revolution. Sensor technology is spreading explosively as it is becoming a core technology connecting the cyber and physical worlds: such as smart phones, drones and environmental sensors (air quality monitors), health sensor (car seats with heart-rate monitors, desks with thermal sensors), etc. Clearly, traditional technologies related to information

J.-S. Um, *Drones as Cyber-Physical Systems*,
https://doi.org/10.1007/978-981-13-3741-3_7

collection will undergo radical changes from sensor technology that links the cyber and physical worlds.

Currently, a variety of company vehicles are working to develop the same technology at the same street corner in Silicon Valley. These cars, each from a different company are committed to developing high-precision mapping technology as an on-board navigation guide for autonomous vehicles [3]. Cartographers for self-driving car today no longer use compasses, rulers and graph paper, but an endless supply of data [4] from the cyber-physical bridging system. Mapping technology is emerging as the core technology of the fourth industrial revolution due to cyber-physical bridging. For instance, South Korea plans to introduce a unique address system for delivery drone and autonomous driving. A unique address will be assigned to each parking space so that the autonomous vehicle will be able to find it by simply recognizing the address. The drone courier service is being prepared through the address system displaying the position and the height of the courier box.

Self-driving drone and cars as representative product bridging between the cyber and physical world bring together a bunch of really interesting technologies – such as a sensor driven machine vision and intelligence [5]. Sensor driven data collection is very different from traditional surveillance and monitoring concerns of information society. The notion of a “sensor society” [6] could be projecting realistic future by replacing information society approach, in the sense of explaining all aspects of cyber and physical bridging. The information society has accepted as the friendly concept in both the IT literature and popular media articles. The shifting frame of the “sensor-society” from the information society takes place when the sensor based monitoring becomes the rule of the society. Uncertainties in technology and future outcomes for cyber-physical bridging can mean both an opportunity and a risk. We need to handle with the current situation that has to create a constantly updated dynamic real-time map for non-human agents. Mapping for the machine or AI agents involves investigations into the most appropriate use of fusion sensors for spatial data capture and the use of these sensed spatial data for feedback control [7]. This cyber-physical bridging offers opportunities for adequate monitoring and feedback control of physical activities, which is important for life-cycle management of the real life system such as the self-driving car [8]. Further, with an increased emphasis on real-time database building for various CPS operations, such bi-directional bridging has great potential to be integrated into the distributed/collaborative physical system (DCPS) [7].

7.2 Importance of Sensor Fusion

CPS is a system that operates by itself by combining position and imaging sensor. Ubiquitous feedback monitoring by combining position and imaging sensor is of increasing interest in cyber-physical systems (CPSs) [9]. Drones have proved their value in the cyber-physical bridging observations, being able to flying into places where a human pilot would be at great risk. Self-driving car is currently receiving attention greatly and being evaluated as a representative of cyber-physical bridging. The high resolution mapping procedure for the self-driving car provides a detailed description in the cyber-physical bridging such as location and imaging sensor approach. Such sensor fusion allows mapping industry to focus on the simultaneous IOT sensing while being away from physical targets, and performing time-lapsed sensing for the real-life system. Spatial big-data from fusion sensors can be acquired at different times concurrently in an ongoing project and compared for progress monitoring.

7.2.1 Concepts of Sensor Fusion

The term "sensor fusion" is generally understood in a broader sense as the process that intelligently combines signal acquired by multiple sensors. The objective of sensor fusion is to combine measurements from different sensors to improve the quality of information since the combined information becomes more valuable than the information from each individual sensor [10]. Successful sensor fusion can be observed everywhere, even in our pockets and a good example can be derived from the smartphone [11] that combines GPS with inertial sensors (such as, accelerometers and gyros) to estimate absolute position. Sensor fusion is a key to the success or failure of these smart machines. Our brain receives the signal from many sensors (vision, touch, smell, hearing and sound) and has always combined several signals from different sensors to make a decision. Humans can sense potential danger by combining several signals from different sensors such as vision, hearing and smell etc. No human can sense poisonous chemicals by vision alone, but the poisonous chemicals can be detected by a combination of smell and taste sensors. Industrial sensor combines vision and location sensors, and it has close resemblance to human sensor fusion [12] that compensate the lack of vision with a combination of other types of sensors such as hearing.

Sensor fusion generates optimal educated guess, given the available data. Let's look at an example of humans that live in a world of edible leaf vegetables. They are equipped with a sensor for 'color' (red, green, yellow, brown), a sensor for 'shape' (round, oval) and a sensor for 'size' (small, large) with which it tries to infer the edibility of different leaf vegetables. They also have a means of measuring the real edibility of leaf vegetables by eating it and observing the body response. All leaf vegetables are encountered with equal probabilities. Some of these leaf vegetables are edible, others are not.

When a person moves, we must generate reliable estimates of our own position and changes in the environment from available sensory signals. Large proportions (estimated 30–50%) of the human brain are involved in the processing of visual information. The senses which tell us something about our position, orientation and motion in space are on one hand the visual sense (optical flow, and location and change of location of identified objects). We perceive self-motion visually by the change of location of identified objects in the visual field. There are tracking neurons in the visual system that fire upon detection of motion [13]. Another sense which tells us specifically about self-motion is the sense of balance and spatial orientation in the inner ear. It measures both the direction of linear acceleration and angular rotations of the head. The combined output of these visual features forms a map showing where most of our attention goes in a scene [13].

The neural processes used to combine information from different senses do not differ fundamentally from those that are involved in the processing of information from several sensors. Let's look at real example where the location of a moving car in space should be estimated from both visual cues (imagery on the eye) and auditory cues (inter aural time delay for the car's engine sound) to be able to point to the car. To find out where the car is in relation to the wheel, the hearing clue of the ears and the visual clue of the eyes has to be used to align the information of both senses. The result could be a spatial probability map for each auditory and visual modality which assigns a probability that "the car is there" to specific location.

7.2.2 Sensor Fusion in Self-Driving Car

Transportation sector is the fundamental backbone that promises economic prosperity of the nation and personal wellbeing. It is expected that advances in CPS technology in recent decades (or years) can completely change the landscape of transport. The self-driving car is one such disruptive technology that may enter real life in the near future, and this is also a good example of a hybrid artificial intelligence system. There are also autonomous driving ships and airplanes that are soon likely to be near our everyday lives. One of the most important aspects of a self-driving car is to know where it is. The eyes of the vehicle are sensor systems. In technical terms, this is called localization. Localization essentially places at the foundation element of autonomous cars. The performance of self-driving car greatly depends on the reliability of technologies observing its surrounding, including self-localization and perception of obstacles. Humans rely on their eyes to perceive their surrounding landscape and can drive cars by using visual information only. However, localization in the self-driven car cannot be achieved from a single sensor. It is considered to be a fundamental approach for automated driving to integrate several sensors. For instance, there are inherent limitations when relying on a single sensor to capture a scene. A webcam works well in monitoring a person walking along the road in front of a car. But as soon as the user leaves this hot-spot, he is out of the coverage area of the functional camera. By increasing the number of cameras, the working range of the vision network can accommodate a much wider area and many of the drawbacks of single camera vision can be avoided.

These systems, known as Advanced Driver Assist Systems (ADAS), use a combination of advanced sensors, such as stereo cameras and long and short-range RADAR, 3D Maps and GNSS technologies to enable cars to monitor and respond to their surroundings. Such sensor-based systems offer varying degrees of assistance to the driver, such as lane-keeping and warning systems, adaptive cruise control, and parking assistance. The fusion of available sensors and artificial intelligence is

Table 7.1 Localization function of sensors and map equipped in self-driving car

Category	Sensors	Driving state of vehicle	Surrounding object classification
Location sensor	Radar and lidar	X	
	GNSS	X	
	Positioning with land based mobile phone (A-GPS)	X	
	INS	X	
	Wheel speed sensors	X	
3D real-time digital map	Location and identifying surrounding	X	X
Imaging sensor	Camera (mono, stereo, 3D)		X
	Camera Infra-red		X
	Camera radar and lidar		X

expected to be capable of seeing and understanding the surroundings of the vehicle as accurately as a human being can. The fusion of available sensors and artificial intelligence is also expected to suggest new solutions not only for self-driving car, but for drone. The primary advantage in using CNN(Convolutional Neural Network) in vision based localization is its ability to preprocess images through its layers. CNNs have proved to be more effective in matching images or identifying objects in recent years and may make traditional feature detection techniques obsolete in future years. The disadvantage of CNNs lie in their requirement of huge training datasets making it computationally expensive during training. However, despite arduous training time, processing test frames is extremely efficient making it suitable for real time applications. Most of the sensors used for self-driving car can be classified into two types (Table 7.1). Based on the physical phenomenon they measure, they could be classified as imaging sensors and location sensors. Examples of location sensors are GNSS, INS, laser based, radar and ultrasonic sensors. Imaging sensors can be vision based cameras covering diverse spectrum such as visible, near-infrared, thermal, infrared. Either by actively probing the environment or passively perceiving the environment, they can be active sensors and passive sensors. Active sensors send the radiations in order to detect the targets whereas, passive sensors perceive the information based on the illumination of the environment.

7.2.3 Location Sensors in Self-Driving Car

There is no dominating positioning technology. Hybrid positioning is the answer (Table 7.2). The update rate of low cost GNSS (about 1 Hz) often limits the update frequency of position and velocity measurements. Inertial sensors can be used to maintain positioning update rate and provide increased resolution between GNSS fixes. Inertial sensors can also be used to extrapolate position information when the GNSS signal is lost due to poor satellite visibility. GNSS systems have the capability to maintain positioning robustness when error exponentially grows as vehicle INS data is continuously updated.

Table 7.2 Summary of positioning technologies used in self-driving car

Category	Satellite-based	Network-based	IMU (Inertial measurement units)
Accuracy	3–30 m	2–50 m	N/A
Hardware	Additional hardware is required	Utilize existing infrastructure such as base stations	Additional hardware is required
Infrastructure	required	required	Unnecessary
Coverage	Large	Limited	N/A
TIFF (Time To First Fix)	Slow	Quick	Quick

The Radar stands for Radio Detection and Ranging. Just like Laser based sensors, the radar sensors emit strong radio waves and receiver collects reflected signals back. Radar is a well-known system identifying location and velocity of targets. LIDAR is more accurate than RADAR. However, LIDAR is more expensive than RADAR since it requires additional packaging space due to power supply. Fusing multiple LIDARs and radars is an essential module of a self-driving car and of advanced driver assistance systems to improve accuracy and data availability. Ultrasonic sensors are generally used in closer proximity applications such as parking.

7.2.3.1 RADAR Sensors

The fundamental properties of electromagnetic waves in Radar systems are used to evaluate the time difference between a transmitted signal toward an object and its echo from the radar receiver antenna. The frequency shift between the emitted signal and Doppler echo[1] is used to calculate the velocity of the object. This property of these sensors made them popular to map the movement of the car and is often combined with cameras to achieve better estimation. The benefit of radars is the long range resolution and the ability to measure size, shape and type of objects such as vehicles, pedestrians and buildings. The camera is then used to identify objects and also follow them with its wide angular resolution. In general, radar is more accurate for longitudinal distance measurements and a camera is more accurate to determine the lateral position. Integrating these sensors results in an increased accuracy of both longitudinal and lateral position [14].

7.2.3.2 LASER based Sensor

Even 10 years ago, lasers (Light Amplification by Stimulated Emission of Radiation) were an expensive tool for special applications, but now lasers have become one of our daily necessities such as laser pointers and laser printers. Laser based sensors

[1] The Doppler effect (or the Doppler shift) is the change in frequency or wavelength of a wave in relation to an observer who is moving relative to the wave source. The Doppler effect can be observed for any type of wave – water wave, sound wave, light wave, etc.

consist of Laser Scanner and Light Detection and Ranging (LIDAR). LIDAR is a digital surveying technology that uses a rapidly pulsing laser light to build up an accurate 3-D representation of the area being surveyed. Light detection and ranging (Lidar) sensors rebound super-fast laser pulses between emission and received pulses for surrounding objects and measure reflection times to create a high-resolution 3D model of the target environment. The EMR (electromagnetic radiation) spectrum includes near infra-red (800–950 nm) or in the ultra violet above (1500 nm). The distance and angle of the target object is calculated by taking the difference between emission and received pulses. Laser based sensors are sensitive to dirty lenses, poorly reflecting targets and changing weather conditions since they will disturb rebounding procedures between emission and received pulses for surrounding objects. Combination of Laser based sensors, the camera of computer vision, 3D Maps and GNSS technologies are encouraging new solutions not only for automatic parking but for collision mitigation in self-driving car.

7.2.4 Imaging Sensors in Self-Driving Car

Almost all relevant information required for autonomous driving can be acquired through vision sensors although they cannot derive range and velocity of the targets unlike Laser based sensors or Radar. Vision based sensors include monocular cameras and stereo vision camera. The concept of stereo vision is to measure the height of objects by providing two different prospective for the same object. Providing two different prospective for the same object is a similar principle that the two different positions of human eyes let each eye detect the same object.

The camera can actually differentiate target objects based on physical properties.

Unlike the active sensors, the camera using the visible spectrum is very sensitive to weather conditions like rain, thick fog and also most of the cameras fail to operate in dark unless it is night vision equipped sensor. Cameras often operate in the different EMR (electromagnetic radiation) spectrum. The visible spectrum close to a human eye yields an output image resembling a human vision. Night vision cameras that are common in vehicles often captures targets sensitive to either a near infra-red (NIR) or far infra-red (FIR) frequency spectra. Thermal radiation of target objects can be detected in FIR (Far infra-red) spectrum in a higher range than NIR.

Integrating vision technologies with LIDAR and radars makes it possible to make a higher level of driving decision than previous methods which fuse only LIDARs with radars. Location sensors such as LIDAR and radars provide both distance and coordinate information, whereas a camera measures the intensity of light reflected by objects. Furthermore, the recent combination of vision-centered approach and deep learning technologies suggest encouraging new solutions not only for traffic signal analysis, but for lane change assist in the self-driving car.

7.3 Drones as Cyber-Physical Bridging Systems[2]

Drone is one of the more highly publicized technological precedents of the sensor society since the drone based infrastructure monitoring allows for moving, distributed, always-on data collection. With the advent of remote sensing from drone, the situation to collect spatial information has faced a dramatic challenge. A drone is a device that collects spatial data for a real-world object in nearby ground environment. The unique capabilities of drone allow for flight that is higher than ground-based cameras but lower than manned aircraft. Recent advances in MEMS technology (miniaturization of hardware, advancement of smartphone technology) have enabled the development of sensors that collect spatial data directly associated with nearby ground human contact and activities. Off-the-shelf drone utilized the sensor, processor, and wireless capability of smartphone.[3] The widespread use of smart phone devices and their ubiquity has brought up new realm named as drone CPS everywhere.

Major sectors of the Fourth Industrial Revolution can be grown by utilizing Bigdata collected through the drone IoT. Artificial Intelligence (AI) is able to be taught by the bigdata. AI supported by deep learning can make appropriate judgment and autonomous control based on big data. Drone offers a simple cloud-based platform which lets you store data captured by drones. Big data stored in drone cloud can rapidly turned into the output you need. For instance, as new data is collected, it can be compared against existing data sets to identify differences over time to be easily spotted. Potential problems in the landscapes or structures being monitored/inspected can be predicted before they become critical [15].

7.3.1 Drone versus Area-Wide CPS as a Tool Conceptualizing Sensor Society

The communication network in the sensor society is one of the most important technologies for enhancing bi-directional synchronization between virtual reality and the physical world, as it enables the exchange of information between cyber and physical world. Bi-directional bridging in typical CPS is basically designed by large number of distributed node-by-node communication for area-wide ground target. A typical CPS mainly consists of the following components: physical objects, sensors, actuators, communication networks, and computing devices (e.g., controllers).

[2] This chapter was revised from the paper initially published in Spatial Information Research (SpringerNature).

Um J-S (2017) Valuing current drone CPS in terms of bi-directional bridging intensity: embracing the future of spatial information. 25 (4):585–591.

[3] There is a company selling a remarkable drone that gives your smartphone wings, allowing you to deploy your iPhone or Android phone as an autonomous aerial camera. Not only does the smart phone have flight planning software so that anyone can fly the drone, the phone is on-board so that you have pictures taken directly with your phone. http://xcraft.io/phone-drone/

Table 7.3 Comparison of the drone vs area-wide CPS in terms of sensor society development stage

	Drone CPS	Area-wide CPS
Combination of sensor and communication technologies	Transition state from prototype to full-scale development	Still prototype
Combination of imaging sensor and location sensor sets (camera, RADAR, GNSS, INS)	Commonly available (combined into a single set)	Not yet commonly available
Autonomous navigation	Almost full-scale development	Transition state from prototype to full-scale development (in the case of self-driving car)
Multiple CPS sensing	Still prototype	Still prototype
Transferring data in real-time	Transition state from prototype to full-scale development	Still prototype

Various sensors and actuators will be geographically distributed and directly united with physical objects. Sensors collect the contextual information for physical objects and send it to certain computing nodes through the communication networks. In order to do this, a central system can be designed to be responsible for triggering all the sensors on the network.

Bi-directional bridging in drone is considerably different from the typical area-wide dimensional bridging (as summarized in Table 7.3 and illustrated in Fig. 7.1). For the orthodox bridging, to derive internal and external communication networks of CPS, it requires various calibration parameters such as diverse node platforms, different node distances, multiple communication networks and operating conditions. For drone CPS, such parameters (e.g. different node distances, diverse node platforms and multiple communication networks of different types) could be employed in one single CPS to collect spatial information.

The progress of technology development for various parameters related to bi-directional bridging in CPS is variable from prototype to full-scale development. The transition from prototype to full-scale development needs to consider various factors (e.g. production cost, quality control, liability and maintenance). The cost incurred to build a CPS with bi-directional bridging capabilities is also a key consideration affecting the embracing rate. Therefore, the technology maturity of a bi-directional bridging cannot be judged solely by observing the demonstrations (for instance, a smart city). The performance for bi-directional bridging should be evaluated based on the 'user-friendly maturity' of developed technology rather than on pure theoretical knowledge and scientific experimentation. It is easy to identify such user-friendly maturity of bi-directional bridging on drones in a realistic way, since the drone is available in the commercial marketplace and easily accessed by potential users. This would be helpful in evaluating objectively the operational bi-directional bridging potential of drone as a simple, effective and relatively inexpensive CPS, since standard procedure and equipment toward sensor society could be understood easily by the end user.

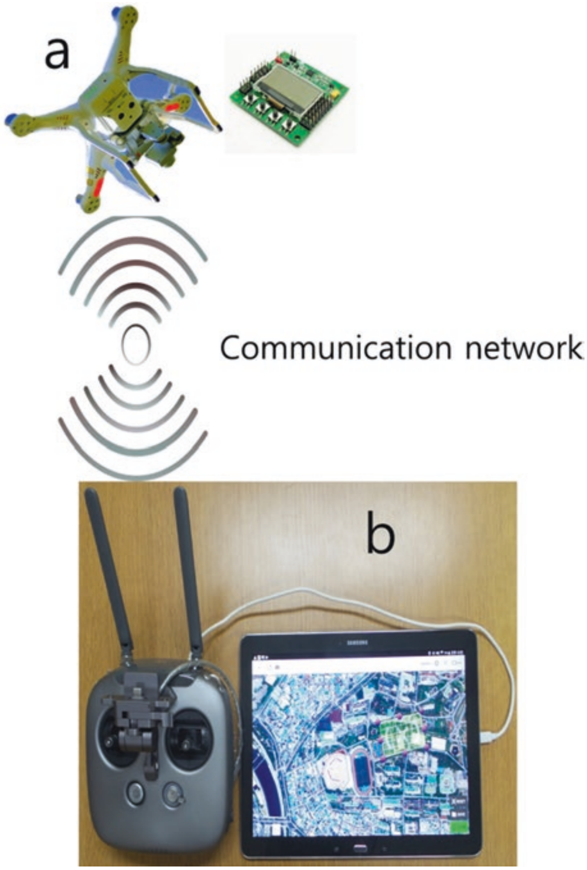


Fig. 7.1 Bi-directional bridging combined into a single set in drone CPS (**a**) physical system, (**b**) cyber-system

A convergence of sensor technologies and connected communications is a key enabler to realize a fully autonomous bi-directional bridging. Autonomous navigation related technologies show different levels of drone autonomy, from the simple ground worker-backing structures to the complicated self-flying. Various imaging sensors with high spatial resolution in drone CPS monitor the ground target by the autonomous navigation system, and intelligent clouds of sensors coordinate with each other to collect data. Imaging sensor technology and location sensor sets are a major component of the drone CPS instrument. Imaging sensor enables users to visually recognize, discriminate, and screen ground target. The communication network enables information transmission between moveable such as airframe in the sky and fixed devices (transmitter) in the ground (GCS, Ground Control System). At this crossroad of development, there are many possible technological pathways, and the ideal combination of sensor and communications technologies is still unclear in most of CPSs. However, it is almost full-scale development stage that data from the drone CPS as physical system can be transferred through the communication networks to the remote computing device as the cyber system and vice versa.

7.3.2 Big-Data Collection Tool

Synoptic coverage of drone CPS makes it possible to delineate and assess the spatial distribution and change of physical (off-line) resources in short periods of time. Assessment can now be done faster, more efficiently and accurately than it was done a few years back. With drone, delivery cycles between the project start and completion could fall from typical long terms (such as months and years) to much shorter (hours and days). The drone imagery can be used to probe the in-situ site at different times to generate even hourly data within 1 day. Further, drone can monitor even millimeter-size target imagery in the ground. Furthermore, oblique imagery from drone can not only match the usual viewpoint of human eye in relation to the ground target and further, near horizontal imagery can over and over again pronounce superior realistic terrain condition.

The autopilot of a drone is able to perform waypoint navigation, while sensors help to perform detailed investigation, quite similar to an in-situ survey. These autonomous features allow for spatial information industry to have multiple-drone surveys for larger amounts of physical (off-line) resources simultaneously. Drone is an aerial cloud medium that is much cheaper in comparison to old-style aircraft. Drone CPS offers a framework that allows users with no professional processing skills for remotely sensed imagery to develop full-featured portable map tailored to their requirements. The rise of drone CPS devices has spawned a revolution in big-data capabilities using remotely sensed imagery that often seems to outpace the budgets and capacity for many spatial data customers. With the emergence of drone CPS, the remotely sensed aerial imagery paradigm shifted from being available only for specialized business to a universally available commodity among the general customer, at an accelerating speed. The price of UAVs has been decreasing considerably, as the MEMS (Micro-Electro-Mechanical Systems) and software components that make up the drone have progressed cheaper and cheaper. This was an extraordinary shift towards the dramatic popularization of aerial imagery, coupled with the explosive growth of the drone CPS.

UAV designers now have access to various navigation software for (including open-source) and autopilot features that allow the drone to complete its spatial data collection mission without human manual involvement. For instance, Pix4Dcapture allows customers to create flight plans for capturing image data. Post-processing softwares (e.g. Pix4D desktop, Photoscan or cloud software) easily produce georeferenced maps and 3D models. This creates entirely new opportunities for drone CPS to be utilized as multipurpose big-data collection devices. The arrival of cheap, functional drone as ubiquity remote sensor may be the key to bringing real-time smart data to a critical CPS sector. Drone can be used as big-data collection vehicles for various CPS sectors, such as the self-driving car or smart city.

The drones as IoT devices collect big data by a variety of sensors. The data collected by drone has a totally different character than the data that that is currently considered Big Data. The drones allow for ultra-high-resolution, georeferenced, orthorectified mosaic imagery at a very low cost with near instantaneous deployment/data capture. Drones can also obtain more valuable data through long-term monitoring rather than a one-time snapshot measurement. Versatile and inexpensive big data acquired by drone has the potential to offer solutions in a wide range of applications, such as a smart home, a smart building, a smart grid, a smart factory, or a smart city. Further, with advances in technology, smaller MEMS sensors are now allowing multi-spectral imaging camera to be carried in the drone. The multi-spectral sensors capture off-line natural landscape and artificial land use such as building with additional wavelengths not perceivable to the human eye (such as infrared or LiDAR). The tiny LiDAR sensor (acronym for Light Detection And Ranging), measuring distance by illuminating a target with a laser light) allows more accurate and higher resolution than DSM (Digital Surface Model) produced from overlapping aerial photos with limited budgets.

As a tool to collect big-data, the application sectors in which drones can be utilized is virtually unlimited, e.g. indoor or outdoor mapping. For example, micro-flying surveillance drones can monitor and track risk factors while autonomously flying indoors. The indoor mapping technology, meanwhile, should help people find their way through large-scale public areas like airports and museums [16]. The indoor mapping technology can save emergency and military personnel in danger by entering buildings or other enclosed areas without knowing what lies ahead [17]. Google or Apple is planning to use drones in a new indoor mapping to improve its own maps service for museums and airports. Small aerial vehicles are able to fully explore the extent of an enclosed space by moving and avoiding obstacles autonomously, without the need for human remote control or observation. Drone can produce unknown indoor three-dimensional map due to its unique ability to traverse any indoor space without access restrictions in the outdoor terrain. A 3D map of the explored space will be created and displayed in real time over a wireless channel.

7.3.3 Flying IoT Mounting Device

In the last decade there has been a proliferation of closed circuit television (CCTV) installations. For many years, field CCTV with visible spectrum[4] has proved to be a very useful means of capturing real-life system and activities. One of the major disadvantages of traditional non-CPS monitoring such as CCTV is that it is costly and time-consuming due to the large number of installation points required. Nevertheless, sampling errors can be quite large, especially where the physical target is not uniformly distributed in real life system. Until recently, and the cyber-physical bridging and real-time area-wide monitoring for various off-line physical targets remained largely theoretical because the non-CPS survey technique has dif-

[4] the portion of the electromagnetic spectrum that is visible to the human eye.

ficulty in assembling multi-temporal images acquired by IOT (Internet of Things) devices simultaneously. Furthermore, non-CPS observations have the disadvantage that they provide only limited information on historical trends and spatial distribution of the off-line target, which is possible through comparison among IOT sensor signals of different dates.

Until now, smart phones, smart watches, and smart TVs are all smart devices, but they were not mobile devices. On the other hand, conventional home robots and industrial robots such as robot cleaners are mostly single-purpose mobile devices and are not flying robots. However, the next-generation drones are merging the smart device with the existing robot by giving mobility to the concept of the Internet (IoT) called data sharing between objects. Thus it presents the direction of the future industry and creates a new blue ocean. In this regard, drone can be called as MMM (Multipurpose Mobile Machine), since it can be used for various purposes. It can be seen that the drone is not just a physical machine, but a smart machine equipped with artificial intelligence. Drone is controlled by the operating system (OS) and application softewares similar to those of the smartphone. The drones are SMM (Smart Mobile Machine) equipped with artificial intelligence along with the characteristics of MMM. The biggest difference between drones and IOT sensors lies in the mobility for the real world and interaction with the virtual world. The drones can be thought as 3D moving IoT, giving mobility to the IoT. Therefore, it has potential as a representative tool of CPS.

The benefits of capturing video and photography have already made the media and movie industry a key user and driving force in commercial applications of drone. Such trends have rapidly expanded for mapping, site surveying and facility inspections. Three-dimensional moving IoT mounting device offers the great potential to investigate facilities and locations hard to access (e.g., rooftop of super high-rise building, flare stacks, cooling towers) without placing employees and workers in danger. The extremely agile inspection drones, equipped with night vision cameras and thermal sensors, will be able to access places unreachable by manned aircraft (e.g., enclosed cave space, flare stacks, inside tanks, underground sewage facility etc.). Today, work is underway, paying extremely expensive cost for hard-to-reach jobs such as factory facility safety management, bridge safety diagnosis, and safety terminal diagnosis of super high-rise buildings. The detailed imagery collected by a drone can be used to forecast the risk of breakdowns and minimize production downtime, therefore improving the industry's competiveness. Improved maintenance by the three-dimensional moving IoT mounting devices minimizes related environmental impact and reduces hazards for personnel. Drone provides a cost effective and safe alternative to manned vehicle for aerial and indoor mapping and offer new opportunities to capture targets closer to offline populated areas. Further, the rapid advance in the AI drone technology justifies a wide adoption of the three-dimensional moving IoT mounting device in various industrial sectors.

7.4 Autonomous Driving versus Flying

In order to understand the fundamental infrastructure related to cyber-physical bridging, it is important to learn the levels of various core technologies such as autonomous driving versus flying and investigate a blueprint to commercialize them. The self-driving car, which links the real world with the cyber world with various sensors, based on IoT, cloud, and big data analysis, is a very complicated platform that requires the connection of numerous physical domains as well as processing a massive amount of data [18]. Therefore, it is very important to establish a systematic roadmap for the selection of technologies to be applied to specific fields by evaluating the realistic potential of cyber-physical bridging.

7.4.1 Autonomous Flying

One of the primary challenges faced by any UAV is to locate itself and plan its route. The capability of UAV to accurately and efficiently determine its position is the fundamental tasks essential for a robotic vehicle to interact with the environment. Historically, integrating GNSS and inertial navigation was the representative of integrated navigation. Map matching was considered as the third important tool for integrated navigation. Multi-sensor fusion approaches have become widely adopted in UAVs, since no single sensor accommodates the requirements for reliable obstacle detection and tracking in urban environments. In most current drone, cameras, GNSS/INS, and conventional odometer have been used to improve the performance of obstacle detection and tracking. Another approach relies on frame-by-frame comparative analysis between imagery captured by onboard cameras and GNSS location data to reduce the error range of the GNSS signal. Furthermore, the vertical distance and movement of UAV relative to the ground is crucial for UAV automatic navigation and landing, but neither GNSS nor INS can provide such crucial information. Vision sensors (e.g., such as camera, hyper-spectral sensors, laser scanners etc.) can be processed to determine the vertical distance and movement of UAV, relative to the ground by sequence of stereo imagery. The map-based method is used to improve the low accuracy of GNSS measurements when satellite signals are unavailable or degraded. In the line of the map-based localization method, an ideal map should provide not only a geometrical representation of the flight route, but also some kinds of sensor-based descriptions of the environment to alleviate the difficulty of self-localization as well as of mission planning. Further, forthcoming integrated navigation systems such as A-GPS and SBAS linked to AI are likely to have many more components. On-board sensors in the self-driving car are mainly used for autonomous driving alone, but sensors installed in the autonomous drone could be utilized to perform various tasks such as aerial survey.

7.4.2 New Road Infrastructure Specialized in Self-Driving

At present, social interest for the self-driving car is prominent as it emerges as the representative product of the fourth industrial revolution. Despite using state-of-the-art object recognition algorithms, the self-driving car still does not recognize things that human beings can distinguish simply. Autonomous cars must recognize numerous objects on the road simultaneously. Various complicated obstacles exist in this extremely dynamic environment such as pedestrians, bicyclists, dog and illegal crossing of the road etc. For example, it should be able to distinguish the difference of hand traffic signals among the police officer, bicycle driver and pedestrian etc. It is doubtful whether it can easily recognize the hand gesture signal that is sent by traffic police to stop the car. Autonomous driving should accommodate a multitude of factors, such as weather, darkness, pedestrians, unauthorized parking along the roadside, as illegal crossing over the sideway, vehicle types, and police signals. Off-roading and urban sideway applications can be considered the extremes of self-driving. It is not easy to differentiate between the road sign for parking restricted and parking allowed for specific timing. It is doubtful that it will be able to park properly in the designated parking space. If one of these complicated variables does not work properly, it can lead to a serious accident and can't guarantee our safety (Table 7.4).

Many companies aim to develop 100% autonomous driving vehicles (fourth level of NHTSA's development Level) by utilizing the high precision map (Table 7.5). Currently, many pilot operations for self-driving car are facing difficulty due to accidents. There is still a problem with safety and demand for high

Table 7.4 Comparison of autonomous driving car versus drone

	Autonomous driving car	Autonomous flying
Difficulty of introducing technology	Many limitations due to various obstacles such as pedestrians, manned vehicles on road	Few obstacles compared to road (manned airplanes, birds, and other drones)
Deep learning	Too many things to learn	Not too many things to learn
Parking vs landing space	Parking space required	Landing space required
Flight route	Road is existing	Need to develop a drone flight route in the sky
Embeded sensor	Sensors confined to road duty	The drone is a versatile mobile device and is equipped with various sensors related to mission performance along with autonomous flight.
Level of technology development	Pilot test operation on Uber, etc.	New product launching Aeromobile 4.0, Terrafugia TF-X, Lilium air taxi, EHang184 etc.
Road failure	Very serious in snow, sleet, ice, during heavy rainfall or a bit of debris	NA (**not applicable**)

Table 7.5 NHTSA's development level for self-driving car

Division	Perception	Control	Responsibility	Human driver availability
Level 0: Non automated	Driver	Driver	Driver	o
Level 1: Automated assisted	Driver	Driver/ car	Driver	o
Level 2: Monitored automation	Driver	Car	Driver	o
Level 3: Conditional automation	Car	Car	Car?	o
Level 4: Full automation	Car	Car	Car?	x

Source: NHTSA (The National Highway Traffic Safety Administration). (An agency of the Executive Branch of the U.S. government, part of the Department of Transportation)

precision map. From the very beginning, the infrastructure of the road such as the network of roads, highways, bridges, and overpasses has been built for human drivers. The infrastructure of the road is not connected and the roadways, street signs, and traffic flows do not communicate each other. If we designed our new cities today for self-driving, we will create a fundamentally different traffic infrastructure system: cloud-based and capable of microscale adjustments to efficiently manage millions of cars in constant communication with each other and the network [19]. It would be more realistic to expect that the limited autonomous driving (Level 1 to 3) for special application (such as trucks in the highway or public bus driving designed route) could be implemented under current road infrastructure. It would be very hard to achieve Level 4 (complete autonomous driving phase) under current road infrastructure, where the driver enters the destination only and the autonomous vehicle reach the target location by itself.

7.4.3 Self-Driving Car and High Definition 3D-Real Time Map

The self-driving car heavily depends on the accuracy and reliability of its environmental perception technologies including self-localization and perception of obstacles. The GNSS precision in a modern vehicle has an accuracy of approximately 5–15 m due to poor visibility (due to tall buildings, trees, in tunnels, or in street canyons) or limited satellite connectivity. This precision is sufficient for a human being to drive (e.g. route navigation) and plan his/her next move. The position accuracy required for parking of a self-driving car is the centimeter level, and the update frequency is about 100 Hz. The accuracy of RTK GPS is typically about 1 m, but it is still insufficient for assessing vehicle lane measurements for a self-driving car. For example, let us consider that the car has to take a left turn to reach a certain destination. If the car does not recognize the left turn point correctly, it will certainly sway out of its lane and cause an accident.

The accuracy of GNSS can be enhanced with other reference signals, such as the map matching information, inertial sensors, mobile phone cell triangulation and local reference signals (e.g. infrastructure, beacons). A visual odometer approach is proposed to identify specific landmarks or objects in the surrounding environment of the moving. This approach can play a key role in autonomous navigation driving an unknown territory where the self-driving car receives weak GNSS signal or get an inaccurate signal due to GNSS error. Based on previously learned databases, the vehicle can identify certain key objects to help determine its location. Although localizing car by visual odometry is possible within a certain tolerance, it is often not sufficient for the self-driving requirement in terms of quick update frequency (about 100 Hz) at the centimeter level position accuracy.

Current technology such as Googles self-driving cars deeply relies on very accurate prior maps. The map determines where to drive, and to explore in advance road signs, traffic lights and roadblocks long before they are recognized by its sensor. With a given map, one needs to establish correspondence between the map and its local perception, and then determines the transformation between the map coordinate system and the local perception coordinate system based on these correspondences. Knowing this transformation enables the self-driving cars to locate the surrounding obstacles of interest within its own coordinate frame. Sam Abuelsamid (senior research analyst at Navigant Research) states that “nominally, you can do autonomous driving without high-definition maps. But if you get into challenging situations like rainy or snowy conditions, or can’t see the curbs or lane markings, it’s almost like putting a blind person behind the wheel [20].” The slightest variation on the road–a construction zone that cracks up overnight, or a bit of debris–could stop a driverless car in its tracks. For self-driving cars to gain real market acceptance, they need to have “anytime, anywhere capability,” Sam Abuelsamid says that, whoever owns the most detailed and expansive version of these maps that AI vehicles read will own an asset that could be worth billions [21]. So to speak, whoever owns the maps owns the future of self-driving cars.

Fully autonomous cars will require maps that are significantly different from the maps that we use today [22]. First, they have to be extremely detailed: if meter resolution maps may be good enough for GNSS-based navigation, map for self-driving cars has to include data on location of every lane mark, curb, the height of traffic light and meaning of every traffic sign at centimeter accuracy. Second, maps for driverless cars have to be real-time ones, almost-constantly updated with information about accidents, traffic jams, lane closures and weather conditions to understand the “big picture” of what is happening on the road. Traditional road maps for a human driver lack the necessary detail (especially in urban areas, over about 5–20 m) to support self-driving applications, which need to show every narrow road division line mark. Google maps or other satellite generated maps are not enough for navigating as the surrounding environment for self-driving is quite dynamic in the real world. Land-based Mobile Mapping Systems (MMS) generally capture image data along the corridor the vehicle travels. The output of MMS system contains a surface description and an inventory of major objects positioned along the mapped corridor. This is exactly the information self-driving car necessities for navigation. But the moving objects in real-time should be mapped too [23]. This local map is created by the various sensors present in the car like a high dimensional LIDAR, a RADAR and multiple cameras. LIDAR maps are used by most of the latest fully self-driving car prototypes. These fully self-driving cars are pre-loaded with a LIDAR map of the trials area in which they are permitted to fully self-drive themselves. Beyond those tools of looking and listening, most self-driving cars also generate a real-time map of the world.

7.4.4 Realistic Potential of Autonomous Flying

Currently, there is a lack of social interest in autonomous flight of drone. The autonomous driving of the drones seems to be much easier than the autonomous driving of the car since there is no tree, human and bike in the sky. Of course, conflicts

Fig. 7.2 The typical traffic condition of self-driving car versus drone (**a**) self-driving car, (**b**) drone

between planes, birds, crashes, and weather uncertainties can be obstacles, but this is a very small obstacle compared to autonomous driving. Accordingly, the route will be shorter and the speed limit will be freer than the ground. There is no restriction on the route of travel because there are no buildings (Fig. 7.2). The roads have already been constructed and have been well organized for a long time. There is no flight route for drone, thus, there is a need for institutional arrangement to establish safe flying routes. The autonomous flight industry has recently showed marked improvement in commercial use. It can be said that the airplane will be more economical than the automobile in the future. If there is an autonomous vehicle on the ground as the representative technology of the Fourth Industrial Revolution, there is a drone in the sky. The drones are very similar to autonomous vehicles in that they are a combination of big data and artificial intelligence. The idea of cars that can fly has been around since at least 1940 when Henry Ford said flying cars were on the way. There are several autonomous drones to go on general sale in the near future: Aeromobile 4.0, Terrafugia TF-X, Lilium air taxi, EHang184 etc.

AeroMobil is just one of several companies currently developing flying cars. Aeromobile 4.0 is a follow-up to the prototype Aeromobile 3.0 and is close to the finished product for sale to customers. Aeromobile 4.0 shows that the future is not far from the reality of a sky-high car [24]. The design is similar to a light plane, not a car. It will be capable of speeds up to 100 mph (mile per hour) on the ground and 240 mph in the air. Massachusetts-based Terrafugia is developing the Transition, a flying car with wings that fold vertically against the side of the vehicle. Terrafugia is planning to provide 'true door-to-door transportation,' with the vehicle capable of being parked in a home garage like an ordinary car. The planned four-person TF-X will be semi-autonmous and use computer-controls so that passengers can simply type in a destination before taking off [25]. The TF-X is a four-seat hybrid vehicle under development. The TF-X is close to the car while the Aeromobile were close to the light aircraft. The main difference is that while the Aeromobile requires a 200-m runway for takeoff, the TF-X does not require a runway (an airport) and is capable of vertical take-off, equipped with an electric motor. The TF-X can travel on its own by avoiding restricted areas. Artificial intelligence manipulates the drones through the collected data. The top speed of the TF-X is 322 km/h, faster than the AeroMobile 3.0, and can travel for about 800 km in full fuel. The TF-X™ will drive on all roads and highways – providing the convenience of true door-to-door transportation [25].

German-based Lilium is testing an electrically powered jet capable of vertical takeoff and landing (VTOL). Uber says it will begin testing autonomous VTOLs in 2020. The VTOL design makes sense because it allows the vehicle to take off and land almost anywhere–as opposed to having to drive to and from an airstrip. Autonomous control makes sense because there aren't enough trained pilots to fly the number of vehicles required for Uber-like service. The Lilium air taxis will be available to everyone around 2025 and as affordable as riding a car. A large network of small and inexpensive landing pads and central places in cities will allow you to quickly enter an aircraft anytime and fly anywhere you want. The Lilium is working actively with leading mobility service providers such as Uber to deliver a seamless user experience from booking through to landing. On-demand air transport is becoming a reality. The Lilium states that the company is planning to start world-wide service and you can book a Lilium jet around year 2025 [26].

Traffic cyber-physical systems (smart cloud traffic control) could be characterized by the introduction of the drone taxi into a current transportation system and the transfer of traffic lights to a virtual cyberspace. The drone taxi demands the creation of a virtual traffic infrastructure such as traffic lights in the sky. Current traffic infrastructure such as traffic lights spends a huge amount of electricity to maintain, millions of dollars to install. Virtual traffic infrastructure such as traffic lights in the sky can be installed as the virtual urban infrastructure in a few minutes. Such virtual traffic infrastructure makes it possible to automate drone traffic in the sky in real time, and to solve the safety problem faced by self-driving car [27].

Low-altitude airspace, on the other hand, is largely untouched. As drones take to the skies, industry stakeholders have the opportunity to build virtual traffic infrastructure that accommodates autonomous navigation from the very beginning: digital, connected, and data-driven, not for humans [19]. Two emerging technologies in the autonomous flying domain are sensor fusion and drone-to drone (D2D)/virtual traffic infrastructure (D2X)[5] communication. Connected-drone systems use wireless technologies to communicate in real time, from drone to drone (D2D) and from drone to infrastructure (D2I), and vice versa. D2D communication in the sky proposes that drone will communicate with each other in real time creating an intercommunicated smart system. D2D communication lets other drones know their position, speed and destination, etc. Cooperative sensing increases the sensing range by means of the mutual exchange of data sensed from drone and virtual traffic infrastructure.

Collaborative data-sharing is the only way to successfully deploy autonomous flying vehicles and to avoid serious traffic congestion issues during deployment. Cooperative maneuvering enables a group of autonomous drones to fly coordinately according to a decentralized decision-making strategy. These features enable the creation of cooperative autonomous drones, which may greatly improve traffic safety and efficiency. The integration of on-board sensors and D2X communication results in a solution that is more cost-effective than an approach based on high-quality sensors only.

7.5 Automation Level of Drone

Mostly current drone can be found in stand-alone physical systems or behind a fence on the work-floor. Perhaps surprisingly, the vast majority of these uses involves low altitude flight over a localized area, perhaps a single parcel of land or

[5] Note that we use the expression D2X as shorthand for communication between drone and any other object.

a few adjoining parcels. This will be changed in the near future. In the near future, drones will present in large numbers everywhere. For example, traffic flow without drone will be almost inconceivable. Soon, stand-alone drones will be evolving into assistants to humans. They will do everything covered by the three Ds: dirty, dangerous and dull work. Drones do it tirelessly, and function with unprecedented precision and often power, which is of major importance to the durability and quality of products: ranging from indoor mapping to air taxi. In that respect, drones are better than humans, just as all the other non-automated tools that we have invented: from the saw to the electric screwdriver and the air-filled hammer. This is where we observe a crucial difference from normal tools: production drones are a part of industrial automation. Intelligent AI drone that can learn independently, that take their environment into account, must be able to collaborate spontaneously with their human colleagues.

7.5.1 Operating Methods Depending on Automation Levels

Drones have different operating methods depending on the automation level of the mounted control system (the flight controller and the communication distance etc.). Some operate via a special radio controller, while others are controlled using smartphones or tablet devices. The smallest drones are often just toys, controlled by a very simple remote or a smartphone, offering flight times of around five minutes and are available for under \$50 or \$100 [28].

Such drone belongs to level 0: non automated stage and based on fully manual flight controlled by ground human pilot. Since most drones are equipped with onboard computational systems, it is relatively easy for an operator to control the drone by adjusting power to the various motors individually. For example, the ability to hover automatically is common, especially with models that use Global Navigation Satellite Systems (GNSS) to enhance navigation. Drones can ascend and descend vertically, hover in place, navigate in any direction, and perform extremely precise movements and acrobatic maneuvers at low or high speeds. Such a drone belongs to level 1: automation stage assisted by human ground pilot (e.g. DJI Inspire 1). This allows many drones to automatically navigate to specific locations, orbit fixed points, carry out pre-drawn flight paths, or stay within certain preset boundaries (Table 7.6). They can automatically avoid sensitive locations like airports. Manufacturers and operators can even set speed and altitude restrictions [28].

Visual Flight Rule (VFR) is a method of flying based on visual information, while Instrument Flight Rule (IFR) operates depending on the flight status display device of the aircraft. The drones can be classified according to the communication distance of the radio wave as a connecting means with the external pilot as shown below; Visual Line Of Sight (VLOS), Radio Line Of Sight (RLOS), Non-Radio Line Of Sight (RLOS). Visual Line of Sight is a type of propagation that can transmit and receive data only in case that there is no any sort of an obstacle between transmission and receiving stations. It is the distance that the ground pilot can visually observe the

Table 7.6 Automation level of drones

Automation level hierarchy	Perception and control	Example, major applications
Level 0: Non automated	Ground human pilot	Fully manual flight controlled by ground human pilot
		Syma X5C, toy level operation
Level 1: Automated assisted	Ground human pilot	Stabilization phase using computer and sensor. The route of the aircraft is manually controlled by human ground pilot. This is the way in which the shooting drone is often used.
	Visual line of sight	Inspire 1 (waypoint navigation), aerial photography
Level 2: Monitored automation	Ground human pilot and drone	A high-precision navigation system, using a computer and a sensor, Automatically fly along a given route point. The ground pilot designs the flight path, executes it, and verifies its status using flight planning software (Pix4D Capture).
	Visual line of sight	Cell tower inspection, bridge inspections
Level 3: Conditional automation	Ground human pilot and drone	If the ground pilot assign a mission (for example, specify the overlap percentage in aerial photography), the flight management system (FMS) create a series of route points to perform the given mission properly and follow it automatically. The external pilot only assigns a specific mission. FMS determines how to perform the procedures to accommodate the given mission.
	Radio line of sight	Delivery service, asset tracking, employee oversight
Level 4: Full automation	Drone	If a flight device with artificial intelligence designates the top-level task (in the case of a delivery drone, to check the stock inventory and deliver the necessary goods items), the subordinate task will be performed by drone itself. If necessary, it is possible to actively collaborate with a manned aircraft or an autonomous vehicle as common distributed/collaborative physical systems.
	Non-radio line of sight	For example, during the 2018 Winter Olympics in PyeongChang (South Korea), Intel's Shooting Star has performed "drone show" operating 1218 drones in the sky simultaneously (swarm drone process).
		Delivering/transporting: online retail, factory inventory management, air taxi as a flying companion

flight status of the drone, which means about 500 m. Therefore, it can not be applied to UAVs that have to carry out long-range missions. There is a disadvantage that it is possible to operate the drone only in the visible distance depending on the driving sense of the pilot. The majority of civilian drones currently belong to Visual Line of Sight (automation level 1 or 2). More advanced drones, have operating times around twenty minutes, stabilized camera systems, and software that provides semi-autonomous navigation and precision flight. Some models possess sophisticated software that gives them the ability to autonomously follow, orbit, and record their operators as they bike, surf, ski, or work. The most advanced systems are increasingly capable of fully autonomous flight under Visual Line of Sight using sense-and-avoid programs to detect obstacles and navigate using image processing software (automation level 2) [28].

Industry grade models and highly tailored systems for longer flight times, durability, and data analytics are also available at Radio Line Of Sight (RLOS) ranges. Radio waves can be reached about 20 km of the horizontal distance without separate relay station. It is possible to transmit far away (ground 120 km, sea 200 km) if the propagation is not blocked by the terrain such as mountain. There is a disadvantage that the transmission distance is limited due to the radio wave intensity and the antenna characteristic. Transportation drones, commercial profit-making drones (pizza delivery drones), etc., are generally operated in the Radio Line Of Sight. In general, a UAV operating at Radio Line Of Sight (outside the Visual Line of Sight) requires Level 2 or higher levels of automation capability. For instance, utility lines (transmission and distribution grids, pipelines etc.) are currently inspected once every 3 to 18 months. Inspections today are carried out either by manned flights, or by on-the ground teams driving along the lines. Drone could drastically reduce the inspection costs while increasing the monitoring intensity and quality once beyond visual line of sight capabilities are more mature. Radio Line Of Sight technology enables the detection of minor gas leaks or can map out temperature differences along the infrastructure. These drones could be composed of small fixed wing drones operating near 150 m altitude with some remaining personnel support or, if cost effective enough, be done at higher altitudes (well above 300 m) where drones would have significantly longer range per flight [29].

In situations that radio waves do not reach directly, it is necessary to utilize a ground relay facility or satellite-based radio relay. It is a method mainly adopted in military drones that require a long operation mission. The Non-Radio Line Of Sight (RLOS) drone frequently used in the US special operations for antiterrorism and in an operation by US forces to repel IS without sending ground troops. It is possible for the drone capable of autonomous flight over 3 automation levels to operate in such continental communication distance mission. It is possible to overcome communication disruption with satellite-based radio relay.

So far, most application of drone was to focus on utilizing the bi-directional bridging intensity under automation level 3 in terms of spatial data collection capability. In particular, practical applications for the bi-directional bridging from full automation level have not yet been fully reported. Although this conditional automation of level 3 shows the single representative example of bi-directional bridging, it could be a starting point to develop or design ideas of how to utilize the strength of cyber/physical bridging in a usable way. Present drone CPS will play a key role as scientific and objective evidence for the bi-directional bridging to be achieved by conditional automation of level 3 in comparison to level 4 of full automation. The future improved technology of full automation will increase the practicality of the bi-directional bridging at much more acceptable levels [7].

It is anticipated that drone will communicate directly with other drone and silently during operations in the near future, changing the way we work. Various types of drones at the level 4 of full automation silently perform their duties without human instruction. For example, drone performing the role of satellite communications ultimately will fly on their own and provide Internet services to the area non-accessible to communications networks. Drones at the level 4 of full automation are expected to offer opportunities for faster, more customised delivery and increase access of communities to the marketing networks near them. These opportunities are expected to be considered value-adding services (e.g., emergency medical supplies, disaster response) that both consumers and businesses are willing to pay a first-class charge for. It is considered that various types of manned aircraft at the level 4 of full automation will be replaced by drone performing their own tasks silently without any human instructions [29].

7.5.2 Distributed/Collaborative Physical System (DCPS)

The emergence of AI drone as DCPS (Distributed/Collaborative Physical System) in our skies, land, and water is not brand new facts, and it is recognized as a natural phenomenon in the sequence of technological development (Table 7.7). However, more robust technology in various fields is still required before many applications are commercially viable and accepted. In the future, because all objects will be unmanned, it will have an open structure in which air, ground, and marine drone vehicles operate together as the distributed/collaborative physical system [29].

This development of small and cost effective drones has led to a variety of uses that businesses and public institutions are starting to influence to reduce risk, optimize processes and drive new forms of customer and societal value [29]. The acquired data has a great potential to get a first overview of the area of interest. Crowd-sourced information from the public – very often with spatial components – has become an important means of obtaining data, particularly for crisis management. For instance, the earthquake in Nepal in April 2015 again demonstrated the usefulness of geospatial tools for emergency management. A global network of volun-

Table 7.7 Major application examples according to cyber-physical bridging level hierarchy

Bridging level hierarchy	Example, major applications
Cyber systems	Google Earth, Geographic Information System (GIS), MIS (Management Information Systems), ERP (Enterprise resource planning), EAM (Enterprise Asset Management), CIS(Customer Information System), ETRM (Energy Trading & Risk Management)
Standalone physical systems	Supervisory Control & Data Acquisition (SCADA) is a system of software and hardware elements that allows industrial organizations to directly interact with sensors attached to valves, pumps, motors, and monitor, gather, and process real-time data.
Distributed/ Collaborative physical systems	Smart home, smart factory, smart farm, smart grid, smart city
	For instance, in the initial response phase of the fire emergency situation, a group of drones perform on-site inspections or imaging more safely and efficiently. Simultaneously another group of the drones drops a powder fire extinguisher or liquid fire extinguisher, based on real time data delivered through the distributed wireless network. In the next step, the swarm of drone sprays water and begins to suppress the spreading fire.

teer – digital humanitarians – assisted with vital information to help emergency workers on the ground. Tools for remote mapping efforts have increased in sophistication since drones were added to the mapping toolkit box. Oblique imagery from drone, taken at an angle, can give better assessment results of damage than the traditional nadir satellite imagery [30].

It is expected in the near future that low-cost drones flying autonomously will be integrated as a fixed part in as distributed/collaborative physical systems (DCPS). Drones as the DCPS could be connected to the global network through a high speed internet link. Then, an analyst could physically look at the area of interest in order to determine any desired actions. Users of unmanned vehicles and sensor payloads will continue to push the limits of compute power bundled with more sensor data acquisition capability. We certainly expect customers to increase the processing capability in order to analyze data locally, which will allow them to make real-time decisions. DCPS sensor payloads continue to capture a seemingly insurmountable volume of data, including high-resolution imagery and full-motion video [31]. Future DCPS is expected to employs optimized system to handle the high data rates coming from sensors. For instance 5G network (ITU IMT-2020 standard) provides for speeds up to 20 gigabits per second [32].

If a drone examined a large field and found that it was ready for harvesting, it could dispatch an “autonomous harvester.” In the delivery market, the most effective solution may be to use an autonomous vehicle to move packages to the target area. Ground robots and drones as a component of DCPS could work together for quick delivery of the various packages in a short time at low cost. The military is leading the way in this area and is studying the use of drone swarms to attack or defend military targets [33]. The drones operate autonomously without pilots and can be maneuvered by another drone if necessary during swarm drone mission. The data obtained during the swarm drone process such as the location information can be stored. If a delivery mission to the same point is performed, it can be reused next time for safe landing and rapid delivery.

7.5.3 Power Sources to Make the DCPS a Feasible Reality

Drones use a variety of different types of power. The power sources can be classified into battery type, solar type, and jet engine type. The different type of power source literally drives flying time and operational capability of the drone such as toy, professional, industrial, ultimately distributed/collaborative physical systems (DCPS). The basic task of (UAS Unmanned Aircraft System) is to collect data from remote locations using onboard IoT devices and share them with distributed/collaborative physical systems (DCPS). UAVs as DCPS require a suitable power source for the embedded sensors, actuators and other IoT utilities [34]. The logic of sensor related technology is circular and continuous – more sensors create more data which in turn open more avenues for new data collection by newly developed sensors. The “sensor society” thus refers not just to the proliferation of automated sensing devices across the offline landscape, but also to the associated energy supply logistics that are characteristic of automated always-power on state [6]. Data generation in the sensor society pushes in the direction of fully powered lives at any time and, further toward a fully charged at any place. Therefore, the question naturally arises; Is it possible to come up with a system that can support power stably and permanently to the multiple cyber-physical cloud environment instead of using single stand-alone cyber-physical sensors? The drone technologies associated with DCPS require an energy supply in different levels, in particular in the infrastructures for intelligent cities as the swarm of drones will be spread. Battery storage prices are dropping much faster than anyone expected, due to the growing market for consumer electronics and demand for electric vehicles (EVs). The expected significant drop in battery prices in the near future would change the conventional concept of drone big data as remote sensor which was generally considered as a snapshot visual assessment tool (due to the difficulty of the long term operation caused by battery capacity).

7.5.3.1 Solar Powered Drone

Solar power is recognized as one of the best candidates to fill this gap. Solar powered drone is the drone to move with the energy produced by solar power panels mounted on the body frame. At night, energy storage system releases the stored energy and maintains the entire system of the normal operation. The future prospect of solar powered drone is very bright as solar radiation is a clean and renewable energy. It is ideal for long endurance missions at high altitude without returning to the ground (communication relay, remote sensing, weather monitoring, etc.) as it does produce energy to operate by itself [35]. Right now there are over a dozen of companies working deeply on the development of solar powered drones [36] such as Airbus, Google, NASA Pathfinder, Helios, Centurion, Atlantik Solar, Boeing etc. The drone has all the advantages of an aircraft and satellite combined [36]. It is capable of taking on similar tasks as satellites. The solar power drone would allow long-term, high-altitude aircraft to serve as atmospheric satellites, or communications platforms.

For instance, the drone could fly at an altitude of over 29,524 m [37] where there is little air traffic that could impede its travels. Flying at that height will also give it unobstructed access to the sun. It can fly at night, which means that this drone can fly uninterrupted for up to 5 years all while producing zero emissions. It will function much the same way as a satellite, though it will cost much less to launch. The drones could be used to deliver internet service to everyone, like communication satellites, regardless if you're living in a world city or in a remote area of a developing country. We believe that in the near future, The meaning of the permanent flight will be able to achieve, riding the sun will no longer be a dream flight [35].

7.5.3.2 Wireless Charging Drone

Unlike conventional battery charging methods, wireless charging drone can deliver power at a distance without using wires [38]. There are two ways to do this: one is a magnetic induction power transfer system and the other is a laser power transfer. In the case of the grounded inductive power transmission system, when the drones arrive at the charging pad, they are automatically charged regardless of the direction of landing, so that the person does not have to replace the battery directly. It is relatively inexpensive and has higher power transmission efficiency than a laser. However, increasing the wireless power transmission distance increases the size of the wireless power system, decreases the efficiency, and affects the surrounding electronic systems. A method of using a laser transmits a power by aiming a laser receiving unit mounted on a drone in real time in a device that generates a laser. It is mainly used for fixed wing drones that have enough space to install the laser receiver. It has the advantage of delivering power wirelessly to a very long distance drones. However, disadvantages are the change in power transfer capability due to weather, relatively low power transmission efficiency, and high cost.

7.5.3.3 Hydrogen Energy

Hydrogen (H_2) energy existing in the form of water is considered as the most promising fuel for the future drone since it is the most abundant element in the universe. The ubiquitous availability of hydrogen fuel has opened a new avenue for environmentally friendly energy in different drone applications. The drone aerospace and aviation sectors have been the earlier to recognize the importance of using this fuel [39]. Hydrogen fuel cell powered drones have the potential to be a disruptive technology for the current UAV market once storage and fueling issues are overcome since the density of liquid hydrogen is very convincing for long-endurance UAV applications [40–42]. Such stable power supply will turn UAV infrastructure in to almost autonomous information processing and response. These developments will give an important input for further progress in the developments of the sensor society through Distributed/Collaborative Physical Systems (DCPS).

7.6 Conclusion

This chapter made a valuable first step toward practical judgement of bi-directional bridging intensity for currently available drone CPS, as well as allowing a valuation of new vision expected by bi-directional bridging of drone. Drone as CPS is designed to support applications that utilize vast amounts of diverse data (such as visual imagery and location data) collected by sensors in real-world environments.

The drone as CPS is analyzed and defined in various ways. But basically, it collects and analyzes the real world data (such as visual imagery and location data). Then it provides the feedback of the results (e.g. avoiding obstacles by AI) to the real world across society as a whole. Specifically, the sensor attached to the drone monitors physical targets and abundant data collected from the sensor are transmitted as big data to the cloud with IoT tools [18].

However, there is a narrow perspective that it is a technology traditionally used to shoot aerial photographs as a sub-concept of manned aviation technology. It is very important to know that the drone technology associated with IOT at this point is the key player in creating future new industries in the era of the fourth industrial revolution. Since the drones communicate via the wireless internet, the popularized IOT has played a decisive role in enabling the public to access the drones at low cost. In this regard, the core of the drone technology called the Fourth Industrial Revolution in the sky is the IoT wireless communication technology. The convergence of two technologies will accelerate as the number of drones with various purposes is expected to grow exponentially and network-based control for drone is required for various applications. In this regard, the bi-directional bridging discussion of this chapter could be re-evaluated much more realistically in the new context of the 'the fourth industrial revolution' which would open up a new potential of multiple drone survey (drone CPS cloud network) beyond the current approach based on the single off-the-shelf drone [7].

References

1. Akanmu A, Anumba C, Messner J (2014) Critical review of approaches to integrating virtual models and the physical construction. Int J Constr Manag 14(4):267–282. https://doi.org/10.1080/15623599.2014.972021
2. Wu F-J, Kao Y-F, Tseng Y-C (2011) From wireless sensor networks towards cyber physical systems. Pervasive Mob Comput 7(4):397–413. https://doi.org/10.1016/j.pmcj.2011.03.003
3. Bergen M (2018) Nobody wants to let Google win the war for maps all over again. Star Bus J
4. Newsroom (2018) The work of the future? The cartographer (for self-driving cars). Morning Future. https://www.morningfuture.com/en/article/2018/05/09/cartografia-mappe-auto-guida-autonoma-self-driving-car/306/. Accessed 26 Sept 2018
5. Mattern S (2017) Mapping's intelligent agents. Places J. https://doi.org/10.22269/170926
6. Andrejevic M, Burdon M (2015) Defining the sensor society. Telev New Media 16(1):19–36
7. Um J-S (2017) Valuing current drone CPS in terms of bi-directional bridging intensity: embracing the future of spatial information. Spatial Inf Res 25(4):585–591. https://doi.org/10.1007/s41324-017-0126-2
8. Akanmu A, Anumba C, Messner J (2013) Scenarios for cyber-physical systems integration in construction. J Inf Technol Constr 18:240–260
9. Chen C, Yan J, Lu N, Wang Y, Yang X, Guan X (2015) Ubiquitous monitoring for industrial cyber-physical systems over relay- assisted wireless sensor networks. IEEE Trans Emerg Topics Comput 3(3):352–362. https://doi.org/10.1109/TETC.2014.2386615
10. Mitchell HB (2007) Multi-sensor data fusion: an introduction. Springer, Berlin
11. Walter O, Schmalenstroeer J, Engler A, Haeb-Umbach R (2013) Smartphone-based sensor fusion for improved vehicular navigation. In: Positioning navigation and communication (WPNC), 10th Workshop on, 2013. Citeseer, pp 1–6

12. Llinas J, Hall DL (1998) An introduction to multi-sensor data fusion. In: ISCAS'98. Proceedings of the 1998 IEEE international symposium on circuits and systems, 1998. IEEE, Piscataway, pp 537–540
13. Altun M, Celenk M (2017) Road scene content analysis for driver assistance and autonomous driving. IEEE Trans Intell Transp Syst 18(12):3398–3407. https://doi.org/10.1109/TITS.2017.2688352
14. Hofmann U, Rieder A, Dickmanns ED (2003) Radar and vision data fusion for hybrid adaptive cruise control on highways. Mach Vis Appl 14(1):42–49
15. Future Aerial Innovations (2018) Future drone cloud. http://futureaerial.com/future-drone-cloud/. Accessed 28 Sept 2018
16. Fingas R (2016) Apple to use drones, indoor navigation data to improve Maps in 2017. AppleInsider
17. Plevny BJ, Armstrong A, Lopez M, Okpara D (2017) Indoor Mapping Drone. Honors Research Projects. The University of Akron, Ohio, USA
18. Kim S, Park S (2017) CPS(Cyber Physical System) based manufacturing system optimization. Procedia Comput Sci 122:518–524. https://doi.org/10.1016/j.procs.2017.11.401
19. McNeal GS (2016) Four reasons why drones, not driverless cars, are the future of autonomous navigation. Forbes. Forbes, USA
20. Berman B (2016) Whoever owns the maps owns the future of self-driving cars. Popular Mechanics. Springer
21. Bergen M (2018) Google won the last maps war. Self-driving cars give other mapmakers a chance to find their own way. LA Times
22. Komissarov V (2016) Future of maps: self driving cars, satellites & UAVs, Crowdsourcing. Medium. Medium Corporation
23. Toth C, Paska E (2007) Mobile mapping and autonomous vehicle navigation. Revue Francaise Photogramm Teledetection 185:57–61
24. AeroMobil (2018) Flying Car. AeroMobil. https://www.aeromobil.com/. Accessed 30 Sept 2018
25. O'hare R, Zolfagharifard E (2016) Flying cars are just TWO years away: Terrafugia claims its TF-X will be ready to take to the skies by 2018. Mail Online. Associated Newspapers Ltd
26. Lilium (2018) The Lilium jet: all-electric. affordable. With the push of a button. Lilium https://lilium.com/mission/. Accessed 29 Sept 2018
27. Hahanov V, Gharibi W, Abramova LS, Chumachenko S, Litvinova E, Hahanova A, Rustinov V, Miz V, Zhalilo A, Ziarmand A (2014) Cyber physical system – smart cloud traffic control. In: Proceedings of IEEE East-West Design & Test Symposium (EWDTS 2014), 26–29 Sept 2014. pp 1–18. https://doi.org/10.1109/EWDTS.2014.7027107
28. Maher K (2017) Flying under the radar: low-altitude local drone use and the reentry of property rights. Duke L & Tech Rev 15:102
29. SESAR J (2016) European Drones Outlook Study. Unlocking the value for Europe SESAR Joint Undertaking:93
30. Coppa I, Woodgate P, Mohamed-Ghouse Z (2016) Global outlook 2016: spatial information industry. Australia and New Zealand cooperative research centre for spatial information. Melbourne
31. Howard C (2012) Unmanned, sensor-laden, and ubiquitous. Military & Aerospace Electronics
32. Roh W, Seol J-Y, Park J, Lee B, Lee J, Kim Y, Cho J, Cheun K, Aryanfar F (2014) Millimeter-wave beamforming as an enabling technology for 5G cellular communications: theoretical feasibility and prototype results. IEEE Commun Mag 52(2):106–113
33. Cearley DW, Burke B, Searle S, Walker MJ, Claunch C (2017) The top 10 strategic technology trends for 2018. Gartner. http://brilliantdude.com/solves/content/GartnerTrends2018.pdf
34. Motlagh NH, Taleb T, Arouk O (2016) Low-altitude unmanned aerial vehicles-based internet of things services: comprehensive survey and future perspectives. IEEE Internet Things J 3(6):899–922. https://doi.org/10.1109/JIOT.2016.2612119

35. Sai L, Wei Z, Xueren W (2017) The development status and key technologies of solar powered unmanned air vehicle. In: IOP conference series: materials science and engineering, vol 1. IOP Publishing, p 012011
36. Dricus (2015) Top 8 solar powered drone (UAV) developing companies. Sinovoltaics. Sinovoltaics Group
37. Ehernberger L, Donohue C, Teets EH Jr (2004) A review of solar-powered aircraft flight activity at the Pacific missile range test facility. Kauai, Hawaii
38. Simic M, Bil C, Vojisavljevic V (2015) Investigation in wireless power transmission for UAV charging. Procedia Comput Sci 60:1846–1855
39. Sürer MG, Arat HT (2017) State of art of hydrogen usage as a fuel on aviation. Eur Mech Sci 2(1):20–30
40. Cavender K, Evans C, Haney J, Leachman J (2017) Design of a helium vapor shroud for liquid hydrogen fueling of an unmanned aerial vehicle (UAV). In: IOP conference series: materials science and engineering, vol 1. IOP Publishing, p 012004
41. Gong A, Verstraete D (2017) Design and bench test of a fuel-cell/battery hybrid UAV propulsion system using metal hydride hydrogen storage. In: 53rd AIAA/SAE/ASEE Joint Propulsion Conference, p 4867
42. Cavender K, Evans C, Haney J, Leachman J (2017) Design of a helium vapor shroud for liquid hydrogen fueling of an unmanned aerial vehicle (UAV). IOP Conf Ser Mat Sci Eng 278(1):012004

Chapter 8
Futurology and Future Prospect of Drone CPS

Abstract Our ancestors could reasonably expect the future lives of their children by looking for the lives of their ancestors. Nowadays, artificial intelligence is rapidly replacing most of the jobs that humans have done with natural intelligence in the current generation. However, currently, it is hard to find out formal education about futurism to prepare for the era of artificial intelligence. Memorizing education useless in the era of artificial intelligence has been currently implemented throughout primary school to university education. The 'CPS Revolution' will radically change the hierarchy of human needs defined by Abraham Maslow, which leads to anywhere CPS economy that affects virtually every aspect of human life such as smart home, smart factory, smart city and smart grid etc. Due to the relatively short history, there is no realistic discussion on future prospect of drone CPS in comparison with previous industrial revolutions in terms of futurology. For instance, rather than producing cars by means of transportation, it is believed that much more weight will be devoted to the production of autonomous flying cars to enjoy leisure time. The purpose of this chapter is an attempt to outline future possibilities that are likely to occur in the drone CPS, such as exponential speed in cyber-physical bridging development and an AI instrument to speed up anywhere CPS economy. Subsequently this chapter presented future prospects of drones as a new necessity such as computer, car and smartphone.

8.1 Introduction

A company that has done well until yesterday could be closed today. If so, a company that is doing well right now can turn into a decline path tomorrow. In retrospect, there were no personal computers 35 years ago, no smartphones 15 years ago, and Google 15 years ago. In other words, there has been such a tremendous change in the last 15–35 years. So what will happen in the next 10–20 years? In an industrialized society, teachers have taught students a standardized curriculum to prepare for jobs; an entrance exam, a qualification system, and a multiple choice test method. The world is changing much faster than ever before. For memorization-based knowledge, artificial intelligence is far

J.-S. Um, *Drones as Cyber-Physical Systems*,
https://doi.org/10.1007/978-981-13-3741-3_8

superior to natural intelligence. However, memorization-oriented knowledge transfer is taking place by formal educational systems at all levels, in almost all countries of the world.

This means that people have very immature and largely unexamined pictures of the future in contrast to the comparatively more mature and purposely trained expert ideas for the classical academic subjects, such as history, geography, physics, biology, mathematics and the rest. Of course people do have ideas about the future, but they did not learn from their formal education, but rather almost entirely from the media (TV and films) or written fiction [1]. It is quite apparent that CPS technology is being integrated into our cars soon and becoming the brains of the machine, replacing the traditional internal combustion engine (ICE) powered by fossil fuels. Numerous futurists have faith in that humans will soon construct sky highways filled with personal drone taxi. Such drones flying over multi-tiered aerial roadways portrayed in the science fiction movies eventually will become popular alternatives to current manned cars [2].

The teacher should always be aware of the changes of educational paradigm due to the rapid transformation of future society. The way to succeed in this situation is to develop new teaching methods on what skills they will most need when the current child become adults. Education should not only follow changing realities, but also find new ways and directions for realities that are acting as obstacles to the coming AI era or CPS era. It is no exaggeration to say that the rise and fall of the nation depends on the teacher, as humans need a completely different skill to survive in the AI-based society or the lifelong CPS era. The present chapter is an attempt to identify future possibilities that are likely to occur and provide solutions for what to avoid and what to do. In other words, future forecasting will allow humans to create a selective future by setting visible trends, alternatives and possible future. It will help students not to fall behind the regional or foreign competitors in job seeking by evaluating the internal and external challenges faced by cyber-physical bridging of drone technology.

8.2 Essential Background Concerning Futurology

8.2.1 Our Daily Lives and Prediction

When we make decisions about the future, we all become prophets. When we decide a travel schedule, residential house, university major, future husband/wife and any other commitments, all of these predict the future. All these projections and plans require certain knowledge, a substantial stock of experience and tacit know-how before deciding the event. In our daily lives we move in and out of such different futures without giving much thought to the matter [3]. The future is always the concern of all of us. Everyone wonders from the weather of tomorrow to the fate of the individual, the future of the earth, and the days after death. Future science is a field that not only provides important help for making a bright future for each human being and human society, but also a way to present a vision to make the country peaceful and energetic.

Companies invest enormous amounts of money to develop new products based on future forecasts. Predicting the future occupies a very important position in Government agencies such as forecasts of the national economy, environmental impacts of specific development projects, and the effects of proposed social programs [4]. Forecasting can help people and organizations to plan for the future and to make rational decisions. For example, what would happen if your government raised the income tax? Or what if it increased the minimum wage? [4] Consider the following. You are now working as a taxi driver, what if your government legalized self-driving car? To determine the best course of action, you should have relevant knowledge on the effect that recommended changes would have on your job [4].

While formal educational systems work hard to give students a specific (often "scientific") view of the world around them, they are so lazy in teaching marketable products or idea through the class. This is essential for survival in stronger competition, particularly in the light of very short product life and increasing globalization in the CPS based economy. Awareness of governing relations and principles of futurology is a kind of scientific prediction which enables individuals to overcome challenges that lie ahead in various fields. The future direction for the CPS and its technological advance speed can be grounds for becoming individuals in line with the resistance economy and finding new jobs. Any individual can take actions to surmount obstacles, to turn threats into opportunities, based on the knowledge about CPS. The companies who know the CPS can produce competitive products to survive in intense market competition, for example, escaping from the reliance on the non-CPS-product.

8.2.2 Concepts of Futurology

Future studies, futurology is a discipline that establishes the theory for the future direction by analyzing the past and present changes in the integrated manner. For instance, in order to understand the fourth industrial revolution, we must look to the past third information revolution. Current available IT technologies can begin to understand how they have reached such an innovative exciting point linking online and offline. It is a multidisciplinary study that shows us probable forms of society to come by means of empirical and analytical data of the past and present societies in the time axis. Alternate terms include future studies, futuristics, forecasting, and futurism, strategic foresight, future thinking, futurology, and futurism. What is the word future studies often mentioned is because the uncertainty about future society has spread rapidly among modern people. The cause of anxiety is a sudden environmental change due to the recent remarkable technological innovation such as environmental destruction and rapid climate change etc.

This futurology is fundamentally different from other disciplines because no one can verify the results of future research targeting the future society. Futurology shares many characteristics with successful new religious movements such as charismatic leaders, authoritative texts, an attraction or mystique, and a notion of salvation [5]. The knowledge and methodology used in futurism are much less proven as compared to other natural sciences or even social sciences. Therefore, there is criticism that it is difficult to accept futurology as an independent field of academic discipline. In general, futurism is regarded as a branch of the social sciences and parallel to the field of history. From this point of view, history studies the past and futurism focus on the future.

Futurists can include professional and academic writers from many disciplines, such as economics, history, computer science, engineering, anthropology, environmental science, mathematics, physical sciences, political science, and sociology. Many futurists have not majored futurology from the beginning. The social science profession, technologists, artists, and others with diverse academic backgrounds utilize their methodology established in their respective majors to study the future. Future practitioners use a wide range of models and methods (theory and practice), many of which come from other academic disciplines, including economics, sociology, history, engineering, mathematics, psychology, physics, biology, astronomy, and religious studies. Because of this, quite a number of futuristic theories are criticized for not having a solid scientific basis. As the social science, art and physical science work together in laboratories and studios, the output they produce is unlike anything done by single discipline.

8.2.3 Historical Background for Futurology

There was a time when the future was considered a subject for prophecy rather than industrial rationality and empirical analysis. From the last decades of the twentieth century, futuristic speculation began to exceed the category of astrology and Christianity forth-tellers [6]. Ancient civilizations such as Greece, Romans, Egypt, Persia, India and China all shared in the belief that human fate is associated with the stars, traced back some 4000 years. Futuristic speculations have relied on astrology to guide their decisions, calm down their gods in the upcoming natural disaster (such as earthquake, storm and famine) and safeguard their collective prosperity. A first change in this ancient knowledge system occurred when Aristotle began to shift his commitment from astrology to the science of astronomy [3]. Christianity and the rise of natural science later have further confronted for the collective appreciation and acceptance of astrology as a means to tell the future. But they had absolutely not eradicated its popularity. Prophecy is a much larger biblical genre than most people think. The prophets of Old Testament (e.g. Samuel, Isaiah, Daniel) and New Testament (the twelve Apostles) actually involved God's messengers speaking the word of God to a contemporary culture. As such, these prophets were forth-tellers who deliver messages needed to cease its resistance to the word of God.

In the second half of the twentieth century, these efforts to predict the future grew more ambitious and sophisticated. Improvements in computational power, data gathering, and analysis were all attempted to open the veil on the future. Some of these made considerable improvement over the last 30 years. For instance meteorologists have drastically improved computer models for weather forecasting. Banks developed statistical techniques to estimate the risk of complex bundles of securities, based on their past performance. Businesses, government institutions gained a reputation for using qualitative futurology to improve their ability to react to the unexpected. But the last decade has not been kind to current futurology. Forecasts of banks and insurance companies turned out to be drastically wrong, destroying the financial system. Political visions for long–term stable economic growth leaded to a long stagnation [7]. Futurology is a relatively new field of study, and the term futurology was first used during World War II by political scientist Ossip Flechteim, to describe this new field of knowledge based on a probable and systematic analysis for the future [8]. Futurology first emerged as a popular non-fiction genre in the early 1970s, with Alvin Toffler's best-selling book, Future Shock [9] and The Limit to Growth that announces wake-up call for the environmental contamination and warns some natural limits to growth [10].

8.2.4 Major Forecasting Principles

Economic theory shows a few different approaches to the conceptualization of the future (Table 8.1). The disclosure or release of the future take many forms: the form of prophecy, prediction, projection, forecast, futurology, plan, scenario and prospective analysis [12]. Forecasting is usually understood as a basis for a plan or strategy, while planning and strategizing is understood as anticipative behavior. Such a wide range of different concepts of the future is often the source of misunderstandings [13]. Futures studies is often summarized as "three Ps and a W", or possible, probable, and preferable futures, plus wildcards, which use a diverse range of forecasting methods; Scenario method, Delphi method, system dynamics, GIS (Geographic Information System), multiple spatial regression modelling, cross-impact analysis, technology road mapping, social network analysis, trend analysis and morphological analysis.

Table 8.1 Different approaches to main concepts of the future

Concept	Definition
Prophecy	Statement of the future made irrationally by superstition or by divine inspiration
Prediction	A prediction is often based upon experience, know-how, or data, information and knowledge. (informed guess or opinion [11])
Projection	Extension of the past behavioral pattern into the future
Forecasting	Forecasting as a basis for a planning is understood as predicting based on specific trustworthy data.
Planning	Planning as a purely socialist phenomenon concerns what the world should look like (anticipative behavior), while forecasting is about what it will look like.

The choice of an appropriate forecasting method depends on the goals of the research project and the context in which this research takes place. For example, for long-range forecasting of the environment or of the market, econometric methods are often appropriate. For short-range forecasting of market share, extrapolation methods are useful. Forecasts of new-product sales could be made critically by experts. Decisions by parties in conflict, such as companies and their competitors, can be predicted by role-playing [4]. Forecasts are divided into three categories according to the temporal range; long-range forecasts (covering several decades), medium-range forecasts (covering the coming decade) and short-range forecasts (covering a few years). Future forecasting is often summarized as three different principles: Principle of continuity, Principle of non-continuity, Principle of Intuitive Forecasting. Viewed historically, futurology has gone through various phases which are closely coupled with these three different ways of understanding the future. This evolution has consisted on the one hand in a shift away from purely quantitative techniques to more qualitative and/or combinative techniques which are often more appropriate for dealing with the complexity of the future [14].

Principle of Non-continuity is different from conventional scientific beliefs, which are factual and objective in their grounds. The scientific forecasting is understood as predicting based on specific trustworthy data. If there are no past and existing aggregates of facts, the future cannot be predicted [3]. Predicting the social phenomenon is hindered by limited past observations. Socio-historical and economic phenomenon clearly does not provide us with equivalent laws. The social past does not determine the social future. History is not a reliable guide to what is to come. Unexpected social change, innovation and progress mean that predicting social futures by scientific means is a far more unjustified business [3]. In this manner of viewing things, our present knowledge is taken to be inadequate for predicting future developments. The future tracks a chaotic, uncontrolled, and random path. This paradigm assumes that a purposeful control of future events is impossible. Instead, up-and-coming strategies or case by case are the appropriate manner of dealing with future courses of events.

Principle of Intuitive Forecasting means that the future is flexible. In this view, the course of future events is not predictable, but neither is its development fully chaotic. The development of the future is open to intentional manipulation and can thus be influenced (at least in part) by our actions. This paradigm puts its trust in strategies of intervention aimed at shaping the future, with an emphasis on the role of those who take action, along with their goals and decision-making processes in shaping the future [14].

Principle of Continuity means that the future is predictable and controllable. Whatever will come to pass in the future can (in principle, at least) be calculated from our knowledge of the present and past. The more knowledge we gather in the present, the more certain is our diagnosis of the future course of events [14]. Principle of continuity is understood as predicting based on specific trustworthy data and depends on above all on a statistical trend extrapolation. For example, scientists refer to cyclical and regularly occurring natural events. Water will always freeze at zero degrees centigrade. If one has full and extensive past knowledge of such processes, one can predict that event in the same status-quos will occur in the same way in the future. The source of knowledge for such predictions is a collection of past observations projected into the future. The past is the basis on which scientific laws are established [3].

8.3 Future Prospect of Drone CPS

This uncertainty and inadequacy of established forecasting tools for the Fourth Industrial Revolution has made our demanding projections and future scenario dependent daily on media such as TV and newspaper. Forecasting attempts to predict future states from current trends and it is a common futurology methodology. Scientific forecasting is not an attempt to predict future technological innovations which are essentially unpredictable, but an examination of possible variants of future technology developments. If we can grasp the situation from the past to the present (back-casting), we can predict the future to some extent. Back-casting often extrapolate present technical and societal trends and assume they will develop at the same rate into the future. But technical progress and social transformation, in reality, take place in different areas at different rates. We had experienced the information society, but we have not yet foreseen where this revolutionary technology development may lead to in the future. Without certainty of past facts scientists had no basis upon which to calculate the future.

In order to understand the CPS future we must look to the past, through research into the origins of the past industrial revolution. Economists divide the factors of production into four categories: land, labor, capital, and entrepreneurship. The past industrial revolution was to increase labor productivity by utilizing new technologies such as steam engine and information technology. The Fourth Industrial Revolution has the same viewpoint as the previous industrial revolution since it is to decrease the demand for labour by utilizing new technologies such as artificial intelligence. Division of labour into AI would lead to the greatest improvement in the productive powers of labour.

8.3.1 Adam Smith versus Thomas Robert Malthus

It was a time when the future was considered a subject for prophecy and science fiction rather than empirical analysis [6]. The sustainable economic growth was a major social issue in the first Industrial Revolution era, with the pessimism of Thomas Malthus contrasting with the optimism of Adam Smith [15]. It began in 1776 when Scottish economist Adams Smith published his Wealth of Nations. In contrast, an Essay on the Principle of Population written by British economist Thomas Robert Malthus In 1798 predicted a grim future economy due to population explosion. Smith was concerned about the nature of economic growth. Malthus, Ricardo and other classical economists were concerned about the question of distribution. The adjective "Malthusian" is used today to describe a pessimistic prediction of human life quality miserable due to starvation via overpopulation.

In the Wealth of Nations, Smith made it clear that machinery can increase productivity since the tasks performed through various steps previously can be simplified through the division of labor. Adam Smith had noted the tendency for machinery to replace and displace human labor in industrial society. The machine is most recognized as systems toward mass production since the same number of workers could produce substantially more output by utilizing machine. Adam Smith saw this introducing machine as a key to economic progress by providing a cheaper and more efficient means of producing goods. Malthus was convinced that, in spite of any technical improvement, the growth of population would inevitably be more aggressive than the growth of production [15]. Malthus emphasized the fact that every resource is limited, and he predicted that as the population grew, resources would become even more limited. Spiraling population growth would eventually outpace the increase in food supply, leading to famine and epidemics of disease. He argued that population will grow in geometric progression (i.e. 1, 2, 4, 8, 16…), while food supply increases arithmetically (i.e. 1, 2, 3, 4, 5,…). His ideas were essentially restricted to the conditions of a predominantly agrarian economy, because his analysis underestimated technological change as a powerful force transforming the productivity conditions both in agriculture and in industry.

The Industrial Revolution made and production of goods more efficient and the lives of people easier. Technological innovations in agriculture also amplified crop yields supporting the population increase. In an industrialized country hunger has disappeared, food expenditure occupies no more than a quarter of the average personal expenditure, expectation of life at birth is well above 60 years. Critics have been tireless in pointing out that Thomas Malthus' economic predictions have not been proved by tangible facts [16]. As Kurzweil points out, history has repeatedly demonstrated that the more technologically advanced cultures have triumphed over the less technologically advanced cultures [2].

8.3.2 CPS as an Automated Invisible Hand: Drones as a New Necessity

CPS (for instance, smart factory) is a system that operates almost automatically to produce the greatest good for the greatest number. The theory for the CPS states that if each CPS is allowed to choose automatically what to buy and each producer is allowed to choose automatically what to sell and how to produce it. Moreover, the CPS would constantly endeavor to improve the quality of products and to organize production in the most efficient and least costly manner possible. This CPS system acts as an "automated invisible hand" that converts private interests into what is most agreeable to the interests of the whole society as Adam Smith indicated in the Wealth of Nations [17].

It is expected that human has little to do with the CPS based economy since the self-regulating behavior of the CPS can make profit and maximize it by minimizing the need for human intervention. The greatest beauty of it can lead to the almost complete lack of human guidance or direction by augmenting AI performance into mutually consistent and complementary activities. Freedom from the human labor economy is compatible with the nature of the CPS economy in which the welfare of each person, as well as the welfare of all society would be maximized. CPS left on their own AI would work for the human-interests as if by an autonomous invisible hand to achieve the maximum good for society. While various CPS such as the self-driving car and drone are engaging in their enterprises for the purpose of earning money, they are also providing products that people want. Such a system, Adam Smith argued, creates wealth not just for the car owner and ground pilots of the drone, but for the nation as a whole when that nation is populated with citizens working productively to better themselves and address their financial needs [18].

As the fourth industrial societies will develop increasingly efficient production techniques, continuing rises in productivity would lead to reduced working hours and expanded leisure time [19]. As CPS will be utilized in everyday life, the quantitative concept of working time and leisure time will be reversed. People would be more likely to spend more time to enjoy leisure (full time) while working time would be the smaller portion in entire human lifespan (marginal). At this stage, many people will have jobs that are not related to the production process of the commercial commodities such as cars. As CPS is dedicated to production of commercial commodities, people will try to spend money to realize the needs of life that were not important in the past. Abraham Maslow defined a Hierarchy of Human Needs. The hierarchy stated that the lower needs (e.g. food) must be met before an individual can strive to meet the higher needs (e.g. enjoying leisure) [20]. As shown by Maslow's famous hierarchy of needs, in the past, most resources have been spent to meet the basic human needs like security, nourishment, clothing and warmth. There will be a time when people will spend money to meet the humans desire to fly over the sky in the not too distant future (Fig. 8.1).

For instance, rather than producing cars by means of transportation, it is believed that much more weight will be devoted to the production of autonomous cars to enjoy leisure time. Ultimately, the end of labor, and the rise of the leisure society is actually forthcoming [19]. There are a number of products that people have consumed a lot of money based on traditional life value standards. However, there is a high possibility that these products will be undervalued based on totally different value standards. The current car can become very cheap or even disappear when unmanned flying cars are released. There is a high probability that products that people do not consider as a necessity are emerging as a new necessity. Considering the primitive instincts of humans wanting to fly in the sky, drone is a representative product having these characteristics.

With regard to leisure, the use of drones such as art, drone show (2018 Winter Olympics in PyeongChang, South Korea), cultural performance, and sports (drone football) is so extensive. As the artificial intelligence society progresses, it will be evident that the drones are emerging as a necessity. More exactly, human driving cars were deemed necessary in the non-CPS era before the fourth industrial societies.

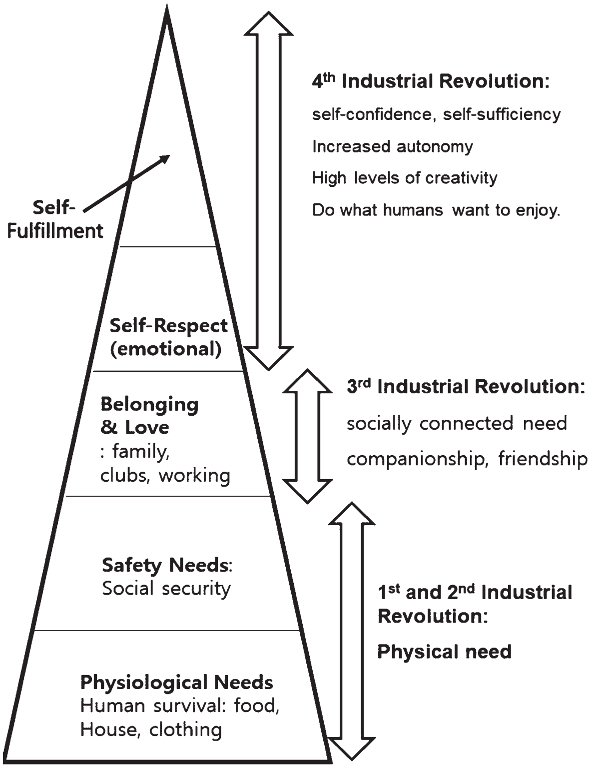


Fig. 8.1 Schematic diagram showing the hierarchal relationship between human needs and industrial revolution

Increasingly, human in the fourth industrial societies will be choosing from everything that is desirable to achieve reduced working hours. Advanced industrial society is in permanent mobilization toward this expanded leisure time. Desirable possibility such as self-driving flying car itself would be going to emerge as a new necessity.

8.3.3 Exponential Speed of Drone Cyber-Physical Bridging

8.3.3.1 Disruptive Power of Cyber Technology

Over the course of the last decade, cyber technologies have increased their potential to disrupt societies, cultures and politics, in positive and negative ways. The television, telephone, and computer have become the prototypical machines of the modern Information Age, although, computer technology is often identified as the central driving technology in the contemporary technological revolution [2]. The list below includes examples of these technologies directly or indirectly, influenced and supported industry change and innovation with the use of computers and information technology.

Visual information → paper map → tablet CNS (Car Navigation System)→ smartphone CNS
Public telephone → portable phone → feature phone, folder phone→ smart phone
mainframe → workstation → PC
video tape lending shop → online music download
typewriter → personal printer and computer
postal service, postal box → email
newspaper → portal, web
magnetic tape → video tape → CD → DVD → USB
floppy disk → CD → DVD → USB
film photography → digital photography
digital camera → smart phone
off-line market → on-line market
remote or wilderness space (such as unbridged glacial rivers and rough mountain) → connected space
constructed social spaces → on line community
slow business → real time business
traditional physical offices, office building → on line market

It is interesting to note how the pace of disruption has increased exponentially. While it took the telephone 75 years to reach 100 million users worldwide (starting in 1878), it took only 2 years and 4 months for Instagram to reach an audience of the same size. In July 2016 the location-enabled augmented reality game ‘Pokémon Go’ took a mere 25 days to be downloaded by 100 million users. We live in times when the adoption of new technology is occurring at an unprecedented pace [21]. Smartphones are the most visible interface of ubiquitous cyber infrastructures. The reason has not been new political or economic doctrines but cyber- innovations are providing novel ways to enable an “always on” the touchpoint for a wide array of products and services. Cyber technology linking mobile, social, and cloud technologies are being interwoven into the fabric of everyday life creating new value or offering new efficiencies.

The first Android smartphone, the HTC Dream (or T-Mobile G1), had been released in 2008. Smartphones have currently attained the most important position in the daily life of ordinary people since there is almost no limit to what you can do with a smartphone these days [22]. All of our everyday needs were replaced by smartphone, for instance, one-stop-shop, cameras, calculators, diaries, satellite navigation and even on-line class such as torches [23]. Some have the ability to talk to you, answer questions, turn off your lights when you are not there, open doors, and even watch movies. We are not only reliant on our digital devices for quick communication, but that we also seek the same comfort and stability from our phone as we do from family and friends [24]. The shocking reality is that smartphones transformed ordinary people’s life and business pattern and changed the world within 10 years. Further smartphones are advancing at a very quick pace. As a result, the potential of cyber-physical bridging has evolved over the last decade to accommodate disruptive power of this computers and connection technology.

8.3.3.2 Cyber-Physical Bridging Explosions

Cyber-physical bridging technologies are those which are unexpected but which have the power to change industries (not always for the good of established players). The world will be changed far more in a few decades than in any previous century due to cyber-physical bridging technologies. Cyber-physical bridging has implications for how people contextualize various aspects of life, their sense of space, culture and social relations. The connections as the greatest invention of the CPS era would colonize every aspect of the human life, since great many mobile users generally tend to stay in touch with internet if space has ensured connectivity. Unseen networks of connected devices and sensors would realize the full ubiquity of media and markets. Embedded microprocessors extend connectivity to virtually all ordinary objects – clothes, appliances, product packaging – in what is being called the Internet of Things, or, more ambitiously, the Internet of Everything (IoE). As a result, cyber-physical bridging can be expanded universally [25].

CPS explosions such as the smart city or smart factory over the next decade will also necessitate a CPS related infrastructure boom. For instance, current roads are not built on the premise that artificial intelligence (AI) drives. In order for an autonomous vehicle to travel, it must be re-constructed so that various objects on the road can be recognized by the sensor. We will see enormous global investment on replacing infrastructure in older, developed countries and the first-generation infrastructure being built in emerging nations. Drone will increasingly be able to act as sensors and create and update maps and related information spaces whilst smartphone expands their users and diverse applications linking with CPS. Examples might include augmented reality games as digital twin where the reality of the outdoors digitized by drone imagery is combined with the virtual reality magic of the computer world. The magic could involve increasingly in touching the lives of citizens since the three dimensional (3D) or 4D (time-sequential) drone imagery could play a key role in delivering various forms of CPS reality such as smart home, smart city. Clearly, new mobile devices like the Samsung Galaxy or Apple iPhone could be very important once augmented reality imagery captured by drone is bundled in.

Satisfactory data collection from a reliable sensor network is one of the most important concerns of the typical CPS project. Although in many previous applications, drone has been used successfully by utilizing stand-alone sensing, many applications could be improved, in terms of information collection by adopting a CPS approach. Until now drone cloud sensing in an area-wide CPS environment has just been at the exploratory stage. Many of the limitations inherent in the current practice of stand-alone drone could be reduced or overcome by fuller use of near future technology since, nowadays, most ‘cutting-edge’ equipment is based on the AI and IOT approach. It is difficult to predict even 2 or 3 years ahead, considering the rapid changes which have recently occurred in IOT and AI technologies. Concerning the computing side, it is difficult to see how fast or far AI computing (which identifies motion pictures and the necessary required computing power) will progress. The AI drone and super connected IOT will soon make present stand-alone drone sensing obsolete, by making it possible to acquire data sets with a hyper-spectral or spatial real-time imagery, depending on the capability of the sensor in terms of memory and extended storage.

An article published in The Economist titled, “Welcome to the Drone Age: Miniature Pilotless Aircraft are on the Border of Becoming Commonplace [26],” parallels the increasing popularity of drones to the rise of personal computers in the 1980s. For a relatively low cost, drones with photography and videography capabilities, the ability to fly more than 100 m above the ground are being purchased by individuals who may not have had previous interest or experience in aeronautics [27]. With the declining cost of the drone, these types of system will be available to broader markets, including video enthusiasts and home users in the not-so-distant future. As more people would have instruments for making high-resolution imagery and share it with the community, there would be closely connected interaction between off-the-shelf drone owner and mapping company to implement crowd-sourced mapping and to assist the time-dependent user.

In this regard, it may not seem a premature to think of introducing drone CPS mapping for routine applications. As the artificial intelligence society flourishes, the demand for various tools to teach artificial intelligence will increase rapidly. A real-time high-precision map is a typical example. It is designed to teach the artificial intelligence mounted on autonomous vehicles. As artificial intelligence begins to be applied to various fields such as smart home, smart building, smart factory, and smart city, the demand of 2D, 3D and 4D drone imageries as teaching tool for AI will surge. A platform for sharing drone imageries for various applications will be an important future industry. In fact, since drone images are a key tool for teaching artificial intelligence, drones will serve as a key tool for the proliferation of the fourth industrial revolution based on artificial intelligence. On-line platform such as youtube will continue to develop as the drone imageries are spreading widely for deep learning of AI. User uploaded drone imagery will play a key role in advancements in “deep learning” of artificial intelligence.

8.3.4 Drones as an AI Instrument to Speed Up Anywhere CPS Economy

8.3.4.1 Drone as AI Instrument

The super-intelligent drone armed with AI will thoroughly change the real world by adding hyper-connectivity to the entire existing system such as building, factory, road and car etc. Drones equipped with a growing array of fixed environmental sensors and interactive deep learning online platforms will infiltrate all aspects of our lives and the possible applications of drones suddenly appear limitless. Drone as AI instrument will cause radical changes to traditional forms of information collection, storage and analysis processes. We will experience a shift from targeted, purposeful and discrete forms of information collection to always-on, ubiquitous, ever-expanding and non-specific forms of data generation and acquisition. The increased use of drone therefore marks important changes to our understandings of surveillance, information processing, and privacy [28]. As intelligent things proliferate, we expect a shift from stand-alone intelligent things to a swarm of collaborative intelligent things. In this model, multiple devices will work together, either independently of people or with human input through autonomic sensing and autonomic control [29].

For example, during the 2018 Winter Olympics in PyeongChang (South Korea), Intel's Shooting Star has performed "drone show" as alternative to the traditional fireworks by operating 1218 drones in the sky simultaneously, breaking the Guinness World Records. Intel's Shooting Star drones created various colorful illustrations in the sky, including the Olympics mascot, the white tiger who comes running above the stadium and a heart drawn in the sky to show the love and appreciation for all the Olympic athletes and fans from around the world. Each drone is able to emit more than 4 billion color combinations and they are custom-built for entertainment purposes. All the drones in the air during the shows are flown by only one ground pilot [30]. The age of autonomic drone shipping corps is approaching, in which dozens and hundreds of drones communicate with each other to accommodate the orders of the customers while the drone located closest to the customers are delivering the ordered goods by themselves (Fig. 8.2). It is anticipated that artificial superintelligent drones will communicate directly and fluently with human brains in the not too distant future, changing the way we work.

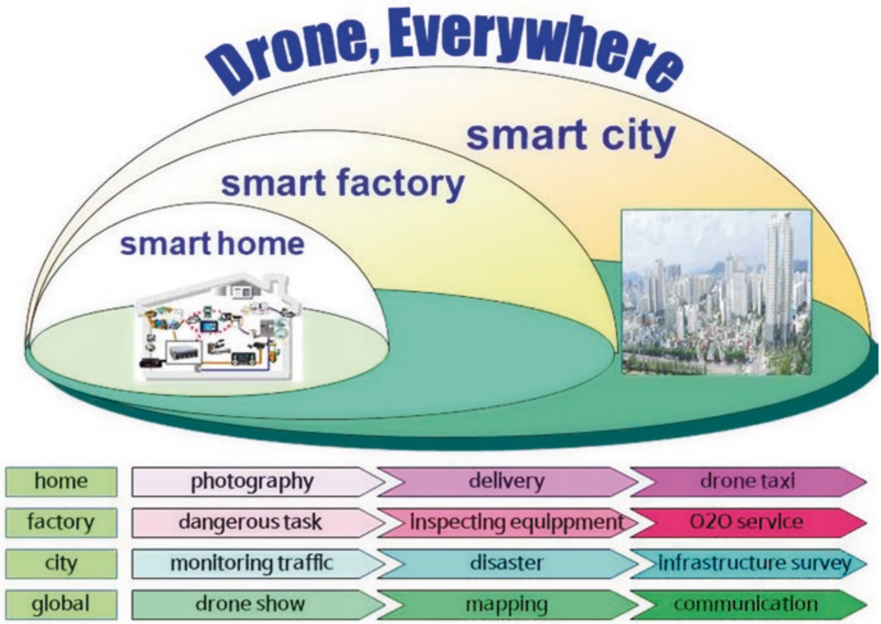


Fig. 8.2 Schematic diagram showing future prospect of drone toward anywhere CPS economy

The recent spurt in AI technology, combined with advanced design, mapping, and visualization techniques, makes possible today something that was unimaginable even a few years ago – a virtual or augmented reality and mobile eye in the sky [31]. The limitation of the movement to the real world can go beyond imagination through the drone imagery. It will provide AR (Augmented Reality) service that allows you to experience a space that is similar to the real physical system, offering touching, stirring and heartbreaking spatial and time elements. For instance, screen golf lets you enjoy the feeling of a real golf course without going directly to the field. There will be a variety of tangible services through 360 degree virtual reality (VR) functions to reflect customer needs such as on-site experience before purchasing real estate, real-time field experience for the construction site, and preliminary exploration of travel destinations.

8.3.4.2 Anywhere CPS Economy

Historically, workers have always lived in the vicinity of the place where they work. The farmer lived in the vicinity of the farmland. Factory workers resided around the factory and relocated nearer to manufacturing centers. However, the past models of such occupations and places of residence will not appropriate in CPS era. Even if the office does not exist, you can do any business if the Internet is connected. No matter what occupation, location would not be important, but information and connectivity will be emerging as the most important factor. Business will operate where and when it wishes, and enterprise will become size-neutral. Cyber-physical bridging tools will make people powerful because they will make them geographically independent of homes and offices. With the right cyber-physical bridging business model, companies can sell their products to global customers using mobile connectivity technologies while still creating and maintaining sticky relationships with customers in a customer-centric way. Cyber-physical bridging technology flexible from staff and clients could bring about the end of traditional offices. Conducting business in a well-connected cyber and physical world means that geography and size will no longer rule. While the world is still exploring and discovering additional opportunities that cyber-physical bridging technologies may offer, it’s clear that we are on our way to an anytime, anywhere CPS economy.

With the deployment of drones, different new business models will emerge such as sensing and services applications. These businesses will utilize these flying vehicles as a platform that works in parallel to the ground Internet or to complement the coverage of 5G. For instance, drones can operate as high altitude communications relay platform that can deliver mobile, persistent connectivity over different regions [32]. For example, Google tests multiple prototypes of solar-powered Internet drones to ensure security for delivering Internet from the sky. Google SkyBender uses the drones to deliver next generation 5G wireless Internet, up to 40 times faster than 4G systems [33]. Moreover, drones are foreseen as an important component of an advanced cyber-physical Internet of Things (IoT) ecosystem [33]. IoT aims at enabling things to be connected anytime, anywhere ideally using any network and providing any service. The IoT concept allows drones to become an integral part of anywhere CPS Economy and infrastructure. This is due to the fact that drones possess unique characteristics in being dynamic, easy-to-deploy, easy-to-reprogram during run-time, capable of measuring anything anywhere, and capable of flying anywhere with a high degree of autonomy [34].

Drones have seen an increasing amount of attention as an evolving industry. Up until recently, drones were mostly used for media and mapping. The game has changed now with leisure drones already selling in the millions. Today's drone technology and market development includes both familiar and new faces to the world of aviation. Leading aerospace and defence players are investing into military-grade systems and related services that are also transferrable for civil uses by government authorities and, at a later stage, to commercial aviation. At the same time, new players emerging from start-up and academic settings are driving growth in leisure drones and many early forms of commercial missions [35]. These start-ups are joined by a variety of other established companies that are investing in drone related capabilities. All over the globe, start-ups and established companies are developing and providing capabilities ranging from drone development and production to drone operations and/or the development of data analytics and user platforms that act as entire area of services [35].

There will be an era in the near future where many moving bodies, including drones, can be combined through internet of things systems. In this case, the flying machine could be merged with other machines and suddenly enter the water or run on the road. For example, when a car meets traffic jam during driving, it could fly to the sky. Drones are commonly used as generic term for moving bodies that are remotely controlled or moving autonomously. It can include bodies moving on the surface of the water or submerging under the water. It can include a robot that imitates animal movements or a robot follows the behavior of insects. Drones' maneuverability, small size, and ability to operate without a human onboard create a vast array of potential uses such as nano-drones, biomimetic drone, underwater drone, and diving drone. There are many similarities in core technologies such as navigation, task assignment, coordination, and communication, and very high synergy is expected when developing as configured common distributed/collaborative physical systems (DCPS). It can carry out the variety of attracting mission being discussed from globally different markets with adaptive integrated operating system for different models and devices.

8.4 Conclusion

Young people of the present age have grown by experiencing changes of various technologies ranging from wired phone, folder phones, touch phones to smart phones. It is the role of education to induce the experience of this technological development in the positive direction as much as possible. This book has sought to clarify the drone could provide potential of new pedagogies to find core elements of cyber-physical bridging. The data collection could be done without the complicated logistics required to acquire aerial photography. As a result, it is possible that drone could completely replace existing remote sensing systems toward 'Anywhere CPS Economy'. The AI drone will resolve significantly many of the difficulties (obstacle avoidance during autonomous flight and distributed/collaborative physical systems (DCPS) in the long duration mission. The 'CPS Revolution' will radically change the means of drone bigdata acquisition, which affects virtually every aspect of Anywhere CPS economy. The improved obstacle avoidance performance will ultimately lead to the practicality of a drone bigdata toward 'Anywhere CPS Economy'.

It can be confidently asserted that there are no insurmountable obstacles in the way of implementing a 'drone big-data acquisition system' for a 'Anywhere CPS Economy'. Drone has a potential to transform our world more in the next decade than any other single factor. Technology can, in turn, affect science as more complex and powerful drone are developed for observing and investigating nature (e.g. the AI drone, the hyper-spectral sensor drone, and solar power drone). Our scientific knowledge will grow through new observations and experimental results as new finding from drone investigation often redefine our traditional values. As a result, the book has opened new possibilities for implementing drone as 'new pedagogies to find core elements of cyber-physical bridging', proposed as an initial aim of this book. However, many of the basic issues in 'cyber-physical bridging', newly suggested in this book, are still at the investigation stage. Many of the issues untouched in this book could be improved by advanced equipment at present and in the future. In particular, the emergence of high resolution sensor and improvement of deep learning power will greatly contribute to automating the drone bigdata collection process. Additionally, regulation and societal concerns related to privacy and safety remain constraints for some applications already feasible from a technical perspective.

References

1. Dator J (2003) Teaching futures studies: some lessons learned. J Future Stud 7(3):1–6
2. Lombardo T (2005) Science and the technological vision of the future. Center for Future Consciousness
3. Adam B, Groves C (2007) Future matters: action, knowledge, ethics. Brill, Leiden
4. Armstrong JSE (2001) Principles of forecasting: a handbook for researchers and practitioners, vol 30. Kluwer, New York
5. Amarasingam A (2008) Transcending technology: looking at futurology as a new religious movement. J Contemp Relig 23(1):1–16
6. Carr M (2010) Slouching towards dystopia: the new military futurism. Race & Class 51(3):13–32
7. Bland J, Westlake S (2013) Don't stop thinking about tomorrow: a modest defence of futurology. Nesta, London
8. Birx HJE (2009) Encyclopedia of time: science, philosophy, theology, & culture, vol 1, Sage, Los Angeles
9. Toffler A (1971) Future shock. Bantam, New York

10. Meadows DH, Randers J, Behrens WW III (1972) The limits to growth: a report to the club of Rome. Universe Books, New York
11. Grunwald A (2014) Modes of orientation provided by futures studies: making sense of diversity and divergence. Eur J Future Res 2(1):30. https://doi.org/10.1007/s40309-013-0030-5
12. Godet M (1990) Integration of scenarios and strategic management: using relevant, consistent and likely scenarios. Futures 22(7):730–739
13. Pfeifer S (2017) A question of time: do economists and strategic managers manage time or do they even care? Manag J Contemp Manag Issues 6(1–2):89–105
14. Kosow H, Gaßner R (2008) Methods of future and scenario analysis: overview, assessment, and selection criteria, vol 39. Deutsches Institut für Entwicklungspolitik, Bonn
15. Ucak A (2015) Adam Smith: the inspirer of modern growth theories. Procedia Soc Behav Sci 195:663–672. https://doi.org/10.1016/j.sbspro.2015.06.258
16. Wilde R (2018) Population growth and movement in the industrial revolution. ThoughtCo. Dotdash publishing family
17. Smith A (1776) An inquiry into the nature and causes of the wealth of nations: Volume One. London, printed for W. Strahan; and T. Cadell
18. Blenman J (2017) Adam Smith: The Father of Economics. Investopedia, LLC
19. Granter E (2008) A dream of ease: situating the future of work and leisure. Futures 40(9):803–811. https://doi.org/10.1016/j.futures.2008.07.012
20. Maslow AH (1968) Toward a psychology of being. Van Nostrand, Princeton
21. Coppa I, Woodgate P, Mohamed-Ghouse Z (2016) Global outlook 2016: spatial information industry. Australia and New Zealand Cooperative Research Centre for Spatial Information, Melbourne
22. John J (2018) Why are smartphones so important in daily life? TrffcMedia
23. Danzelman N (2018) Top 10 – things your smartphone will replace in the next 10 years. RL360. International Financial Group Limited
24. Emm D (2017) Digital companions: are smartphones replacing our loved ones? HuffPost News. Oath family
25. McGuigan L, Manzerolle V (2015) "All the world's a shopping cart": theorizing the political economy of ubiquitous media and markets. New Media Soc 17(11):1830–1848
26. Economist T (2015) Welcome to the drone age: miniature, pilotless aircraft are on the verge of becoming commonplace. The Economist
27. Municipalities CCo (2016) Regulating drone use. Connecticut Conference of Municipalities, Connecticut
28. Andrejevic M, Burdon M (2015) Defining the sensor society. Telev New Media 16(1):19–36
29. Cearley DW, Burke B, Searle S, Walker MJ, Claunch C (2017) The top 10 strategic technology trends for 2018. Gartner. http://brilliantdude.com/solves/content/GartnerTrends2018.pdf. Accessed 28 Sept 2018
30. Kesteloo H (2018) The 2018 Winter Olympics close with another spectacular "Shooting Star" drone show from Intel. DroneDJ
31. Padmanabhan A (2017) Civilian drones and India's regulatory response. Carnegie India, New Delhi
32. Zheng DE, Carter WA (2015) Leveraging the internet of things for a more efficient and effective military. Rowman & Littlefield, Washington, DC
33. Motlagh NH, Taleb T, Arouk O (2016) Low-altitude unmanned aerial vehicles-based internet of things services: comprehensive survey and future perspectives. IEEE Internet Things J 3(6):899–922. https://doi.org/10.1109/JIOT.2016.2612119
34. Snow C (2014) Why drones are the future of the Internet of Things. Skylogic Research, LLC. http://droneanalyst.com/2014/12/01/drones-are-the-future-of-iot. Accessed 28 Sept 2018
35. SESAR J (2016) European drones outlook study. Unlocking the value for Europe. SESAR Joint Undertaking. SESAR Joint Undertaking