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Internet of Things for Smart Environments

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Preface

The Internet of Things (IoT) is a paradigm that aims to deliver processing and communication capabilities to physical objects through integrated sensors and actuators with Internet access. IoT may prove to be a crucial framework for the design of novel smart environments. The book covers a range of major research subjects that will foster future implementations. These include smart learning environments, crowdsensing applications, participatory citizen sensing, and multimodal perception systems. Moreover, security challenges are addressed. The aim of this book is to discuss recent advances in IoT and its applications for smart environments. A total of seven chapters have been contributed by several authors from across the globe, namely Australia, Bangladesh, China, Czech Republic, India, Iran, Italy, South Korea, Turkey, and the USA.

Chapter, "**Smart Learning Environments: Overview of Effective Tools, Methods, and Models**," explores the possibilities of IoT and the applications of machine learning in the development of smart environments and smart cities. Digital learning has become one of the most rapidly developing areas in recent times. Designing only digital technologies or tools does not make environments smart, but it is, above all, the presence of methods and models oriented towards digitization that makes the process innovative. Furthermore, the frontier of contemporary digitization lies in the creation of hybrid environments in which the virtual and the real coexist to provide services that are increasingly flexible in adapting to the needs of users. Today's virtual models or real models do not enable systems to be innovative if they are separate; a design that mixes the elements of the present system (space, contents, subjects) with digital elements (design, media, technologies) has the capacity to make university education more competitive.

Chapter, "**IoT for Smart Environment Applications**," reviews recent applications related to education, smart buildings, transportation, smart health, water quality, waste management, and traffic management. Moreover, it also emphasizes the use of IoT-based applications in marketing, which have changed the industry as such. IoT-based military applications and disaster recovery are also explored. The chapter begins with a description of some of the smart city attributes. Then, the challenges of different types of smart city applications are analyzed and the techniques that are applied are overviewed. Moreover, real examples of smart cities all around the world are discussed along with the challenges they face.

Smart city is a concept where infrastructure and structural facilities utilize a fusion of information technology for the citizens. Smart citizens demand technology-based services to improve their quality of life. IoT plays a pivotal role in the collection of sensor data from the citizens of smart cities and in using these data to acquire knowledge for user-centric applications. There are a variety of smart city applications. Chapter, "**IoT-based Crowdsensing for Smart Environments**," introduces the basic paradigm, tools, and technologies required for monitoring the different dynamics of a city, such as pollution, traffic and road condition, smart home applications, and citizens' health using IoT-based crowd/participatory sensing. Acquiring data from crowdsensing or participatory sensing is used to create the data input of smart environments. In this chapter, an IoT cloud based on an end-to-end architecture is presented as the solution of smart city-centric infrastructure.

Water is one of the essential key substances on Earth. The existence of the human race depends on it. Although 71% of the earth's area is covered by water, only 0.3% is usable by humans, which makes it more precious than any other substance. Quality water is essential not only for drinking but also for agriculture, fisheries, and all other sectors. However, for the past few years, the quality of usable water has been decreasing at an alarming rate, so for a smart city and its environment, a water quality monitoring system is essential to ensure human and animal safety. Among the different approaches for water quality monitoring, an IoT-based system could be effective, cost friendly, and easy to use. Chapter, "**Water Monitoring Using Internet of Things**" presents an IoT-based water pollution monitoring system that provides real-time results and a comparison report on water quality and pollution using different parameters.

Participatory citizen sensing (PCS) means using sensors to gather and share the data to generate knowledge, solve problems, exchange information, or have fun. PCS projects deal with smart environments at three levels: nature and ecology (air pollution, noise), urban issues (traffic, condition of roads and sidewalks), and extreme events (floods, earthquakes, epidemics). Compared to the broader concept of the IoT, sharing in this context is always intentional; participants either actively share their data or agree with the sharing. From the technical viewpoint, the IoT and PCS devices are similar. Chapter, "**Participatory Citizen Sensing with a Focus on Urban Issues**," brings a comprehensive and systematic view of the PCS, addressing the following three issues: (1) the areas in which PCS is used, (2) the means by which citizens are recruited and motivated, and (3) what technical issues must be solved.

Chapter, "**Design Strategy of Multimodal Perception System for Smart Environment,**" focuses on the design strategies for sensing human behavior and intentions in architectural spaces so that they may be upgraded to intelligent environments in the future. Creating a perceptual system for an architecture environment is the basis for allowing buildings to have an intelligent system that can continuously iterate and evolve into an intelligent and autonomous entity. The integrated processing of multimodal perceptual information helps improve the accuracy of the information from a building relating to all kinds of behaviors and needs within the building's space. In the context of IoT, the perceptual system of building space can be extended from a single building component to all home appliances in multi-dimensional space-time, forming a three-dimensional integrated multimodal perceptual system. In this process, the designer's systematic and logical design of the intelligent environment multimodal perception system can help cover all corners of the road space and avoid the waste of repeated sensor arrangement, facilitating the upgrade iteration and evolution of the intelligent environment perception system over time. This chapter describes the classification of multimodal perceptual systems, design principles, information processing methods, technical routes, and design strategies to improve environmental intelligence with the help of relevant design cases and knowledge from psychology, biology, and other related fields.

IoT technology continues to develop in many areas. In developed countries, the concept of IoT is rapidly increasing the use of applications that facilitate human life in smart cities. Technological development also directly contributes to people's social lives. Smart cities collect data using IoT technology and use the information obtained from this data to manage resources and services efficiently. Thus, the living conditions of people living in cities are facilitated by the quality services offered to them. Smart city IoT applications, especially smart parks, smart buildings, smart homes, smart health, smart business, and smart environment applications, are widely used. As systems and applications become smart in smart cities, it is important to evaluate them, especially in terms of security, and this topic is addressed in Chapter, "**Cyber-Attack Measures in Smart Cities and Grids.**" The fact that IoT devices used in smart cities have intelligence does not mean that they are safer. In smart environments and cities, the IoT applications' data communications protocols should be geared towards security. All smart systems should be managed from a security perspective and necessary precautions should be taken. In addition, all systems used in smart cities that have a smart environment should be one hundred percent environmentally friendly.

Aiming to give background for future research, a detailed description of the recent advances in IoT for smart environments is provided. This book is intended to support the development and research of future IoT systems for smart environments. Finally, we would like to express our gratitude to everyone participating in this project for their contributions and for allowing us to edit this book. We would also like to thank the European Alliance for Innovation (EAI) and Springer who collaborated with us, especially Eliška Vlčková (Managing Editor), for their assistance and support during the preparation of this book.

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About the Book

This book aims to introduce recent advances in IoT and its applications for smart environments. The state of the art is reviewed with a focus on the technologies, applications, challenges, and opportunities. At this stage, a comprehensive understanding of the formal and practical applications of IoT in the different scenarios of smart environments is necessary to support future research. Therefore, the main contribution of this book is a comprehensive study of the most recent proposals for smart environments. In addition, this book synthesizes existing information and highlights common threads and gaps that lead to new and complex areas of future research. The book covers a range of major research subjects which will foster future implementations. The topics include smart learning environments, crowd-sensing applications, participatory citizen sensing, multimodal perception systems, and security challenges. This book seeks to provide a valuable framework for future research projects by expounding the topic to academics, engineers, and industry professionals, which is necessary for the design of future IoT architectures for smart environments.

Contents

Smart Learning Environments: Overview of Effective Tools, Methods, and Models

Limone Pierpaolo and Toto Giusi Antonia

1 Introduction

Digital learning has been accelerated in response to the COVID-19 pandemic globally, and it will impact the future of education in learning institutions [1]. Paradoxically, the recorded problem concerns accessibility to the Internet and is instrumental rather than a matter of scarcity in terms of the effectiveness and efficiency of the teaching and learning process. The imposition of social distance and telematic relationships has demonstrated the structural insufficiency of many sectors of production and daily life.

Research has found that the expenditure on education technology is deemed to expand rapidly in the near decades. Most education systems have embraced technology by encouraging tutors to be tech-savvy. They use technology purposefully for effective learner interactions in the classroom and portray the basic technology-related tutoring skills. Digital learning differs from traditional face-to-face learning significantly in various ways, such as the place where learning occurs, the learning materials, and social interaction. The shift to digital learning has provoked mixed reactions, especially by parents who have protested for the full resumption of traditional learning after the COVID-19 pandemic [2]. School tutors have responded to the protests by devising ways to integrate digital and face-to-face learning, thus incorporating the hybrid learning models. Indeed, the availability of necessary resources to support digital learning is significant to its success and benefits attributed to it, such as enhancing collaboration, student engagement, and achievements [3]. The adoption of digital learning in the future will require tools, methods, and models that support digitization. Digital learning environments mostly use

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computer-based technological advancements that have general and specific domain contents to support student and teacher interactions as well as Internet access. The main reasons for the development and triggering of innovations develop from the digital skills of the subjects involved in the process, ensuring a real transformation of the physical environment. The realization of this process depends on the degree of adaptation of the subjects to the phenomena of digitization of society. It is clear that the transformation of the real-life context requires an increase in digital literacy and digital skills to accept and support innovation. Contemporary evolution in the post-COVID-19 era concerns precisely the hybrid evolution (also defined as blended or mixed) of digital environments.

The methods that will be incorporated by learning institutions in the future are digital-friendly; the main ones are presented below.

2 Learning Methods

2.1 Mobile Learning

Mobile technology has revolutionized over the years, from offline landline telephones to more sophisticated digital smartphones that have increased connectivity and social interaction. Browsing and learning through mobile applications will continue to be a vital part of e-learning in the future of education. Mobile devices will indeed expand learning beyond the traditional classroom because they are characterized by unique features such as increased connectivity, affordability, unique educational tools such as cameras to support video conferencing, flexibility, and the ability to customize learning features [4]. Since mobile technology is the most familiar globally, the students and tutors will be more familiar with the essential tools to expand their knowledge, achieve satisfaction, and improve education outcomes. Another essential feature of mobile learning is that it helps achieve social interaction via relevant platforms, thus achieving learner synchronization. However, the value of such systems may be reduced due to the emotions that students experience, including fear of poor grades, stress from family circumstances, and sadness from losing friends [5].

2.2 Open Education Resources

This new learning approach is crucial for the future of education since it is characterized by free accessible resources available for the public online [6]. It also requires relevant open licensing and collaboration. There are, therefore, no issues of unaffordable costs, and learners will utilize them to achieve various educational outcomes. In addition, they are content- and practice-based approaches enabling users to redistribute, revise, and reuse content, thus making them unique for future education. Learners will access quality content long-term learning ideas to help them achieve the desired educational outcomes while remaining innovative and active. Open online resources (OERs) differentiate content and complexity according to the level of education and degree of complexity in learning [7].

2.3 Online Courses

The adoption of online educational courses has improved gradually, and many learners have incorporated this form of learning for both formal and informal education. Many e-learning platforms support learning online courses. According to researchers, the future will be characterized by more individuals enrolling for online courses to achieve their academic goals such as degrees and certificates [8]. Tutors, therefore, ought to be motivated to prepare the most relevant online course materials for their students to learn effectively. However, the main challenge will be to ensure that dropouts are minimized and learners remain motivated with relevant workloads, equality, and detecting fake student registrations. Online learning allows a perfect integration between life and learning times. Thanks to digital media, it is possible to connect anywhere, and at the same time, technology is perfectly integrated into daily life (not only in the area of entertainment). The flexibility of the model allows it to be open to multiple users with different training characteristics. The quality of the courses is also very high because wherever the users reside in the world, it is possible to access the best teachers in the world [9]. However, the lack of experimentation in traditional training contexts has emphasized the system's unpreparedness with respect to online teaching, and school courses have become less fun and less interesting, have reduced the value of learning, have encouraged less attention and effort, and have incorporated less cultural content since the transition to online instruction.

2.4 Cloud Platforms

These are ICT-based interactive platforms to support learning. Moreover, they contain relevant websites, applications, and social media. Various cloud platforms during the pandemic incorporated teleconferencing via Zoom, Microsoft, and Google Meet to enhance communication between tutors and students, thus improving interactions. The future of digital learning is anticipated to continuous use of the cloud platforms in diverse ways [10]. For instance, they share classroom ideas via group discussions and textbooks through tools such as laptops, built-in cameras, and sensors supported by Internet access. Education institutions in the future will upload relevant content in their servers to ensure that virtual classrooms are robust, increase student accessibility, and secure data storage while transferring learning content between users. The digital platform makes it possible to make classrooms in schools much more hybrid and allows for the integration of laboratory and collaborative teaching methods within the classroom.

2.5 Adaptive Learning

The adaptive learning technology is a relatively new concept that will be implemented in future digital learning scenarios. This method uses artificial intelligence by computers to generate algorithms that adjust educational content to suit learners' pace and style. The algorithms are in a position to detect various patterns depending on the students' feedback on the educational content. Therefore, in the future, student and teacher interventions will be more accessible since adaptive learning algorithms will help detect anomalies and propose relevant revisions and recommendations according to the needs and abilities of learners. Improving education networks to be innovative, faster, and safer will be relevant to the success of adaptive learning [11]. In fact, adaptive learning systems incorporate big data and the use of artificial intelligence, especially to focus interest on the dimensions of motivation, attention, and emotion in learning processes.

Digital learning environments in the future will also implement various models to enhance education in schools. These models assist in acknowledging the relevance of technology to enhance student outcomes, and they are as follows.

3 Models of Digital Learning Environments

3.1 Connectivism Model

Technological shifts in the digital age have increased the ability of learners to be independent and access relevant information on topics of concern. This model will be relevant for future digital learning since learners will easily connect past information and current information to create better understanding, decisions, and new meanings. Since technology has become more personalized, it will be easier for students to learn through digital devices. Also, physical student connections can be enhanced through engaging in extracurricular activities where advisors and educators converse and interact with learners. This will integrate physical and digital interactions to assist learners in making the best decisions and improve self-motivation in learning [12]. A specific model concerns self-regulated learning (SRL) and is considered fundamental to lifelong learning. In addition, SRL skills are necessary for personal fulfillment, self-determination, and motivation, and students' SRL skills are considered essential to make high-quality teaching possible in large groups of students [13]. An evolution of the theory concerns the studies of Sanna Jarvela [14], who identifies the component of collective synchronization in learning processes in social and self-regulated learning.

3.2 RAT (Replacement, Amplification, Transformation) Model

This model is commonly known as the RAT model in the field of education. The relevance of this model is to help in understanding whether technology replaces, amplifies, or transforms education practice. Focusing on replacement, technology will not replace student learning processes or overall institutional practices, but it serves as a different means to reach educational goals through different mediums. Moreover, amplification suggests the improved efficiency and productivity in student learning linked to technology while tasks remain unchanged and improved capabilities. Transformation gives new insights powered by technology, such as the availability of new content, restructuring ideas, and revolution in learning and instructing students [15]. In the RAT model, the transformation will be more relevant in integrating technology by tutors to explore means of digitization that help improve practice and problem-solving. This process allows for the emergence of critical thinking if properly guided in the development phase by the teaching intervention. The minds of individuals who live immersed in digital technology are experiencing profound changes at the cognitive level and in the organization of thought [16].

3.3 TPACK (Technological Pedagogical Content Knowledge) Model

Technological pedagogical knowledge of content is the primary definition of this model. It implies how technology is a relevant factor by integrating it into tutors' content and pedagogical knowledge in this digital era. This model will be relevant in future education since teachers are incorporating digital means of conveying education content and complex concepts to learners, such as uploading an online video to explain a subject matter. Moreover, the model will act as a guide to tutors' education and curriculum development. First, learning outcomes are chosen, followed by the type of activity, and finally, the best education technology tools to support the classroom activity are implemented to help learners [17]. This model will ensure productivity since it considers a wide array of knowledge and how tutors can utilize it and also serves as a basis for instructor professional development and training. The quality of teaching and learning can be found in balancing and rethinking those three components in a systemic key (content, technology, and pedagogy) and in using strategies that address real and contextualized problems [18]. The enthusiasm and pedagogical fervor for these innovations have brought to light three interesting issues on the international scene: (1) the sense of community and participation in virtual teaching, (2) the learning of digital skills by students and teachers, and (3) the dissemination of digital technology in classrooms.

3.4 SAMR (Substitution Augmentation Modification Redefinition) Model

This model comprises four major approaches to educational technology that can be divided into enhancement and transformation. Teachers have experienced more straightforward ways to replace the traditional learning methods using substitution as a mechanism where classroom lectures will be replaced by digital content such as PDFs uploaded online via sharing devices such as Google Drive. Lectures held through videoconferencing are made accessible to learners anytime when the tutor records them, thus enhancing student engagement in classroom activities. Augmentation is a student interactive approach where they are able to give feedback on how they understand specific topics through digital portfolios, comments, posting questions, and using hyperlinks. Modification is where tutors use virtual classrooms to track student progress, communication, posting assignments, and calendar updates. This is a significant feature because it will be inclusive to students who have been marginalized in physical classrooms [19]. Redefinition is a critical feature in this model, allowing for the impossible activities in the physical classroom to be made possible in the virtual classroom. Therefore, this will allow collaboration and connectivity to other students globally, interactions with experts, and sharing ideas to solve common setbacks in the community. Computer technology will be essential in the implementation of the SAMR model. This model demonstrates that the use of the integration of various digital technologies inside and outside the classroom improves student learning.

3.5 ADDIE (Analyzing Design Development Implementation Evaluation) Model

This will be a valuable model for complex technology-based teaching and training. It is characterized by clear objectives, structured content, relevant workloads for learner activities, and integrated media. Moreover, the ADDIE model is built on the principles of instructional design, thus supporting virtual learning. The rapidly changing digital era of learning will have to adjust this model to meet the relevant education goals in the future.

Digital Tools for the classroom that will enter the school curriculum is comprehensive for teachers' and students' innovations. These are tools that help in making presentation videos, questions, assessments, and information graphics [20]. Students become more engaged and curious, resulting in a better understanding of the subject matter. For instance, YouTube Channels are digital tools for various academic contents through visual representation and explanation of concepts. Therefore, they will continue to gain relevance in the future since they enable self-directed studying through instructions. Similarly, Dropbox is another tool that will continue being helpful in enhancing learning where file sharing, backup, and storage are possible over the Internet. Mobile application tools such as Quizlet will enable learners to make quick assessments of their learning by using games and other fun activities. Teachers can also use the Socrative tool to get information about their students' knowledge more interactive. Another emerging digital tool is BoomWriter, and it allows learners to engage in writing activities collaboratively, thus motivating those that may seem reluctant. Creating animated videos is made possible through a digital tool known as Animoto, and both students and learners can use it for education. Enhancing children's skills via visuals is also possible through tools such as Pixton, and it will indeed improve their imagination and creativity. The relevant data sets obtained from the digital tools will help tutors to identify the strong and weak areas that their learners may be experiencing.

Following this, the necessary measures to improve skills and enhance improvement are recommended to promote better education.

The goal of this project is to investigate the impact of digital technology on teachers' school practices or work environments in the context of COVID-19. This impact has been studied in relation to the constructs of motivation, perceived stress, sense of self-efficacy, and resistance to/acceptance of technologies [21]. The massive and coercive use of digital technologies (and the relationship with innovation and change) is a predictor of motivation and perceived stress. Therefore, the integration of technology with physical environments and actual use passes through a period of acceptance to and modification of the perceptive systems of the entire society.

4 Hybrid School Models

The emergence of the COVID-19 pandemic created new perceptions on hybrid learning for the future by showing that education happens in physical classrooms by face-to-face tutoring and online digital platforms. Parents, teachers, and students have adapted to using the new education mechanism, which is more flexible with a wide array of learning methods in the long term. Hybrid learning is an approach that combines traditional face-to-face classroom learning and online learning methods to happen simultaneously [22]. Indeed, it is deemed to be the future of education since there is no going back to the old practices. In the future, there is the possibility that schools will have students learning from home and at school on a part-time basis. Since hybrid learning is a new strategy in the education system, various measures and strategies have been put in place to enhance its effectiveness in meeting future needs. There is a need to improve connectivity in schools by ensuring that the relevant technical requirements are available such as stable Internet connection, adequate training for teachers on technology use, simplicity of procedures, and improved connectivity.

There are various advantages linked to hybrid learning that will impact future learning environments positively. For example, it will enable monitoring progress easily where teachers can track performance on their dashboards and evaluate the strengths and weaknesses that students may face. Therefore, getting immediate feedback allows teachers to make proper adjustments according to students' needs. Also, personalized learning is achieved via hybrid learning where competency-based learning activities and modules are created to meet the students' needs, thus increasing retention and achieving deeper comprehension and personalized healthy interactions with their teachers. Additionally, tutors are more empowered to meet the needs of each student due to diverse interactive options beyond the physical classroom, thus addressing potential learning barriers. Learning through the hybrid model will be more interactive and engaging due to the availability of multiple learning models that are more engaging as compared to the traditional model that was monotonous. Therefore, learners will develop additional skills that help in social interactions. Deeper learning by accessing more diverse education material is another advantage of hybrid learning since it enables students to have flexible schedules for their classrooms [23].

Connectivity is crucial to the success of hybrid school models for students and learners [24]. Some technological solutions will be needed for the model to thrive in the future. Safe access to data is one of the core solutions where students are guaranteed safety while accessing data, and unacceptable content is filtered and blocked. Also, sensitive information in the student database ought to be protected from malicious cyber-attacks and breaches. Bridging the take-home assignment gap with smartphone connectivity is also crucial. Regardless of the learning conditions of students, there should be adequate Internet devices connectivity from their homes. Parents need to ensure that wireless connection is accessible from home to enhance continuous learning. On the other hand, relevant digital resources should also be available in learning institutions to facilitate hybrid learning because inadequate technological tools are limited. Governments also have a significant role in ensuring the resources required for hybrid learning are availed to learning institutions through regular funding and the adoption of supportive curriculums and policies. A specific new learning space is the hybrid or blended synchronous learning environment, where both on-site and remote students can participate in learning activities simultaneously. As synchronous hybrid learning is relatively new, few studies have investigated its use and effectiveness.

Conversely, hybrid learning is characterized by various significant challenges in its implementation process [25]. First, there are considerable hardships in student engagement. In this context, tutors will admit that it is indeed challenging to ensure students in the physical classroom are engaged with those learning remotely from home for equality in learning experiences. These phenomena occur due to different teaching methodologies that lead to unequal engagement. The solution could be tutors focusing on activities that can improve engagement, such as discussion groups and tests, through engaging technological platforms such as live streaming and sharing screens. Learner body language can also provide awareness of their engagement levels. In addition, there are possibilities of technical malfunctioning in hybrid learning environments. Technical issues result in lessening disruptions since they interfere with the students' access to critical information. For example, Internet connection problems limit access to live streams and online meetings, sound issues disable learner comprehension, and complex software can limit the students' ability to access information. To overcome technical issues, there is a need to train teachers on how to overcome them. Also, connecting remote learners before beginning lessons is crucial since the technical issues will be detected beforehand and friendly solutions provided. Another technique to minimize technical issues is uploading previously covered lessons for future reference to the learners that were unable to access.

Moreover, the issue of facilitating collaboration, teamwork, and social interaction is a significant challenge for hybrid school models [27]. Placing learners in a shared physical setting as groups is not achievable due to remote learning, thus leading to collaboration setbacks. However, technology can help resolve the collaborative barrier by incorporating synchronized communication through live streaming and online chats, thus duplicating the advantages of personal interactions. Besides, sharing learning materials can be pretty challenging in hybrid models due to the phenomena where students use different learning software. Therefore, there are situations where a remote learning student and the one in the classroom cannot collaborate with similar learning materials, thus causing potential delays and disruptions. Resolving this issue requires standardization of educational technology to enable easier access to all learners and promote uniformity in delivering learning outcomes. For example, using cloud platforms for file sharing is safe and secure for all students.

The process triggered by the pandemic that produced a sudden acceleration of the diffusion and experimentation of digital teaching in all segments of training has promoted moments of profound reflection on the results of this phenomenon in the post-COVID-19 era and the need to build theoretical models that translate into concrete paths of intervention within traditional training. Not only has the university education system been affected by a renewal request that overcomes the physical limits already questioned by the open logic of distance learning, but also, the change in market rules in the last 10 years has not been matched by an equal change in rules of the so-called training market that exploded in a moment of crisis.

Collecting the requests of the training actors involved and capitalizing them in a theoretical model are the aims of this research. The hybrid model of the university is divided into three main features: the porous university, the transferability of skills, and the new professionalism of professors. These characteristics across the hybrid model are broken down between elements of training (users, market rules, and didactics) and dimensions in training (time, space/place, media and technology, learning design, and content). These elements are shown in Table 1.

The dimensions hybridized with the elements of training create a composite chessboard that represents the five key rules for a hybrid university:

1. Time: In the contemporary situation, students approach university at the age of 18 (at the end of the secondary school path) and finish their path 3–5 years later. This organization of the training system no longer works because a further 5–6 years of vocational education does not meet the needs of the labor market. This model provides knowledge pills that can be achieved in a short time (MOOC

Table 1 Elements of the hybrid university

Elements of training	Time	Space/place	Media and technology	Learning design	Content
Users	Flexible profiling	Blended and hybrid space	Traditional tools and ICT (use and training)	Badging or microcredentials	Responding to the world of work
Market rules	Explosion of the standard years in courses adapted to the subjects	Blended simulation systems for the professions	Certified evaluation systems	Hybrid and professional courses	Training reform (rigid structure of degree program)
Didactics	Personalization and individualization (hands-on, blended courses, peer evaluation)	Ubiquitous learning (classroom, laboratory, e-learning platform)	Learning management system – Gamification	Codesign of the didactic intervention	Flexible disciplinary teaching with respect to multiple integratable paths, professional teaching

logic) and can be combined to achieve the learning objectives step by step. The last point goes beyond the logic of the didactic systems and the preparatory aspects between the courses. In this way, we can truly personalize the learning path for each student. In this highly diversified path, which should last for a lifetime (lifelong learning), the entire existential path of the subjects is sewn and can cross various topics.

2. Space/place: Hybrid education must be a mix of physical and online learning, in which the experiences of machines and humans and their interactions converge. Places and spaces for working and learning collaboration should be integrated. Multiple access to training should also be available – that is, it must be enjoyed not only as a physical experience but also as an integrated process (to e-learning), giving full realization to the concept of ubiquitous learning.
3. Media: Polarization between physical instruments and digital media should no longer exist; there are holders of both instrumental forms. The world of training needs new experiences in the use of media oriented toward a certified system of skills and co-designed didactic frameworks (LMS and gamification).
4. Learning design: The need to redesign the university appears clear to live the teaching experience and to adapt to an omnipresent learning need, which explores study plans and professional training courses. A concrete example of hybrid design is the use of skills certification systems such as badging or microcredentials. The demands of employment take the form of educational offers that are also hybrid and professionalizing (which involves experiential moments of experimentation with the knowledge acquired).

5. Content: The content, especially in the frontal lesson, is characterized by the immediate and comprehensive transmission of codified information. Contemporary contents change because times, spaces, tools, and didactic planning (the previous dimensions) have changed, which retroact on knowledge. The pressing demands of the labor market require content that is more responsive to professional needs and a more flexible qualification mechanism. From a didactic point of view, this requirement translates into greater interdisciplinarity and awareness of the learning process.

The reimagining of the existing university system proposed in this model is by no means superficial but must be radical enough to make the international university system competitive. The educational crisis faced in terms of changing educational ecosystems must be a cultural, perceptive, and identity phenomenon. In other words, the model must be accepted socio-culturally to allow a real overcoming of the current crisis; it must effectively affect the processes of perception of the training systems by all the actors of training (students and teachers) and establish itself as a new identity structure of the subjects and institutions involved in the evolutionary process. An idea of a university, therefore, which is open to and utilizes the potential of the context and safeguards the role of the student (and of the teacher as a designer of training) as an active constructor of knowledge. Such structural and cultural innovation at the same time requires reflection in relation to the barriers, problems, possibilities, and challenges [26]. The barriers concern the obstacles that block the realization of the action, the problems instead (less insurmountable) do not obstruct but delay the possibilities for the redefinition of contexts in relation to the emerging needs, and finally, the challenges foresee a planning process in relation to the prospective future realization. In the context of hybridization of training, all five of these dimensions must be considered for the best future implementation of this system.

5 Conclusion

The bottom line is that the COVID-19 pandemic has significantly transformed education, and the future of digital learning environments is expected to revolutionize. Achieving potential educational outcomes will necessitate the adoption of necessary methods, tools, and models. Students have been significantly affected by the pandemic causing discontinue learning to many of them, due to financial burdens. This trend has necessitated many students to work part-time to afford education facilities. The availability of hybrid learning will assist them in pursuing education and careers since they can study online at their desired time. Indeed, various stakeholders in the education systems such as governments, administrators, parents, students, and the community as a whole are vital to ensuring that digitization in education will come to success [28]. While teachers pursue their education, it is necessary to include technology-related tutoring skills so that they can conveniently engage students learning with the necessary digital technologies. There is also a need to revise educational expectations to facilitate better and more transparent learning modes in the future. Given the necessary infrastructure, teaching curriculums, financial support, and networking applications, students and teachers will be self-motivated and competitive to transition to a new education era.

Most of the existing literature is exploratory and qualitative in nature and has focused primarily on describing student experiences, organizational implementation, and technology design. Future research perspectives should therefore also concentrate on the quantum analysis of the hybridization process of learning environments. Digital transformation is seen as a major change process that takes time and often encounters resistance and avoidance from those involved. The COVID-19 epidemic forced teacher and student training to skip the gradual transformation and transfer of educational activities online, which emphasized the lack of digital skills in training paths. The digitization of systems and skills, however, does not only concern the world of schools but also that of services and businesses. Also, there has been strong shortcomings in these areas in relation to smartworking or teleworking; therefore, the instrumental apparatus alone does not guarantee innovation if it is not accompanied by a real revolution that also innovates cultural and social systems.

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IoT for Smart Environment Applications

Azadeh Zamanifar and Ali Yamini

1 Introduction

Internet of Things (IoT) features a large number of technologies. It processes the types of objects around us through unique means of addressing and standard communication protocols that can communicate with each other and cooperate with their neighbors to achieve common goals [1].

Considering communications, we have always sought to develop human interaction with humans by sending and receiving data (or information) using different methods and environments. In the present world, it is done using the Internet or the World Wide Web, which, if we look closely, we see that is between humans and humans. To break this connection between humans and humans, we can soon create a human connection with objects, objects to humans, and objects to objects. All objects can be connected. The network of machines (objects) that can be connected directly and captured or placed in virtual data can be known as the IoT. Usually, the IoT uses the secure service layer (SSL), connected to a central command and control server in the cloud [2].

The IoT is the ability to connect various objects to the virtual world. Thus, all household appliances, cars, stationery, and everything you want to be connected to the Internet. These tools are sent to the Internet by connecting to the Internet, receiving data, and receiving the required data and change. If required, to change itself or by notification to its user. In addition to this feature, the possibility of connecting two or more objects is another feature that can be mentioned. The main consequence of the IoT is the internal communication of the devices. In this case, the

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devices will be smart with consistency and security, so the "IoT" scheme needs a communication network [3].

The search for any particular service offered by the Internet devices represents a crucial point; the number of objects connected to the network increases, resulting in a vast search space. Also, the number of Internet devices is increasing every day. The interactive models are currently based on human–object interaction. However, shortly, interactions will be an object–object interaction so that objects seek to provide complex services for the interests of humans. Finally, the scalability issues will occur due to an appropriate object search for the desired service. In IoT environments, many natural-world objects, from sensors to vehicles, have become intelligent objects that can provide information and service capabilities to users. In addition, mobile services such as smartphones, mobile phones, and wearable devices are becoming more powerful and more common every day. They are considered an integral part of the IoT environment. The IoT enables objects to share tasks and information between humans and causes inanimate objects to have a digital identity. A significant challenge in the IoT environment is to find the appropriate services for an out-of-service activity in the environment. To determine the quality and prioritize the available services based on their capabilities, quality of service (QoS) parameters are considered to increase the accuracy and speed of the service.

Sensor nodes related to various Smart City applications create much information that is now essentially under-utilized. Utilizing the existing ICT framework, created heterogeneous data can be brought together. A portion of the current remote innovations that can be misused to accomplish this data collection is 3G, LTE, and Wi-Fi. With regard to the use of installed gadgets and existing web foundations, the IoT incorporates PC and other encompassing electronic gadgets. The Smart City vision is reliant upon working billions of IoT gadgets from a typical spot. The new development of low-cost remote organization principles for sensors and actuators has empowered supervision and control broad scopes of sensor organizations and actuators distantly. The proposition is to send the engineering on a help stage. Sensor applications can be associated and used by various web applications for brilliant working conditions [1, 2]. IoT applications have influenced every person's life and have changed human applications more conveniently.

Smart urban communities utilize different innovations to make the health framework, power, learning, and water supply more proficient for their occupants. This implies bringing down costs and utilizing energy and making correspondences with staff more productive and imaginative. A thorough examination of information is a similar innovation that will broaden the smart metropolitan foundation. Information mining has prompted enormous numbers and can be utilized in various significant manners, as a critical component of regular day-to-day existence is digitalization. The misuse of various information is significant in numerous scenarios and utilities in the smart metropolitan domain [3]. Figure 1 shows a different part of a smart city.

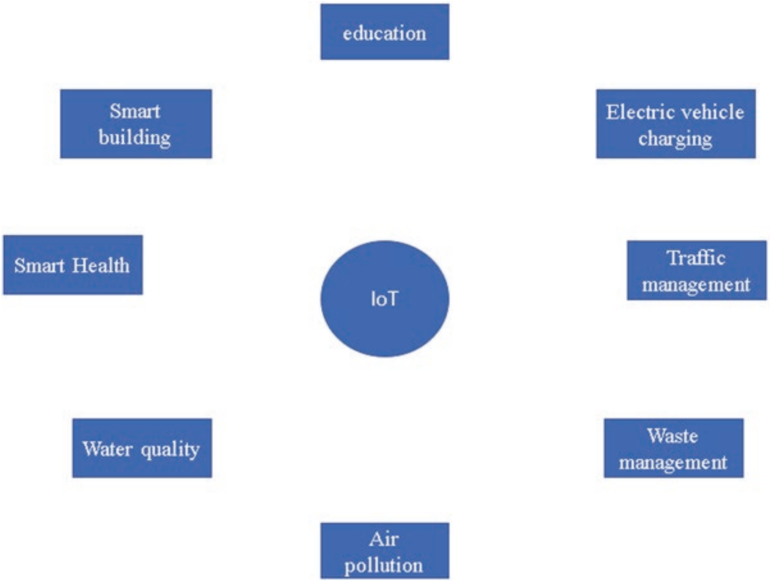

Fig. 1 Smart city parts

In this chapter, we aim to review some crucial applications in this regard. Smart city has gathered many intelligent applications. In Sect. 2, we review the general attributes of the smart city. In Sect. 3, we discuss smart city architecture. Then, we take a look at some smart city applications in Sect. 4. In Sect. 5, we review some notable real implementations of smart city and the challenges. Section 6 discuss notes and the chapter is ended with a conclusion.

2 Smart City Attributes

The IoT, which is referred to as the "new industrial revolution," has revolutionized the interactions between the governments and their surrounding world with the virtual world and technology because of the change in life, work, entertainment, and travel. The arrival of the smart car with the set of applied instruments to create interaction between the user, house and intelligent buildings, the possibility of playing music by a few words, and thousands of other applications in smart city, transportation, agriculture, defense industry, the insurance industry, oil gas and mining industries, monitoring and security of public and private, retail, logistics, banks, health and treatment, and the hotel are excellent indications of the importance of IoT.

Expanding the norm and building more powerful specialized arrangements inside different metropolitan organizing administrations of the city life is a feature of the intelligent cities' philosophy [4]. IoT is a standout among other known models for making a smart city, and it is an IoT capacity for making and overseeing intelligent applications for smart networks. IoT coordinates sensors in everyday items and interconnects them across the web to and share data to various administrations and metropolitan occupants. IoT is an incredible assortment of things conveying over a system administration or the Internet.

In IoT, things join gadgets, sensors, and programming to control how different pieces of the object perform. Each object creates, catches, and moves information from its current circumstance through sensors to other objects or channels. One of the most significant difficulties in IoT today is to keep this information and its progress and is one of the most significant issues for all organizations utilizing IoT innovation [5].

3 IoT Smart City Architecture

The basis of providing more intelligent services on the IoT is collecting, aggregating, and processing data. The high volume of connections and processing of the collected data associated with them provide various requirements. In short, IoT applications are the primary sources of big data production. Data on the IoT are generated by recording data in the registration of users' performance, billions of daily multi-structure interactions, logs of mobile sensors, etc. The big data and data generated traditionally are different and are rapidly evolving interactively. For example, the data rate that 20 sensors produce per hour is equal to 240 records per hour, which hits 5760 records per day; if that amount per 10,000 equipment (not too high for IoT applications) is multiplied, it reaches 2,400,000 records per hour and 57,600,000 records per day.

The product design of the IoT smart city intends to boost the utilization of cutting-edge correspondence advances as help for city and resident organization administrations [4, 6]. Military, mechanical technology, smart administrations, schooling, vision and sound, and social mindfulness are not covered by the IoT programming engineering, and extra work is expected to adjust to the product design [7]. As per an adaptable programming engineering segment-based, IoT applications can be coordinated with security instruments to recognize dangers and inconsistencies for investigation and advancement of incorporated security [8]. Applying IoT programming design to cloud arrangements empowers Cloud of Things, another product engineering based on IoNT (Internet of Nano-Things). The mix of these strategies and arrangements brings a broad scope of new framework usefulness called IoT [9]. The IoT programming engineering has openings for development in the semantic also, security section. One answer for further developing the product design might be to create a specific cosmology or philosophy design [10].

Gadgets that help programming engineering segments do not have normalized web availability aside from systems administration conventions. Along these lines, security highlights are an issue (sensors, gadgets inside electronic vehicles, houses), and it is crucial to empower expanded security and assurance of data [11]. It is feasible to see programming segments as independent parts that have the capacity (utilizing a specific calculation) to get data about client inclinations, accessible assets, accessibility of context-oriented data, and organization correspondence [12]. Sending application administrations and unified cloud forms empower handling information from billions and even trillions of heterogeneous items through layered programming engineering. The layers ought to be run on the gadgets through the "Administration Composition" layer, which gather and measure the information. The improvement of product engineering for the smart city should incorporate the said layered programming engineering progression to accelerate the handling of information from different gadgets in the framework [13].

Furthermore, the identified parts' product design abilities empower correspondence with the sensor organization and distinguish all the climate requirements for which the product item is planned [14]. The product engineering ought to incorporate an intelligent framework that organizes client collaborations, an interface for the client that empowers cooperation with the framework, the Internet that permits various information from different sources (sensors). The actors might be inside the product parts of the identified programming design and the kinds of sensors that gather information inside the framework [15].

The execution of a smart structure offers extra help to the control and association of a smart city, just as lessening support costs and improving energy efficiency. The IoT arrangement of innovative structure incorporates sensors for estimating temperature, development (in light of development in the structure and flexible control), and stickiness, which make it simpler to work the structure. Inside the smart working, there is a cloud building (smart Building Cloud Server) on the lower level in the building itself, which speaks with the different sensors introduced in the structure. The hybrid geography of the network (star and cross-section geographies that offer high shortcoming resistance) gives a dependable organization without any problem figuring out how to investigate and resolve mistakes. Cloud-based layered design can likewise be utilized to oversee smart homes utilizing camera gadgets for object recognition. The framework utilizes a calculation to distinguish different actions under different lighting and different distances [16]. The layered design permits any outside asset such as a sensor, IoT smart gadget, or AI programming to call middleware (that use REST and JavaScript Object Notation-JSON) to trade messages. Because of data from outside assets, it is feasible to start activities inside the framework [17]. Multi-sensor convention (NAMRTP) can dependably send information from a far-off climate to multi-sensor information that is constant. Cost decrease, a more secure climate for clients' lives, basic applications to oversee, and the compatibility of an energy-efficient smart structure (and surprisingly a green smart building) can be accomplished by applying new advancements—furthermore, different kinds of sensors for monitoring inside the structure [18]. If the state of a structure is appropriately controlled, such a framework can be applied to any structure in a smart city and consequently work on the energy efficiency of the whole smart city.

The main thing inside smart homes and smart building frameworks is anticipating occasions and learning given specific qualities and propensities for framework clients. In this way, the framework gathers data and can react to changes in client conduct whenever [19]. Calculations and procedures for keeping up power supply of a smart structure or complete smart city climate permit all framework usefulness to run as planned. Different kinds of deviations caused by noise, sounds, and spikes can prompt energy utilization problems and issues inside the whole smart city network. The insightful mixture execution of a five-layer power lattice gives dependability, settling time, a decrease of identified deviations to acquire low energy in a total smart city framework [20]. Sensors set through the nearby sensor network in various items (home or building) give a structure for gathering and handling information inside an IoT framework. The expert unit makes an assortment of information from the sensor organization and identifies the conditions between them. Sensors are utilized progressively to diminish the repetition of power utilization [18]. Inside the IoT framework, a few cycles are executed to change the data read on the sensors into information that can be utilized in the client's application. To more likely distinguish the genuine circumstance inside the IoT framework, the following cycles are performed:

Information acquisition—using different sensors, advanced filtering, and partition capacities (gathering different data and changing over to many qualities) [20].

Information preparing— removes superfluous commotion and noise that is gathered on sensors with other information. The point of this interaction is to isolate applicable data from minor signs.

Highlight extraction—addresses getting valuable data from the information filtering measure and finding the most efficient qualities from different capacities.

Characterization choice or model coordinating—the last stage is design acknowledgment, design classification, or model coordination.

The improvement of the IoT framework is reflected in the improvement of the calculation to save energy and work, as indicated by the data obtained from the sensors [21]. In light of these investigated works, there is a need for an examination that will dissect the product structures of the web of things frameworks specifically for the spaces of smart city, medical care, and agribusiness and suggest the improvement of presently accessible programming planners.

4 IoT Application

4.1 Healthcare System

There are many wearable devices like ECG, EEG, and temperature sensors. The data from sensors are either gathered in the patient's smartphone that acts as a gateway [23] or sends them directly to the fog or cloud to further computing. In this phase, some machine learning approaches are applied to extract some knowledge from data. The result is sent to the doctor at the remote to decide for the patient either by sending an ambulance to the patient's location or calling the patient. Predicting a patient's health status is one of the main goals of these systems [24–27]. Figure 2 shows a typical IoT-based health care system.

Versatile ICT can uphold well-being checking and intercession at different scales going from personal information assortment to a whole city. At the individual level, cell phones have become a backbone for individual medical services. Ongoing measurements report that 52% of cell phone clients accumulate well-being-related data on their telephones, and 61% of clients have downloaded a mHealth application. Most regularly, individuals look for experiences on a clinical or protection issue. However, clients likewise search for hints on nutrition, wellness, medications, and specialist decisions.

As well as researching explicit clinical issues, another famous individual use for versatile and wearable ICT is step counting, which gives an establishment to numerous wellness applications. Cell phones and applications provide step checks from the 3D accelerometer signals. While there can be an absence of consistency among elective advance checking gadgets, the more significant part of the conflict is the wearing site of the tracker instead of the installed signal preparing calculation that computes knowledge from the accelerometer information. Studies have shown that these gadgets also perform and are solid for ordinary conditions, even though they encounter execution problems when the individual moves along with an adornment

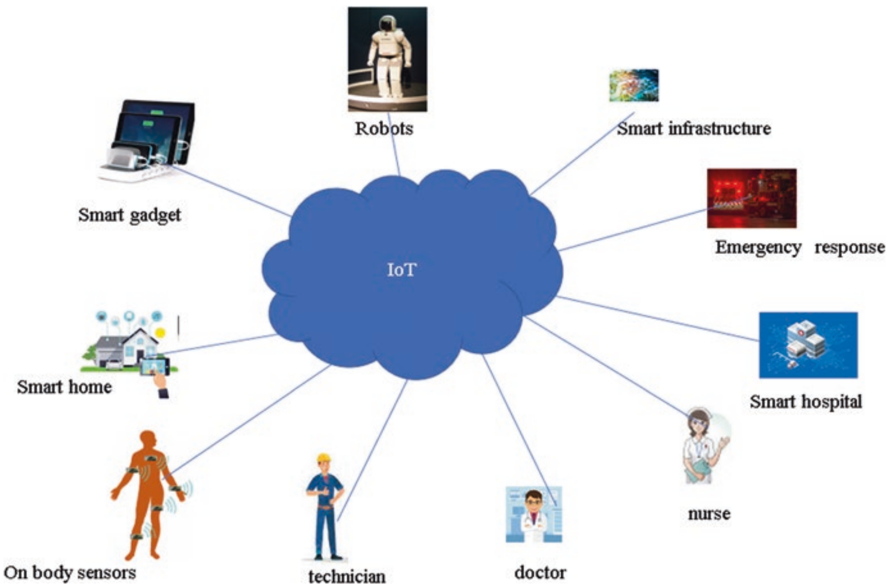

Fig. 2 Typical IoT-based health care system

(e.g., walker, shopping basket) or performs enthusiastic non-strolling action to the cell phone following site [28].

A benefit of versatile ICT-driven medical care is that constant checking of personal conduct standards works with recognition of health problems side effects that are generally hard to notice and connect with analysis. For instance, older adults may encounter psychological decay, but since they hold several levels of self-rule, this change might be hard to catch and treat. Be that as it may, the beginning phases of dementia are related to successive episodes of spatial confusion and an improved probability of not doing significant day-by-day activities [31]. These progressions convert into strange portability designs. The SIMPATIC project [32] investigates these portability examples to convey distinguished anomalies to patients and care suppliers. On account of strange paths, versatile direction likewise directs the person back to their home. As far as infection observation, Patsakis et al. [29] proposed a mechanical design that could be utilized to permit people to send their well-being information without unveiling their character, which may be valuable for constant metropolitan scale virologic and epidemiological information checking. Concerning accident recognition, Shikhar et al. [30] proposed an information system to foresee and lessen the effect of auto collisions and reveal significant examples. Important information for investigation was obtained by the Office of the Traffic Commissioner at Bangalore and incorporated the accident, light condition, seriousness, speed zone, and alcohol utilization. As to checking of natural conditions, four articles were recovered: Sánchez Bernabeu et al. [31] proposed the advancement of an application to screen the file of electromagnetic radiation of structures also, spaces of a smart city, devoted to people who experience the ill effects of the pathology of electromagnetic excessive radiation; Wray et al. [32] recommended a miniature level checking network of static gadgets that could monitor air toxins and UV radiation with the intend to anticipate cellular problems in the lungs and skin cancer, individually, by further improve air quality and diminishing UV exposition; Federico et al. [33] proposed an application to supervise singular conditions (e.g., infrastructure, climate, or social connections) to all the more likely comprehend the connection between hereditary problems further, diseases by utilizing genome-wide affiliation contemplates; and Guo et al. [34] introduced a versatile application to monitor the level of sun radiation in every individual was exposed to at some random time and also area. As to observation of proactive tasks, Clarke and Steele [35] depicted particular kinds of wellness sensor applications and introduced a calculated design for information assortment and accumulation just as the sorts of optional uses for this gathered information inside smart urban areas. Six articles were investigated [36]: Dipsis et al. [17], Roza and Postolache [37], Guo et al. [38], Jianqiang [39], and De Oliveira and Painho [40] proposed an online system through which people could give individual information (e.g., age, sex, or family pay) along with their emotions; Guthier et al. [36] gave an outline of the applicable emotional states and showed how they could be distinguished separately and afterward totaled into a worldwide model of influence, which could be utilized to advance an influence mindful city; Roza and Postolache [37] introduced a cell phone application that analyze people's feelings and their connection to various city regions; Guo et al. [38] endeavored to plan, also relate, broad information to metropolitan geology highlights and therefore tried to comprehend the fundamental sources of satisfaction in the city scene; Jianqiang [39] investigated different pre-handling techniques to evaluate what they meant for the exhibition of Twitter related classifiers; and they [40] pointed to introduce a surrounding geographic data (AGI) way to deal with collect geo-labeled information identified with a people's discernment and sentiments about a city from Twitter, Flickr, Instagram, and Facebook.

4.2 IoT-Based Marketing

One of the main paradigms in knowledge management is the real-time concept. This means getting the correct information from the right people at the right time without any delays.

A knowledge system is a searching processing system that provides knowledge sharing infrastructure in the logistics operational environment. The system structure consists of five modules. The goods and equipment (such as trucks and goods) and all identification cards of arrival and exit have RFID labels. The reader has one or more antennas embedded in the reading frame in each device to detect hundreds of tags in the reading frame. Therefore, it can be determined through operational logistic data, such as equipment location and the current location of human resources.

In some marketing stores like Walmart, each item is placed in a part. Each part has an RFID that sends the availability and type of item to the RFID reader, which shows the remaining item. Each basket is also smart that shows the total price of the items that the customer picks.

It has decided to use multiple palettes along with the sensor and the handwheel that maintains the product. It measures the increase or reduction of the temperature in real time. The strategy to use IoT in logistics is to be integrated into Data Diagrams to ensure that the current situation is safe. It uses several databases and uses specific modeling to maintain moisture and detect temperature. Products use them to preserve their freshness [41]. Some labels show the recent time of sold and the number of times that the items were sold. Walmart shop will soon become a robotic marketplace. Life would be more comfortable for the employees of a bigger store. Walmart plans to use such robots in the future. For example, the payment process has managed to maintain quality by allowing customers to purchase at a low cost. According to Gartner research company, the retail market should be 200 billion dollars in new establishments that they announce. They should know the need of customers. The Internet can be considered as a key system in this area. IoT makes customers feel comfortable inside and out of the stores, and thousands of technologies can go through this technology.

4.2.1 Amazon Go

This application is one of the smart applications that use IoT. It provides a comfortable environment in which people can take the products and go out of the store. It is possible via RFID technology. Customers register once. When they pick a product, the price is read by an RFID reader at the store and is added to the basket [22]. When they go outside of the market, they not stop at the cashier. The Amazon Go app must be installed on the smartphone. The total price is generated, and the customer receives a receipt.

4.3 Disaster Recovery

Cataclysmic events like tremors, tropical storms, tidal waves, and volcanoes can cause broad impact, at times with practically zero notice and planning time. At the point when such enormous scope catastrophes happen, they request similarly huge scope recuperation tasks to help the casualties, which are very difficult and spot critical requests on different assets, including nearby, provincial, public, and global crisis reaction staff, non-governmental associations (NGOs), Public Guard, and the military. During these catastrophe recuperation tasks, quite possibly the most necessary is for the responders to have the option to comprehend the circumstance in the space of tasks – an idea named Situational Awareness (SA). Getting and keeping up with cutting-edge SA is essential to arranging and executing the recuperation tasks, including settling on allotting assets and focusing on recuperation activities. As the recuperation activities proceed, the SA should be consistently refreshed, dependent on changing conditions in the influenced regions. Conventional sources of SA incorporate reports from the casualties of the catastrophe, just as perceptions made by the crisis responders. Be that as it may, this SA can be exceptionally upgraded through the IoT innovations, which can fundamentally decrease the idleness in acquiring SA and simultaneously increase the degree of detail just as the topographical inclusion. Specifically, in an intelligent city climate with a massive sending of IoT sensors, they have the potential to change SA according to numerous viewpoints, including expansive also, exact detailing of conditions in the influenced region, the status of administrations, and coordination [42]. Figure 3 shows an IoT-based disaster recovery example in firefighting.

4.4 Military

Setting up a smart city foundation incorporates establishing a wide assortment of sensors, actuators, and correspondence methods. This hardware may be commercial-off-the-shelf (COTS) IoT gadgets or existing inheritance gadgets to fit in the different use cases and situations required. For instance, for the smart city traffic observing

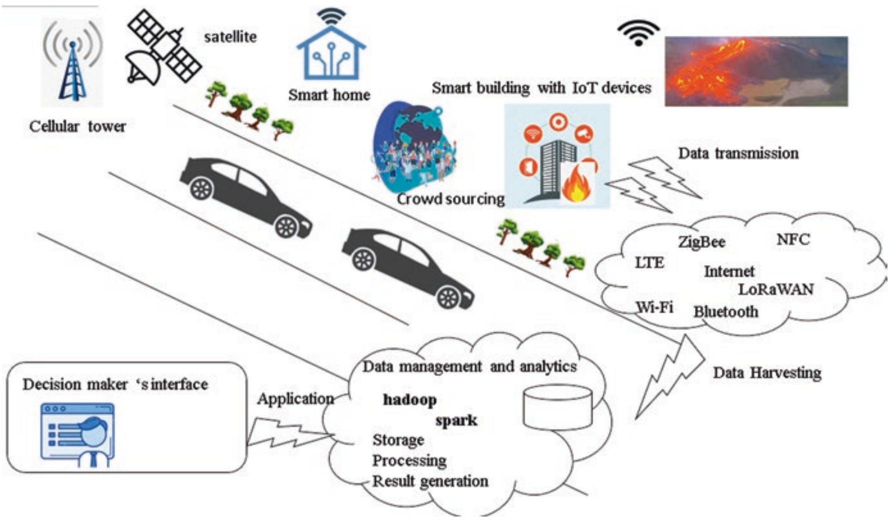

Fig. 3 IoT-based disaster recovery mechanism

framework, traffic signal posts may consolidate cameras to screen the traffic stream at intersections. There may be sensors to screen the level of contamination and current climate conditions at the equivalent areas. These and other data sources assist the city with arranging traffic progression to adjust contamination just as diminish gridlock [43].

Furthermore, the Alliance countries' military can bring their own IoT sensors and interchange hardware to check the ground conditions. These could be statically sent to critical areas or even be mounted on UxVs. This data can then be imparted to neighborhood specialists to work on their administration of the circumstance. Combining these irregular data sources is essential to giving and keeping up with SA and empowering powerful military tasks [44].

4.5 Transportation

In IoT environments, many natural-world objects, from sensors to vehicles, have become intelligent objects that can provide information and service capabilities to users. In addition, mobile services such as smartphones, mobile phones, and wearable devices are becoming more powerful and more common every day. They are considered an integral part of the IoT environment. The IoT enables objects to share tasks and information between humans and cause inanimate objects to have a digital identity.

Transportation is affected by the IoT a lot. It grows the quality of life and makes it possible to reduce the traffic too. For instance, in Madrid, EMT [17] works the city transport lines (altogether 215 lines) through an armada of 2095 vehicles, which have a regular period of 6.04 years. Figure 4 shows an example of IoT-based transportation.

In 2011, EMT worked a sum of 7.11 million hours and 95.45 million kilometers, with a normal working rate of 13.43 Km/h. Given the enormous number of vehicles and their activity, the objective of the situation is to advance the driving states of the transports to limit air contamination.

The transports are outfitted with GPS gadgets giving data in regards to their area and speed. Besides, the City of Madrid has conveyed sensors on the roads for the traffic signals, the ecological conditions, the traffic clog, and so forth. In this situation, some researchers consider the accessible data from portable sensors conveyed in the transports, for example, vehicle speed, street slope, area data from GPS gadgets, just as from static city sensors like road cameras, traffic signals area and evolving stretches, speed of vehicles, street lights, and temperature in everyday climate data (for example, ice, downpour, and so on). Residents from their cell phones might give extra data (for example, cell phones and tablets), providing from the gadgets' cameras regarding street conditions or expected mishaps. Through this data, an inventive situation alludes to the upgrade of transports control to consider different perspectives (for example, eco-efficiency, climate, gridlock, and so forth). Some applications will offer eco-saving features, considering the area of the transport, the street slope, and the speed of other vehicles in the course (for example, no compelling reason to speed up and accordingly devour gas when in 1 km the speed

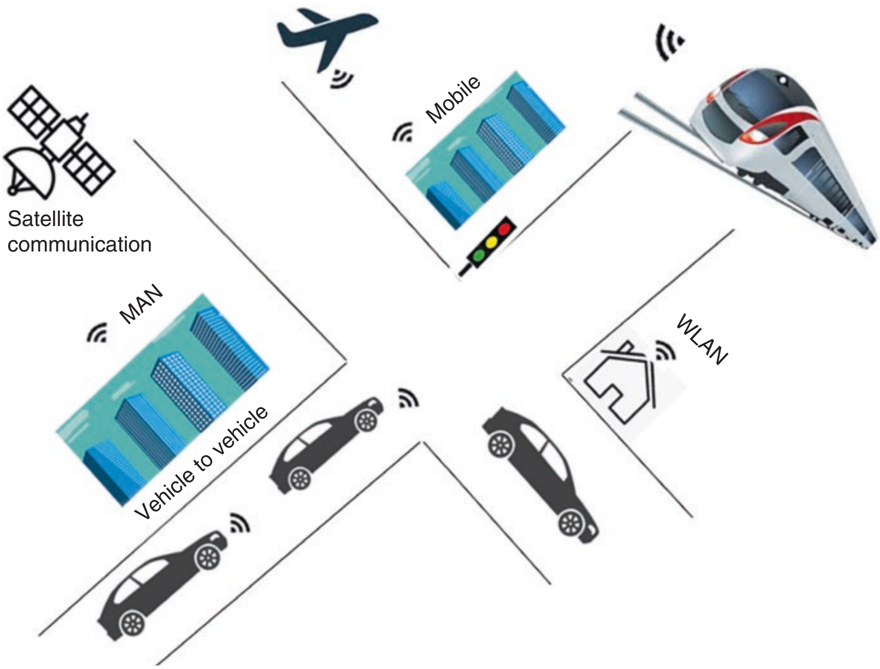

Fig. 4 An example of IoT-based transportation system

of the vehicles is 40% less than the cruising speed or when a traffic signal will become red). IoT advances will deal with the unwavering quality of things and comparing data streams. They will separate information at ongoing out of the information streams contributing to the situational mindfulness both in regard to the transports and different vehicles (for example, position, CO_2 outflows, plan, and so forth) just as in regard to the climate (for example, gridlock, traffic signals, CO_2 emanations, temperature, dampness, and so on). In addition, security will be expanded by using data concerning the area and speed of the transports, the street lights, potholes, the climate conditions (for example, ice), and the speed of different vehicles. IoT advances will permit things to gain from the others and accordingly adjust to continuous circumstances. To accomplish ideal breaking, things used to find and recognize the transport development will give data to the transport framework (for example, breaks or tires) response for exact circumstances such as the climate, the driving conditions and the temperature. This data will be imparted to other transports with similar attributes (for this situation with the same breaks or then again tires) to advance their cruising [45].

5 Real Implementation of Smart City

The Smart Campus project two at the Indian Institute of Science, the top graduate school in India, is one such effort to configure, create, and approve a vast IoT scheme [46]. This "living research facility" will offer a stage to attempt novel IoT innovations and smart city administrations, with a hostage base of about 10,000 understudies, workforce, staff, and family who, to a great extent, live nearby. The gated grounds spread across 1.8 km^2 have more than 50 offices, and around 100 structures have workplaces, auditoriums, research labs, supercomputing offices, inns, staff lodging, coffee shop, and well-being focus supermarkets. This is illustrative of massive networks and towns in India and offers an actual novel environment to approve IoT advancements for Smart Cities. The task means to configure, create, and convey a reference IoT engineering as a flat stage that can uphold different vertical utilities like smart force, water, and transportation. The exertion for this task is to filter through and choose the prescribed procedures and principles in the public space across different layers of the IoT stack, coordinate them to work flawlessly, and approve them for one sanctioned area at the ground scale. By its actual nature, these cutoff points work in a lab arrangement yet are infeasible, unrealistic, exorbitant, or do not scale. At the equivalent time, engineering additionally offers an open stage for examination into detecting, systems administration, cloud and big data stages, and examination. Figure 5 shows a different part of the smart city as an example.

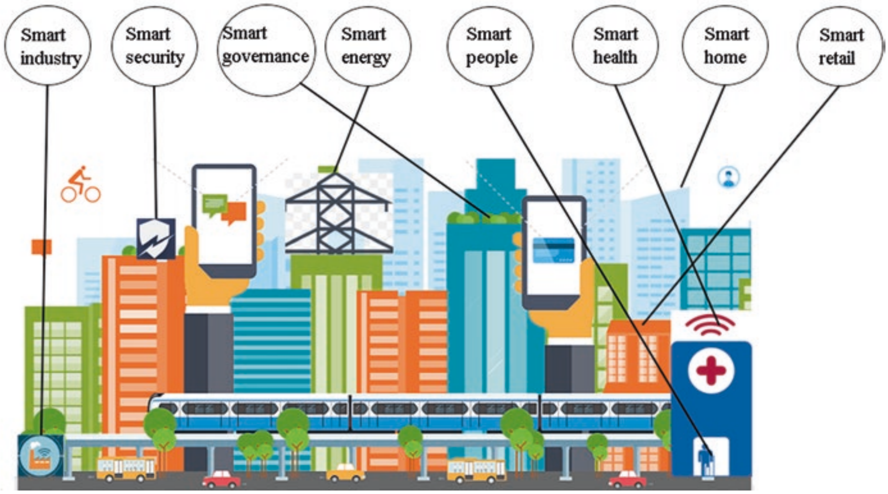

Fig. 5 Different parts of smart city

6 Discussion

The value chain of data analysis and data management in IoT applications includes data collection, integration, storage, analysis, and presentation. As mentioned in the previous sections, gathering, preparing, and analyzing this data volume is not an easy task because the data volume is not fixed. The data type (type and nature) also has inherent complexity. The existence of complexity due to variation in the form of data gathered together and the fact that it produces analytical solutions also changes the type of application or level of application. The value chain is an essential part of the business model. The chain shows how the service is delivered to the end customer. The IoT has a complex value chain because it contains many processes.

Smart city has many challenges, which are addressed in research and also in a real application. However, still, some challenges are not addressed. We enlist it as below:

1- Security: In IoT applications, many data must be collected to increase intelligence, which needs decreasing security and privacy.
2- Speed of analyzing: The speed of analyzing the data collected from IoT infrastructure is increased due to fog computing and serverless computing, but there are some unsolved problems in this area.
3- Accuracy of the decisions and predictions taken in smart applications autonomously is still a challenge.

These challenges can be addressed in upcoming research. Smart city applications pave the way for a better life and increase the quality of life.

7 Conclusion

For the first time in 1999, the IoT was used by Kevin Ashton, describing a world in which anything, including inanimate objects, can have a digital identity for itself and allow computers to organize and manage them. In other words, the IoT can be viewed as the next evolution of the Internet, which has a giant leap in collecting, analyzing, and distributing. The most important result of the spread of the IoT is the ability to connect all kinds of objects and devices to the virtual world. Thus, all household appliances, cars, hotels, stationery, and whatever you like will connect to the Internet.

These devices communicate the required data by connecting to the IoT, receiving the required data, changing the necessary change if required, or noticing to your audience. In addition to this feature, it is possible to connect two or more objects from other traits that can be learned.

The primary outcome of the IoT is the internal communication of machines. Devices with compatibility and security are equipped with high intelligence, so IoT design requires a communication network. The statistics of different global associations, as discussed, indicate an increase in the number of objects connected to the Internet in the coming years, followed by an increase in the use of IoT.

In this chapter, we explain different smart applications in smart city related to different industries and requirements. The discussion part is about some challenges that have not been addressed properly and can help the researcher to focus on more.

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IoT-Based Crowdsensing for Smart Environments

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1 Introduction

Sensing and monitoring of different aspects of a city (pollution, traffic, and heath) for improving the quality of citizens' life is an essential component of building smart city environments. In recent years, Internet of things (IoT)-based crowdsensing has grown as a captivating approach for sensing and acquiring data for smart environments. Sensors and communication technologies incorporated in regularly utilized smart handheld devices (e.g., smartphones and tablet) and wearables are employed in crowdsensing systems. These devices typically include a large number of sensors, allowing them to acquire a variety of data such as image, audio, video, geo-location, and environmental information. In this context, these smart IoT devices could be utilized for effective monitoring of different dynamics, namely traffic and road condition, environmental pollution, smart home and health. More specifically, IoT-based crowdsensing is helpful to monitor and manage a city's infrastructures as well as its resources efficiently based on the acquired sensor data.

IoT-based crowdsensing has several benefits over standard sensor networks that require the installation of a huge number of stationary wireless sensor units, especially in urban settings [1]. The widespread availability of smartphones and wearables, as well as a large number of built-in sensors, are unquestionably significant facilitators for the effectiveness of the crowdsensing paradigm. The sensors such as accelerometers, microphones, gyroscopes, and cameras are some of the examples

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that have aided the creation of a variety of applications in a variety of settings, including traffic and road conditions, environmental pollution, smart home, and health monitoring. A lot of crowdsensing-based applications were already designed and implemented in the past and are in use today. In order to provide representative examples, Nericel [2], Wolverine [3], and ScanTraffic [4] are some systems for traffic and road condition monitoring. For this purpose, these applications utilize smartphone-equipped sensors like accelerometers and GPS (global positioning system). On the other hand, applications like AirSense [5], HazeWatch [6], Common Sense [7], and GasMobile [8] develop light weight and low-cost devices for air quality assessment. These applications depend on citizens' direct involvement in air quality monitoring, which necessitates the use of IoT-based modules to acquire data. Similarly, several applications are also available for health monitoring and smart home. HealthAware [9] and SPA [10] are examples of smartphone-assisted systems for health care and well-being. Dutta and Roy [11], Lee et al. [12], and Froiz-Míguez et al. [13] are some existing works on various smart home solutions.

In this chapter, the details of IoT-based crowdsensing applications for various city dynamics, available techniques, issues, and solutions are presented. A general four-layered architecture is presented in order to better illustrate different existing crowdsensing-based systems of different dynamics and their working methodology. More specifically, an IoT–cloud-based architecture is provided for this purpose consisting of four layers: sensing layer, communication layer, data processing, and application layer. Several existing crowdsensing-based systems are compared and analyzed in this chapter depending on various aspects such as techniques used, nature of the system, real-time behavior and types of sensors used. Moreover, some open research issues (namely incentives, reliability, privacy, security, and quality) and constraints are also presented to direct future researchers.

The rest of the chapter is organized in the following sections: Section 2 presents four applications of the smart environment of the city. Section 3 provides the system overview explaining the layered architecture and the components used in each layer. Section 4 elaborates the methodology and paradigms used for these applications. Section 5 highlights the current research issues for IoT-based crowdsensing and Sect. 6 concludes the chapter.

2 Smart City Application

2.1 Smart Home

In present days, improvements of low-cost sensors, remarkable progress in crowdsensing along with edge and cloud computing, and a new era of smart homes have been created. Previously in most of the cases, all smart home appliances used expensive controllers as the controlling mechanism. But with the use of IoT–cloud-based system, a wide range and less expensive solutions for smart home are possible. Moreover, in controller-driven systems, control operation is only possible in short-range communication. But for cloud-based systems, as we are using the Internet through our smartphones, it is possible to control the IoT device from anywhere in the world.

In [11], a prototype for smart building/home is generated using IoT, cloud, and fog computing. Different sensors like optical, ultrasound, and gas are used for automation and security of the building. Arduino-UNO is used as a cross-platform software for the connection of firmware attached to the sensors. In [12], an integrated solution for a cloud-based home management system is described. Home management system connected with surroundings generates a solution for community infrastructure, and a community broker is deployed to manage the architecture as a whole. A low-cost fog-based solution for smart home is presented in [13]. Due to fog computing, instead of cloud, the latency of the solution is greatly reduced. Other existing works for smart homes are presented in [14–16]. A review work on fog-based framework is presented in [17]. A detailed review of IoT-based application of smart homes and the related publication statistics are elaborated in [18].

2.2 Health Monitoring

Smart healthcare has gradually developed with the advent of paradigms evolved in computation and information technology. A real-time solution of the detection of medical emergencies can be possible through a smart healthcare system. Similarly, in the remote or ad hoc infrastructure, smart healthcare can be a solution in emergency medical situation.

There are several applications of smart healthcare systems like (i) *Personalized smart device:* in different standard smartwatches, like the Apple Watch and Galaxy Watch Active2, it can monitor heart rate and keep a step count and irregular heart rhythm notification; blood oxygen application is also available in these kinds of devices. It may be used for the recording of 30-second ECG (electrocardiogram). (ii) *Safe home:* smart homes for senior citizens and disabled persons with embedded medical facilities like medical sensors, and monitoring IoT devices. Deviations from the normal conditions are notified through the notification systems in cloud and appropriate authorities take the measures against the data. (iii) *Patient monitoring system:* patients can monitor their health conditions using different applications embedded in sensors and data are stored in cloud via IoT devices. The recommendation system of cloud analyzes the data and sends a warning in case of any anomaly from the normal distribution is recorded.

Several approaches of smart healthcare systems are proposed in different literature. In [19], the authors propose a health monitoring system based on certain basic parameters like heart rate, oxygen saturation, eye movement, and temperature. In [20], a patient and room conditions of the patients are monitored using an IoT environment. In [21], a survey on different aspects of smart healthcare is presented. This paper also discussed the threats related to security and data privacy of crowdsourcing-based health monitoring systems. In [22], using two smartphones a heart monitoring system is proposed. Several other applications of smart health monitoring systems are proposed in several research papers [23–26].

Another approach of smart healthcare systems is personalized health monitoring system known as digital twin. Combining machine learning and artificial intelligence in health centers led to the use of human health digital twin, also referred to as patient's digital twin. In [27, 28], a framework for health twinning is designed for the citizen health and fitness. In [29], a smartphone-based digital framework is designed for smart city. Review works on health twinning have been presented in different recent literatures [30–32].

2.3 Traffic and Road Condition Monitoring

One of the key problems that the city authorities face is managing and tracking city traffic and road conditions. Specifically, effective monitoring of several dynamics like traffic flow, traffic density, aggressive driving, traffic jams and road conditions is proved to be a very important and challenging task these days. For instance, due to inadequate managing and tracking of city traffic, road traffic accidents (RTA) have become one of the world's major causes of injury and death, that not only responsible for the loss of human lives but also result in considerable economic losses. According to the World Health Organization, RTAs claim the lives of about 1.35 million people per year. Additionally, non-fatal accidents affect approximately 20–50 million more individuals, with most of them resulting in disability due to injury. In the above-mentioned context, constant assessment of traffic and road conditions at a large scale is necessary for citizens and policy makers for better decision-making.

Several existing works [2–4, 33, 34] focus on building effective road traffic and road condition monitoring systems based on IoT devices. In [2], Mohan et al. developed a system called Nericel in order to monitor road and traffic conditions of a city using the inbuild sensors (e.g., accelerometer, and GPS) of a smartphone. They showed that Nericell could be used for monitoring chaotic traffic conditions (like honking and braking). Another interesting system named Wolverine [3] is presented by Bhoraskar et al. for estimating traffic and road conditions. Specifically, they utilized a variety of smartphone-equipped sensors (accelerometer, magnetometer, and GPS) for identifying congested traffic as well as road conditions (e.g., speed bumps).

Hull et al. introduced a mobile computing framework called CarTel [33] that acquires various sensor data from On-Board Diagnostic (OBD-II) interface on vehicles to monitor their movements. The task to collect, process, distribute, and view data in this environment has been simplified considerably by CarTel. In order to build an Intelligent Transport System (ITS), Alessandrelli et al. designed and implemented a system called ScanTraffic [4] using a network of smart cameras. For parking monitoring, the system collects vehicle flow data and parking area occupancy status. In [35], Thiagarajan et al. present a framework named VTrack for estimating road travel times based on smartphone sensors. Specifically, they focus on providing an energy-aware solution for traffic delay prediction. Moreover, there are several research works on estimating traffic flow [36] and driving patterns [34, 37]. The details of the applications are provided in Table 1 in terms of their contributions, end-to-end system, real-time monitoring, reference, and year.

2.4 Pollution Monitoring

The adverse effects of rapid urbanization and population growth have negative environmental consequences. The existing works highlight that urban air and noise pollution have become a growing source of concern for both the citizens and policymakers around the world [38–42]. In this context, several research activities and community-based initiatives are focused on pollution monitoring in smart cities. More specifically, various IoT-based applications are developed for continuous as well as high granular monitoring and mapping of air and noise pollution levels in smart cities. This subsection provides the details of existing IoT-based pollution monitoring applications.

Several approaches for air quality monitoring in smart cities are described in [5, 43–47]. To illustrate representative examples, the applications like AirSense [5], HazeWatch [6], Common Sense [7], and GasMobile [8] develop light weight and low-cost devices for urban air pollution monitoring. It is worth noting that those systems rely on the active participation of citizens for such monitoring where they need to carry IoT devices for collecting air pollution data. Also, there exist some systems like CUPUS [48] that makes use of wearable sensors to sense ambient air quality levels. Mobile air quality sensors, which are mounted on the tops of public transportation vehicles, are another important research direction that is currently being investigated [49]. Here, air pollution data are recorded as the vehicles travel around the city. Most of the above-mentioned applications employed cloud services from various cloud computing platforms (e.g., AWS—amazon web services [50], GCP—google cloud platform [51]) to store and analyze high granular data for exploring pollution dynamics of the city. Existing literature [52] also assesses urban air quality by combining traditional monitoring stations along with IoT-based air pollution monitoring. Similar to the air quality monitoring, several urban noise pollution monitoring applications [53–56] are available that acquire ambient sound levels to study noise pollution dynamics of the city. These applications mainly utilize citizens' smartphones as IoT devices, which citizens are encouraged to carry for urban noise pollution data collection. For instance, an application called NoiseTube [53] uses GPS-equipped smartphones to collect geotagged ambient noise measurements as well as contextual inputs from the citizens. They provide PoI (point of interest) based pollution maps for visual assessment of urban noise pollution.

Table 1 Details of the smart city applications for pollution monitoring, traffic and road condition monitoring, health monitoring, and smart home

Application type	Application name	Author	Year	Contribution	End-to-end system	Real-time monitoring
Pollution monitoring	Air sense	Dutta et al. [5]	2017	Low-power, low-cost, light weight IoT device called AQMD, developed to monitor air pollution levels	✓	✓
	Noise sense	Dutta et al. [59]	2017	Noise pollution monitoring system, based on context-aware smartphone sensing	✓	✓
	Haze watch	Sivaraman et al. [6]	2013	Low-cost participatory sensing framework for monitoring urban air quality levels	✓	✓
	Gas Mobile	Hasenfratz et al. [8]	2012	Low-cost and light weight off-the-shelf hardware for assessing ozone levels	✓	×
	Noise tube	Maisonneuve et al. [53]	2009	Use GPS-enabled smartphones to determine noise exposure of individuals	✓	✓
	Noise SPY	Eiman Kanjo [56]	2010	Develop a platform for real-time monitoring and mapping of urban noise	×	✓
	Ear-phone	Rana et al. [54]	2010	Urban sensing approach to monitor roadside ambient noise	✓	✓
	Common sense	Dutta et al. [7]	2009	Air quality monitoring using handheld air pollution monitoring devices	×	✓
	–	Gupta et al. [60]	2019	Introduced an IoT–cloud-based framework for real-time assessment of urban air pollution	✓	✓
	JU sense	Middya et al. [58]	2020	Unified framework to combine applications like NoiseSense [59], and AirSense [5] to gain benefits from their interactions	✓	✓

Traffic and road condition monitoring	Neri cell	Mohan et al. [2]	2008	Monitor traffic and road condition of a city using the inbuild sensors of smartphone	×	×
	Wolverine	Bhoraskar et al. [3]	2012	Identify congestion with road conditions based on smartphone sensors (accelerometer, magnetometer, GPS)	×	×
	CarTel	Hull et al. [33]	2006	Acquires, analyzes, delivers, and visualizes data from sensors of cars	×	×
	Scan traffic	Alessandrelli et al. [4]	2012	Collects vehicle flow data and the occupancy status of parking areas for parking monitoring	✓	✓
	D&R sense	Bose et al. [34]	2018	Identify unusual driving patterns and road conditions	✓	✓
	–	Khan et al. [61]	2021	Data fusion-based traffic congestion monitoring and control	×	×
	–	Dhingra et al. [62]	2020	Fog and cloud-based framework for traffic congestion monitoring using IoT	✓	✓
Health monitoring	Smartphone-based ECG monitoring	Joseph et al. [22]	2010	Two smartphone-based ECG acquisition and real-time analysis of statistical anomaly	✓	✓
	–	Islam et al. [20]	2020	Sensor-based monitoring of room and patient	✓	✓
	Health monitoring	Tamilselvi et al. [19]	2020	IoT-based monitoring on preliminary health conditions like saturation of oxygen, and heartbeat	×	✓
	Cloud DTH	Liu et al. [27]	2019	Digital twin healthcare system using cloud infrastructure	✓	✓
	Human digital twin	Barricelli et al. [28]	2020	Smartphone-based twin network for fitness management of athletes	✓	×
	Digital twin	Laamarti et al. [29]	2020	Smartphone-based twin framework for citizens of smart city	✓	×
Smart home	Prototype of smart home	Dutta et al. [11]	2017	IoT-, fog-, and cloud-based prototype for smart and green building	✓	✓
		Lee et al. [12]	2016	Cloud-based home management system	✓	✓
	Home automation	Mignez et al. [13]	2018	Fog-based home automation system	✓	✓
	Home automation	Izquierdo et al. [15]	2010	Indoor ambiance automation	×	✓

Similarly, in [54], the authors developed an end-to-end framework called Ear-Phone for participatory-based urban noise mapping. Becker et al. created a smartphone application named the WideNoise [55], which allows citizens to participate in noise measurement activities. It was created to collect both the objective (i.e., ambient noise) and the subjective (feelings, opinions, and so on) data. Also, there are real-time noise monitoring systems like NoiseSPY [56] in which the developers performed experiments and displayed noise pollution maps. Finally, there are unified frameworks [57, 58] that can combine both air and noise pollution monitoring applications for smart city. For instance, in [58], an urban sensing system named JUSense combines applications like NoiseSense (for noise monitoring), and AirSense (for air pollution monitoring), to gain benefits from their interactions.

3 System Overview

This section presents the details of crowdsensing systems [11, 63, 64] that are used to study various dynamics of a city (e.g., pollution and traffic condition). As shown in Fig. 1, the crowdsensing system can be introduced as a layered architecture. The

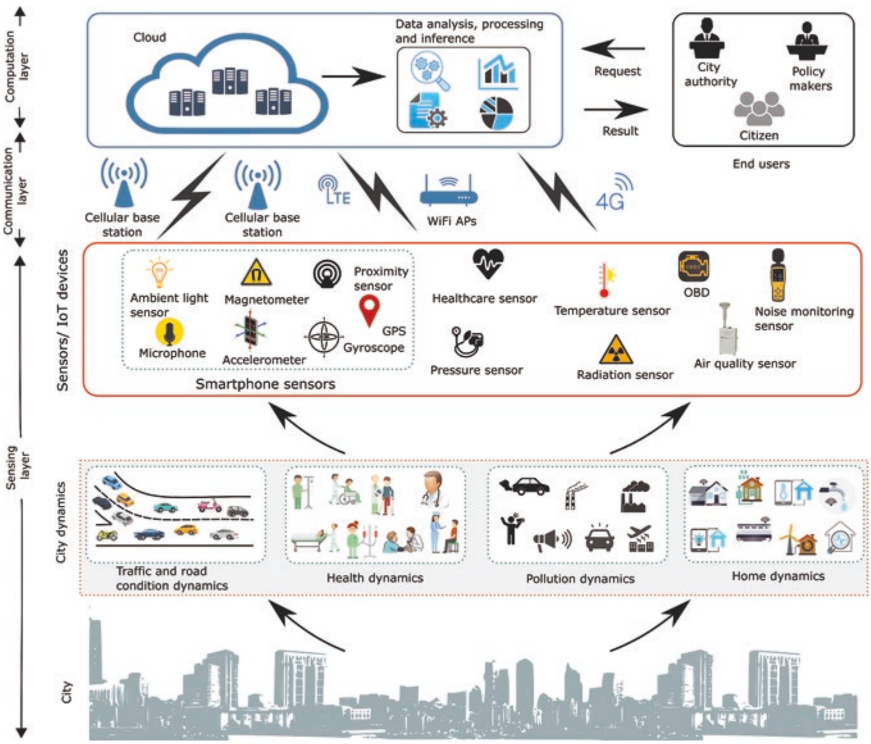

Fig. 1 Framework of crowdsensing system

major parts (i.e., layers) of the architecture are arranged as follows. The bottom layer is the *sensing layer* that mainly includes the city, its dynamics, and the sensors used to sense those dynamics. The *communication layer* is the second layer of the architecture, which consists of communication technologies for delivering data from sensors. *Data processing layer* is the third layer, which has responsibility for the storage, analysis, and processing of the data that has been collected. The last layer is the *application layer* that includes top-level features like participant allocation, assignment of sensing tasks, and services. The following subsections present the major components of different layers in detail.

3.1 Sensor

The sensors used for data collection are the heart of any crowdsensing-based smart city application. The sensing layer involves data acquisition from different dynamics (e.g., traffic dynamics, health dynamics, pollution dynamics, home dynamics, etc.) through IoT devices including smartphones. Specifically, smartphone-equipped sensors along with the specialized sensor modules are employed for the sensing tasks for various applications. Examples of smartphone-equipped sensors include microphones, magnetometers, GPS, gyroscopes, proximity sensors, accelerometers and light sensors. On the other hand, IoT-based external sensor modules often expand the sensing capacity of a smartphone by adding sensing capabilities that the smartphone alone does not provide. Table 2 presents the details of smartphone sensors as well as external sensors used in various applications of different city dynamics.

3.1.1 Smartphone-Based Sensing

In this subsection, we will discuss how smartphone-equipped sensors are utilized to monitor different dynamics of a city.

As given in Table 2, the accelerometer and gyroscope sensors' data were extensively studied as a potential means of developing methods for detecting traffic and road surface irregularities [3, 65]. Most existing traffic and road condition monitoring approaches require that the smartphone be kept in the proper orientation, with its axes aligned with the vehicle's axis. The 3-axes accelerometer's data indicate the acceleration of the vehicle in all three directions. Along with the accelerometer sensor, the GPS sensor is used in many applications for sensing the current location estimates (latitude and longitude) of the vehicle [66, 67]. Moreover, images captured from smartphone cameras are used in various applications to monitor road surface anomalies [65]. Similarly, in the case of city pollution monitoring, smartphone-based sensing is utilized to sense the ambient environment. For instance, environmental sound levels are collected using the microphone sensor of a smartphone along with the GPS location for ambient noise pollution monitoring and mapping. Smartphone sensing can also be used along with the IoT-based external sensor modules for

Table 2 The details of smartphone sensors as well as external sensors used in various applications of different city dynamics

City dynamics	Application name/Author	Smartphone sensors	External sensors
Traffic and road condition monitoring	CarTel [33]	–	Camera, OBD device, WiFi
	Nericell [2]	GPS, microphone, accelerometer	–
	Wolverine [3]	GPS, accelerometer, magnetometer	–
	RCM-TAGPS [69]	–	GPS, accelerometer
	PotSpot [65]	GPS, camera	–
Pollution monitoring	NoiseTube [59]	GPS, microphone	–
	HazeWatch [6]	–	Gas sensor, Bluetooth sensor
	AirSense [5]	GPS	MQ-135, HC-05
	NoiseSPY [56]	GPS, microphone	–
	GasMobile [8]	GPS	MiCS-OZ-47
	Idrees et al. [70]	–	MQ-135, MQ-7, MQ-9, GP2Y1014AU0F, DSM501
Health monitoring	Liu et al. [27]		ECG, DBO, blood pressure meter
	Smartwatch [71]		Blood pressure, heartbeat
	Tamilselvi et al. [19]		Heartbeat, SpO_2, temperature, and eye blink sensors
	Acharya et al. [26]		Blood pressure, eco cardiogram sensor
	Islam et al. [20]		Heartbeat, ambient and body temperature sensor
	PGFIT [68]	Google fit app, smartphone sensors	
Smart home	Dutta et al. [11]		LED, laser, gas, flame, ultrasonic sound, movement detection
	Lee et al. [12]		Touch panel, environmental sensor

monitoring citizens' air pollution exposure (details are provided in Sect. 3.1.2). For example, in [5], ambient air pollution data (PM2.5 and PM10) are collected using DSM501 sensor along with the smartphone data (GPS, user context, and timestamp) for spatial and temporal air pollution monitoring. In smart home systems, different cross-platform software packages like Arduino IDE are used for code editing and compilation of different firmware attached with the sensors. It can be used as the web service and can be attached with smartphones with different applications. In health monitoring systems, smartphones can act as sensors or a sensor can be attached into smartphones. As the mobile device has an advantage of being easily carried out by patient all time, it is easy to collect data on 24X7 basis without restricting the movement. For example, in [22], two mobile phones are used to collect the ECG data, and data is delivered to the system, which enables an online detection (in the present scenario, holter monitoring is used to record continuous ECG data, which is very inconvenient to carry and the data can be retrieved only when all data are recorded and analyzed by a medical person; therefore, a real-time detection or measure of any anomaly is not possible). In [28], a smartphone-based twin network for fitness management of athletes is generated. An app is created in the framework, where athletes have to submit various inputs like their food, rest, practice schedule, and also some qualitative quantity like mood, for the analysis. Similar smart healthcare systems for the citizen based on smartphones are generated in [29], where five sensors collect the data and send the data in smartphones. In [68], the Google fit app is used for data collection, and smartphone sensors are used to capture the input data. Some smartphone-based data collection software packages used for health monitoring are described here: (i) *Teamscope*: it can be used in Android, iOS, and web applications. It is a secure and user-friendly app for the collection of sensitive clinical data. It is cross-platform software and has a high-security feature; (ii) *Open data kit*: it is open-source software used in Android applications. It is open-source and free software. A large community support is available for this software; (iii) *Kobo ToolBox*: it is free and open-source software used in Android and web. It is widely used in nonprofitable organizations for the collection of patient data; (iv) *REDcap*: this software can be used in Android, iOS, and web application. It is used for secure electronic data capture; (v) *Magpi*: it is a mobile data recording app used in Android and iOS. It can be used to generate excel data from different unstructured input; (vi) *Jotform*: it is used in Android, iOS, and web to collect different data types and organize the data. It can generate an alert system or notification to the end user; (vii) *Survey CTO*: it is a reliable, secure, and scalable mobile data collection app that can be used in Android and web for researchers and professionals; (viii) *CommCare*: it is a data collection platform in Android and web. It is widely used for medical data collection. The platform supports both cross-sectional and longitudinal data and data collection through web and is very user friendly.

3.1.2 Sensing Using IoT-Based External Sensor Module

IoT-based dedicated sensor modules are also popularly used for sensing various city dynamics. In the case of monitoring road and traffic conditions, a set of sensors/devices like on-board diagnostic (OBD) scanners, GPS, accelerometers and cameras, are installed in cars for monitoring the movements and behavior of vehicles. Note that OBD is a tool that can continuously monitor the status of the vehicle. Similarly, for different air pollution monitoring applications, several IoT-based external sensor modules are proposed in the literature. In [5], an IoT device called AQMD (air quality monitoring device) is developed that consists of a gas sensor (MQ-135) and a Bluetooth module (HC-05). Note that the MQ-135 is an air quality sensor that can detect the presence of various gaseous pollutants such as NH_3, CO_2 and NO_x. There exist several other IoT-based systems such as HazeWatch [6] and JUSense [58] that also use MQ-135 for acquiring air quality data. Sensor modules like GP2Y1014AU0F and DSM501 are mainly used as dust sensors for measuring particulate matters (PM2.5, PM10). IoT-based external sensor modules containing MiCS-OZ-47 are used for the purpose of sensing the pollutant O_3. Laser (used for security), DHT 11 (temperature and humidity), MQ2/MQ6/MQ7/MQ9 (gas sensor), and flame sensor (used for fire security) are some examples of commonly used sensors for smart homes.

In smart patient monitoring systems, sensors collect data from the patients and send it to some Wi-Fi systems, from where data are collected and processed in cloud. Smartphones are generally used for data collection and security. Some sensors like smartwatch are directly connected with mobile phones, and the information like heartbeats is continuously monitored through smartphones. Another application of mobile smartphones is that to collect data when patients are in a mobile state. Pressure sensors (used to measure blood pressures, almost similar to clinical meter but with a digital display), blood sugar monitoring sensors (used to collect data from blood about the sugar level), and pulse oximetry sensors (measure oxygen saturation and pulse rate) are commonly used sensors used to measure health condition in home. Force sensors (used on dialysis machine to monitor pressure and dialysate weight), thermistors (temperature control), and airflow sensors (detection of ultra-low levels of oxygen) are some of the sensors used in medical facilities. These sensors are Wi-Fi connected, and the data are warehoused in cloud/server for analysis.

3.2 Communication Technologies

The communication layer, depicted in the framework of Fig. 1, contains technologies and methodologies for delivering sensing data to the cloud from smartphones and other IoT devices. Smartphones and IoT-based external devices generally have many radio interfaces (like Bluetooth and Wi-Fi), and there are numerous optimizations that may be made to make the communication interfaces more effective such as avoiding repeated sensor measurements or encoding unnecessary data. The communication technologies could be broadly divided into two classes, namely (i) infrastructured and (ii) infrastructure-less. Cellular and WLAN (wireless local area network) are examples of infrastructured technologies, in which the network depends on the base stations or access points to create a communication connection. On the other hand, technologies like Bluetooth, Wi-Fi-Direct and LTE-Direct, come under infrastructure-less category to enforce proximity-based communication.

3.3 Computation Layer

The computation layer in a crowdsensing framework is mainly responsible for *data management* in cloud and *data processing*. The storage, format, and dimension of collected sensor readings are different aspects of data management. Both databases and data storage are usually employed to store the data collected via smartphones and external IoT devices. The data storage could be centralized or distributed depending on the applications. The format of the data on the other hand indicates whether the data is structured or unstructured. Another aspect of data management involves the data dimension that is associated with the types of data acquired. For instance, multidimensional data involves different types of data from different sensors; e.g., accelerometer data of vehicle and road segment images from dash camera creates a multidimensional dataset for monitoring road condition dynamics. A particular type of sensor, on the other hand, generates single-dimensional data, such as data produced by air quality sensors for air pollution dynamics.

In crowdsensing-based applications, data processing is a critical step. Preprocessing, analysis, and postprocessing are the three major components of data processing. Before analysis, preprocessing tasks are conducted on the acquired data. Frequently used preprocessing tasks in crowdsensing systems involve missing value imputation, context-aware data cleaning, calibration, and map-matching. Through a variety of methodologies, data analysis tries to extract and disclose valuable information. These methodologies generally include various statistical, machine learning and deep learning techniques. Also, several postprocessing tasks are performed for predictive analysis. For instance, in the case of air pollution dynamics, forecasting air pollution levels can be considered as a postprocessing task.

4 Methodologies

In this section, the details of the methods used in data preprocessing, analysis, and postprocessing is provided.

The raw sensor data from various city dynamics suffer from missing sensor readings due to the factors like power disruptions, device failure and irregular maintenance. The methods of imputation are roughly classified into two categories: univariate methods (use single predictor variable to estimate the missing values) and multivariate methods (use multiple predictor variables to estimate the missing values). Unconditional mean (UM), median (MD), last observation carried forward (LOCF), next observation carried backward (NOCB), auto regressive (AR), and auto regressive integrated moving average (ARIMA) are some examples of univariate methods of missing value imputation. On the other hand, several machine learning-based multivariate methods of imputation exist such as random forest (RF), artificial neural networks (ANN) and k-nearest neighbors (KNN). Now, context-aware data cleaning is a preprocessing task to eliminate inaccurate sensor readings not collected in the proper sensing context. Existing literature highlights that machine learning algorithms could be used to first identify the sensing contexts. If an identified sensing context is not appropriate, then the corresponding sensor readings are eliminated to enhance the quality of data. For example, in [72], Rana et al. developed a context discovery module using k-nearest neighbor (kNN) algorithm for noise pollution monitoring in urban areas. Now, calibration is also needed as a preprocessing task to estimate actual sensor readings from the responses of low-cost IoT devices. It is because low-cost IoT devices may not always provide precise, high-quality readings. The existing literature usually develops calibration models by estimating a relationship between the sensor readings and actual ground truth measurements [58]. In applications like pollution monitoring or traffic and road condition monitoring, map-matching is used as a preprocessing procedure that involves mapping raw sampling coordinates (i.e., places where sensor data samples were taken) onto existing road networks. Interactive-voting-based technique [73], probabilistic approach [74], force-directed technique [75], and feature-based technique are some examples of map matching approaches.

In the previous works, after data preprocessing step, several predictive methods are usually employed to perform analysis on the preprocessed data. The statistical, machine learning and deep learning techniques are popularly used as predictive methods. These methods are used to infer knowledge, spot patterns, and discover trends. Environmental pollution monitoring, traffic and road condition monitoring, smart health and smart home, are some of the city dynamics where the crowdsensing-based applications use these techniques. For instance, the application Wolverine [3] uses machine learning techniques in traffic and road condition monitoring. Specifically, they use models like K-means clustering and Support Vector Machine (SVM) to detect road bump, vehicle braking, etc. Statistical techniques like spatial and temporal interpolation are used in many applications of city pollution monitoring for air and noise pollution mapping [1, 58]. In [1], IDW (inverse distance weighting)- and OK (ordinary kriging)-based interpolation techniques are proposed for spatially continuous urban noise pollution mapping. In the case of smart health and smart home dynamics, machine learning- and deep learning-based techniques are frequently utilized for various event detection. For example, in [76], fall detection is performed using machine learning (SVM and NB) and deep learning models. Finally, postprocessing techniques are sometimes employed for predictive analysis, such as forecasting future values. In various application domains of city dynamics, statistical models (ARIMA, Seasonal ARIMA, etc.) as well as deep learning models (recurrent neural network (RNN), long short-term memory (LSTM), bidirectional-LSTM, etc.) are popularly used for forecasting future values [39–41].

5 Research Issues

In IoT-based smart sensing, there are several unresolved issues that required attention from the researchers. For crowdsensing, data are collected from user level, which is an uneven distribution set. It is important that users should participate in data collection, but it is obvious that everyone will not be enthusiastic in a similar manner. Therefore, it is required to device incentive strategies in such a way that quality information can be collected. Now uneven distribution of smart devices for data collection may reduce the reliability of the system. For example, smartphone sensors may vary in a wide range depending on the pricing. Security of the data of the crowd sense system is another research issue to be addressed. As data are stored in public or private cloud, it is difficult to maintain the security of the information both in plain or cryptic text. Sensitive data like medical records should be secured in IoT-based systems. Therefore, lots of research work addressed cloud security. Another research issue in this area is to maintain the quality of service (QoS) of the system. In each layer of the architecture, some quality control measures have to maintain, and it is a challenge for the researchers to improve the standard.

5.1 Incentive

As previously stated, crowdsensing (also known as participatory sensing) is a new paradigm of sensing in which participants acquire high granular data using IoT devices such as smart handheld devices. These data can then be used to investigate different aspects of a city's dynamics (e.g., traffic condition, urban air and noise pollution and road condition). In the case of crowdsensing-based systems for collecting sufficient data for such investigations, active participation of a large number of participants is necessary. However, in crowdsensing-based monitoring of city dynamics, users incur costs because of the energy requirement, bandwidth requirements for sensing, processing, and uploading of data. Therefore, the users might not be able to contribute their resources as the cost issues demotivate them from actively participating in the sensing. In this context, a satisfactory reward or incentive would compensate users and encourage them to participate in the sensing process. An effective reward mechanism would therefore have an important role in sensing and overall performance of the crowdsensing systems for monitoring various city dynamics.

Several incentive strategies [77–80] for crowd/participatory sensing-based frameworks have been developed in the literature to motivate participants in the sensing task. It is observed that most of the existing incentive mechanisms come up with a game theoretic solution. For instance, in [80], Yang et al. introduced an incentive mechanism called IMCC based on a Stackelberg game. Some auction-based game theoretic models such as reverse auction and double auction-based models are also frequently used. Lee et al. [77] developed a dynamic price incentive mechanism with virtual participation credit using a reverse auction. In [81], Wang et al. developed a quality-aware, truthful, individual rational, and budget-balanced incentive mechanism called MeLoDy based on the reverse auction. They consider long-term characteristics of workers' quality that can dynamically change over time. Table 3 provides a detailed list of existing literature that focuses on the issue of incentives in crowd/participatory sensing-based systems. Some attempts are also made to develop incentive mechanisms for air pollution monitoring [82], health monitoring [83] and traffic monitoring [84].

Table 3 A detailed list of works that focus on the issue of incentives, reliability, quality, privacy, and security in crowd/participatory sensing-based systems

Research issue	Mechanism/framework name	Author	Year	Contribution
Incentive	RADP-VPC	Lee et al. [77]	2010	A dynamic pricing incentive model, using reverse auction
	IMCC	Yang et al. [80]	2015	A Stackelberg game-based incentive model
	ABT	Wang et al. [105]	2017	An incentive mechanism, developed for crowdsourcing system ability-balanced team
	Geo-QTI	Dai et al. [106]	2018	A quality-aware incentive model for cyber-physical participatory sensing
	MeLoDy	Wang et al. [81]	2018	A quality-aware, truthful, individual rational, budget-balanced incentive mechanism called MeLoDy is developed based on the reverse auction
	BiCrowd	Zhang et al. [107]	2020	Formulate the incentive model with two optimization goals (namely maximizing the reliability and maximizing the spatial diversity of selected workers) based on the reverse auction
Reliability and quality		Liu et al. [27]	2019	Standardize sensor and communication link
		Restuccia et al. [85]	2017	Develop privacy-preserving, budget-feasible, truthful crowdsourcing-based dataset purchasing framework, quality of information in mobile crowdsensing.
		Truong et al. [86]	2019	Developed a system for evaluating trust in mobile-based crowdsourcing
		Dasari et al. [87]	2020	Game theoretic approach to generate reliable data
	SecPMS	Maitra et al. [115]	2017	Security for patient monitoring system
		Ray et al. [104]	2020	Proactive fault-tolerant system for reliability enhancement in cloud
Privacy and security	CKD	Chi et al. [89]	2017	This paper focuses on combining k-anonymous and differential privacy-preserving mechanisms to preserve location privacy
	Crowd buy	Zhang et al. [90]	2018	Develop a privacy-preserving, budget-feasible, truthful crowdsourcing-based dataset purchasing framework
	PEPSI	Cristofaro et al. [91]	2011	A framework called PEPSI is proposed for protecting the privacy of both data consumers and producers in participatory sensing
	PMP	Agarwal et al. [92]	2013	A system is developed for detecting the access to private data and provide privacy recommendations using crowdsourcing
	PPDCA	Tsou et al. [93]	2018	A C-RR (complementary randomized response) method is developed to ensure the data privacy of individuals
	SecBCS	Lin et al. [94]	2020	Designed a block chain-based security system for crowdsourcing hierarchy

5.2 Reliability

In crowdsourcing-based monitoring, reliability is an important criterion. In crowdsensing, one of the components is human entity. Therefore, the sensing can be biased, judgmental, or even mischievous [85]. For real-time crowd sense systems, another parameter that is connected with the reliability of the architecture is the response time and variation in delay. As the system includes different layers in the architecture, it faces congestion and other communication delays in the system. Delay can be reduced using larger bandwidth, load balancing, and other mechanisms, but variation in delay may cause a reduction of the reliability of the system. Different methodologies for assurance of reliability in crowdsensing-based systems are proposed and tested. Though the reliability of the system is very application specific and no common framework is emerged to date, a lot of research work has been done in that direction. In [86], a trust evaluation mechanism is proposed. In [87], a comprehensive survey on reliability based on the game is done. Another factor that may cause a lack of reliability is the sensor device used for input data collection. Unidrive is a consumer cloud storage application enhances the reliability of the cloud service [88].

5.3 Privacy and Security

The crowdsourcing-based mechanisms usually suffer from potential privacy and security problems because sensitive data of the users are disclosed. For instance, the sensed data might include location information that could implicitly reveal the mobility of a participant. Security refers to preventing illegal access, use, alteration, or damage of the acquired data. In addition to security, a crowdsourcing-based system should protect the privacy of both the users and the crowdsourcer. In most cases, privacy refers to an entity's ability to choose whether, when, and to whom its information is shared or revealed. Hence, an effective crowdsourcing system should be able to handle security and privacy threats, keep the acquired data and processing results out of the hands of unauthorized users, and also keep the system running normally. Issues of security and privacy are becoming increasingly important and challenging in crowdsourcing systems because of human involvement, dynamic network topology and heterogeneity in various communication networks.

The scientific community has spent considerable time and effort in the last few years looking into privacy and security concerns [89–94]. Ding et al. [95] present an application for s-Health (i.e., smart health) and the associated privacy issues. The privacy-aware solution enables them to easily deal with people who have respiratory disorders by suggesting low-pollution paths for individuals in order to alleviate their respiratory-related issues. In [96], Xie et al. proposed a system called PAMS for privacy-aware traffic monitoring. They demonstrated that the collected information can preserve the location privacy of drivers while ensuring effective traffic monitoring. In [97], Zavalyshyn et al. developed a privacy-aware framework called HomePad for home environments. The framework intends to offer the users with control over how applications access and process confidential data acquired by smart devices (such as web cams), as well as to stop applications from running unless they adhere to the privacy constraints set by the users. Also, several other existing works [98–100] focus on the security aspect and privacy of IoT-based health and home environment. Some IoT-based pollution monitoring applications are also focused on privacy issues of the end users [56, 101]. In [27], the authors propose a security system in eight levels, which consider security in the system level, network security, users' personal privacy, information, and application security. Another security system for patient body monitoring system is proposed as SecPMS [102], where a cryptosystem is generated both on user data and sensor data.

5.4 Quality

Quality of service is used to measure the overall service we are delivering through the smart system we are using. It depends on each component used in the system hierarchy. In crowdsourcing, input data are collected from sensors and transferred through a wireless communication system. Data of the crowd sending systems are generally stored in the cloud system, where the quality of service is dependent on the cloud service provider. Moreover, a huge data is processed for analytics in crowdsensing, which can lose the reliability of personalized information. Therefore, to maintain the overall quality, it is required to standardize each level.

5.4.1 Standardization of Sensor

Sensors used for collecting data input from the users are not very standardized in the present scenario. They are different proprietary devices and generate different standardization. ISO/IEEE11077(X73) is a standard protocol for the standardization of the sensors. But only a few devices are using this standardization. Therefore, the other devices have to be standardized. A proper calibration is required for this purpose. A standardization mechanism for sensors and communication link compliant with X73 is discussed in [27]. Quality control of sensors is a prospective research domain for future crowdsensing.

5.4.2 Standardization of Communication System

As discussed in the previous section, the hierarchy uses different kinds of communication link/systems. It can be structured wireless or mobile systems, or unstructured systems. For the unstructured communication, links are not always standardized and may cause interference. For example, Wi-Fi communication may create resonance to other devices used in medical infrastructure. This can be solved using other wireless technologies like Zigbee.

5.4.3 Expert System

Expert recommendation systems for the crowdsourcing data systems should be reliable and secured. The service we are delivering in crowdsensing is very much dependent on the expert systems we are generating. Statistical approaches or machine learning systems are dependent on the input feed used to train or learn the system. It cannot have 100% accuracy. Therefore, for surveillance systems, it can be used in a proper manner but where a critical decision has to be taken, a manual intervention along with the recommendation of an expert system is required. For statistical-based approaches, better interpolation and in machine learning, proper learning and training can deliver a precise recommendation system. Proper feedback from the user level also assures quality service from an expert system.

5.4.4 Cloud Infrastructure

Cloud services used for infrastructure services are not always maintained by all service providers. Moreover, security and privacy of user information are two important issues for quality services. There are different approaches like game theoretic approaches and load distribution algorithms to ensure the quality of services of cloud infrastructure [103]. Cloud federation is a concept where cloud providers share unused resources to generate a fault-tolerant system. It is important for the crowdsourcing system to access a reliable and fault-tolerant cloud hierarchy for storage and computation. In [104], the authors propose a proactive fault-tolerant system for enhancing cloud federation to ensure the reliability of the crowdsourcing system for a smart environment.

6 Conclusion

Crowdsensing and its application can be emerged as key components of the smart environment of a city. This chapter presents the details of crowdsensing systems that are used to explore city dynamics in forms of four applications: smart homes, smart health monitoring systems, air and noise pollution monitoring systems, and road and traffic condition monitoring systems. In this chapter, we introduce the crowdsensing system in a layered architecture. The lowermost layer is the sensing layer, which mainly includes the city, its dynamics, and the sensors used to sense those dynamics. It can be defined as the data collection layer. Both smartphone sensors as well as connected sensors are elaborated. The communication layer is the second layer of the architecture, which consists of communication technologies for delivering data from sensors. The third layer is the data processing layer, where all data preprocessing, analysis, and expert systems are generated. The topmost layer is the application layer that generates the services through the crowdsourcing systems.

In this chapter, we have classified sensors into two divisions: smartphone sensors, where built-in sensors of smartphones are used, and wearable sensors that are connected through IoT devices. A detailed discussion on the sensors generally used in four applications is presented. In the communication layer, both infrastructured and infrastructure-less wireless communication are used. In the computation layer, data is preprocessed and analyzed, and results are generated with feedback. All these components are discussed in the methodology section. Research issues related to crowdsensing are also presented in the chapter.

In crowdsourcing-based applications, paradigms like the IoT, mobile-based or Wi-Fi-enabled sensors, cloud, edge and fog computing, and big data analytics generate a big leap over existing technologies. Crowdsourcing is a concept where inputs are generated by the citizens of smart city collectively. Shared data generates a recommendation system. Sensors are utilized to acquire the data from the individuals. These sensors are cheap, easy to use, generally movable in nature, and connected or communicate with the smartphone device. These collected data are stored in cloud servers, and analytics are derived in the server. For thin client services, analytics can be performed in IoT devices also (fog or edge computing), which is very useful in real-time operation. Privacy, security, and quality of services are of great concern in the real-life implementation of crowdsensing-based infrastructure. Cloud service providers, public or private, are prone to security attack and a lack of data secrecy. Sensitive data can be hacked from the system. Another issue is the power consumption of IoT devices and consequent harm to the environment. Therefore, green computing is another aspect, where the focus should be concentrated.

An in-depth analysis of the chapter focuses and elaborates the scope, architecture, and recommendation system relevant to crowdsensing-based applications in smart city. The review in each topic of concern can serve as a reference for future research work in this area. Moreover, in the future, the research issues and challenges identified in this chapter may be useful to the research community in developing more robust IoT–cloud-based crowdsensing systems.

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Water Monitoring Using Internet of Things

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1 Introduction

As far as human technology has reached, the earth is the only planet to have an ecosystem where live species can survive. The most important link that maintains the earth's ecosystem is water [1]. In the cyclic process of our ecosystem, water cannot be replaced with another substance. In our society, water plays the most vital role. It is indispensable in our homes, industries, transport, food, farming, and daily activities to have usable water. However, the rapid civilization and population growth in past decades have caused a frightening effect on water quality [2]. If this situation does not change, then it could disrupt the natural balance of the ecosystem.

On the other hand, up to 60% of the human body is water so drinking enough water is important to stay healthy [3]. But contaminated water can cause great harm; for example, according to the World Health Organization, almost half a million people die every year only because of diarrhea by drinking contaminated water [4]. However, now, people are more aware than at any other time about the ecological

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balance and the effect of pollution on the human race. Leaders are making rules to discourage activities that cause pollution, and people are getting mindful of such acts.

But the pollution monitoring system, especially for water, is not readily available to our community [5, 6]. Many garments and industries dispose of their chemical contaminated water without proper treatment behind the authority's back and pollute the river and canals [7–9]. In most impoverished and underdeveloped countries, water pollution monitoring does not get enough precedence. The situation comes to light only after the final deterioration, for example, in the river of Markanda in India, water measures of pollution with organic matter – BOD rate is 490 mg/l where 1–2 mg/l of BOD indicates good water [10], which is not only unusable human water but also any aquatic life that cannot survive there. Then, the conditions of the pond water are also much miserable.

In megacities like Dhaka, Delhi, or others, because of the rapid population overgrowth, ponds are often filled up and turned into land for housing and industries, and the remaining are mostly unusable because of the dangerous water quality [11, 12]. Now, as the water quality checking and pollution monitoring process is less prior to work and the authority gets notified after an alarming situation, people already suffer from various health hazards and economic disruption. Also, in farming and fisheries, people are not always able to easily monitor water quality and make the right decisions [13]. In that condition, if water pollution and monitoring systems can be easily available to the public, it can give them an opportunity to get all the necessary information in hand, get aware of the situation, and act smartly. Nowadays, IoT is a popular word for everyone. IoT or the Internet of Things enables electronics devices to communicate among themselves and establish a low-cost embedded system for automation [14]. For water quality and monitoring systems, IoT can be both a cheaper and reliable method to provide real-time sensor data feed to cloud databases. As a result, we have proposed an IoT-based water pollution and monitoring system that can monitor and show real-time conditions and pollution information of different water like ponds, rivers, or drinking water.

The main objective of this study is to provide a universal water pollution monitoring system at a competitive cost, and the contribution of this paper is as follows:

- Low-cost IoT model for water pollution monitoring.
- Cloud base data storage and monitoring system.
- Discussion on the various sensors specification.

We have organized the paper in the following manner: Section 2 for literature review, Section 3 for proposed methodology, Section 4 for results and discussion analysis, and Sect. 5 for conclusion.

2 Literature Review

Due to a rising global crisis, different methods have been proposed for water quality and pollution monitoring. A narrow-band Internet of things-based water quality monitoring for aquaculture has been proposed by Huan et al., which collects different pond water parameters and helps maximize aquaculture production [15]. Pasika and Gandla have shown a system designed to monitor drinking water quality using IoT to ensure drinking water quality [16]. Besides that, a machine learning and IoT-based drinking water quality monitoring system has been shown by Koditala and Pandey [17]. Ramón Martínez et al. have proposed an IoT system for wastewater treatment plants to monitor the quality of water [18]. For detecting the contamination and flow of water, Saravanan et al. have proposed a system combined with supervisory control and data acquisition (SCADA) and IoT [19]. Earlier, Moparthi et al. have shown [20] a system to detect the pH level of water using IoT. Those papers have proposed either a discrete water quality measurement system based on a parameter or targeted to work on a specific type of water such as drinking water. Then, a paper proposed a water quality monitoring system based on IoT combined with radio-frequency identification (RFID), wireless sensor network (WSN), and Internet protocol [21].

Rony et al. have proposed a model for sewerage water monitoring systems using IoT sensors and cloud services [22]. Aqua fishing-related work such as prediction using different approaches has shown IoT-based approach for data collection [23, 24] and then processed those data using machine learning for prediction. Different water parameter checking studies have been conducted earlier; for example, Alam et al. tested water samples of the Surma river with respect to different water quality parameters [25]. Water toxicity analysis was done by Vijaya Kumar et al. where the industrial area's water quality was analyzed [26]. Tube-well is the primary drinking water source for a large number of people. A study was conducted in a Bangladeshi flood-prone area to analyze the tube-well water quality and contamination check [27].

A comparative study is shown in Table 1.

Table 1 Comparison study

Paper	Year	Water type	Method
[15]	2020	Aquaculture	NB-IoT
[16]	2020	Drinking water	IoT
[17]	2018	Drinking water	IoT & ML
[18]	2020	Wastewater	IoT
[19]	2018	Surface water	SCADA & IoT
[20]	2018	Drinking water	IoT
[21]	2017	Surface water	IoT
[22]	2021	Wastewater	IoT
[23]	2021	Aquaculture	IoT & ML
[24]	2021	Aquaculture	IoT & ML

In this study, we have proposed a model that is both budget friendly and has a wide range of usability from different perspectives. To ensure a smart city environment, water pollution monitoring is a vital issue, and this study proposed a user-friendly and cost-effective solution to address the problem.

3 Methodology

The system diagram of the proposed model is shown in Fig. 1. Required different water quality checking information is input through different sensors such as pH sensor, temperature sensor, and turbidity sensor. The whole process can be divided into three main parts: data collection, processing, and monitoring.

3.1 IoT Devices for Water Monitoring

There are some popular sensors for monitoring water quality like pH sensor, temperature sensor, turbidity sensor, MQ7 sensor, and HC-SR04 sensor.

pH Sensor Chinese robotics manufacturer "DFRobot" manufactured a pH measurement sensor that can measure at a range of 0–14 with ±0.1 accuracies at 25 °C temperature. The specification of the pH sensor is shown in Table 2.

The pH sensor kit may be used in water quality monitoring devices, water tanks, and fish aquariums. It can also be used with a GSM phone and a nodemcu esp8266 Wi-Fi module for remote notifications.

Temperature Sensor The model of the waterproof temperature sensor is DS18B20. It is manufactured by US company "Adafruit Industries." The specification of this sensor is shown in Table 3.

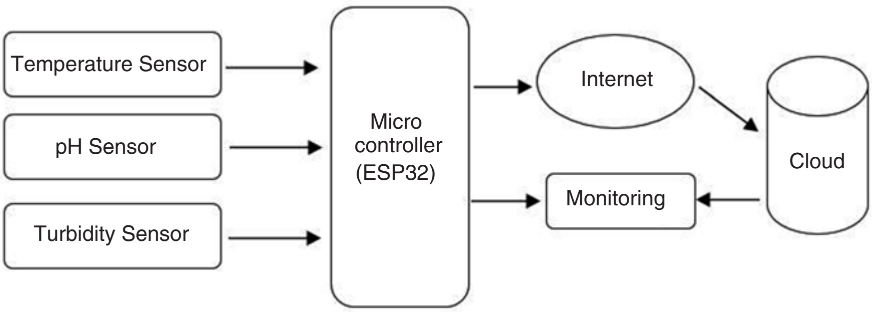

Fig. 1 Block diagram of the proposed system

Table 2 Specification of pH sensor

Type	Analog pH sensor/Meter Kit for Arduino
Manufacturer	DFRobot, China
Parts	Power indicator, a BNC connector, and a PH2.0 sensor interface
Accuracy range	±0.1
Supply voltage	5 V
Measuring range	0–14 pH
Measuring temperature	0–60 °C
Response time	≤5 s

Table 3 Specification of temperature sensor

Type	One-wire digital temperature sensor
Manufacturer	Adafruit industries
Power supply range	3.0 V to 5.5 V
Operating temperature range	−55 °C to +125 °C
Accuracy	±0.5 °C (between the range − 10 °C to 85 °C)
Pin	3 pins: GND DQ VDD

Turbidity Sensor Turbidity is a measurement of how many suspended particles are present in a stream. Aside from potable uses, water is employed in a wide range of industrial and domestic settings; for example, water is used to clean the windshield of a vehicle, it is used to cool the reactors of a power plant, and washing machines and dishwashers rely on it like fish.

The specification of the turbidity sensor is shown in Table 4.

There are some applications of turbidity sensor including washing machines, dishwashers, industrial site control, environmental sewage collection, water quality monitoring using IoT, and oil quality monitoring.

Ultrasound Sensor This sensor is used for measuring water levels. The most popular model of this sensor is HC-SR04. It uses SONAR to determine the distance of an object. It can measure from 2 cm to 400 cm or 1 to 13 feet. The specification of HC-SR04 is shown in Table 5.

In this study, we utilized three sensors for collecting real-time values. They are temperature value, pH value, and turbidity value.

All the device connects to an Arduino UNO microcontroller, and the microcontroller transfers data through WIFI communication using the Arduino WIFI shield. In Fig. 2, the complete hardware setup is shown.

Table 4 Specification of turbidity sensor

Manufacturer	DFRobot
Power supply range	5.V DC
Operating current	40 mA (max)
Response time	<500 ms
Insulation resistance	100 M (min)
Output method	Analog and digital
Analog output	0–4.5 V
Operating temperature	5 °C–90 °C
Storage temperature	−10 °C–90 °C
Weight	30 g
Adapter dimensions	38 mm × 28 mm × 10 mm/1.5 inches × 1.1 inches × 0.4 inches
Pin	3 pins: GND Signal VCC

Table 5 Specification of HC-SR04 sensor

Manufacturer	ETC2
Power supply range	5.V DC
Working current	15 mA
Quiescent current	<2 mA
Measuring angle	30 degrees
Resolution	0.3 cm
Ranging distance	2–400 cm/1–13 ft
Actual angle	<15°
Pin	4 pins: GND TRIG VCC ECHO

3.2 *Processing Unit*

Microcontroller: As the brain of the system, a low-power microcontroller Arduino UNO is used, and to provide communication, an Arduino WIFI shield is used. This device has sufficient analog and digital input/output pins, enough processing power, a compact size board, and many other features at a very competitive market price. The microcontroller is directly connected to all the sensors; it reads and processes all the sensor values after a period of time. The processed information is shown in the attached display. Besides that, network connectivity is established to store the data in a cloud database for remote monitoring and further usage.

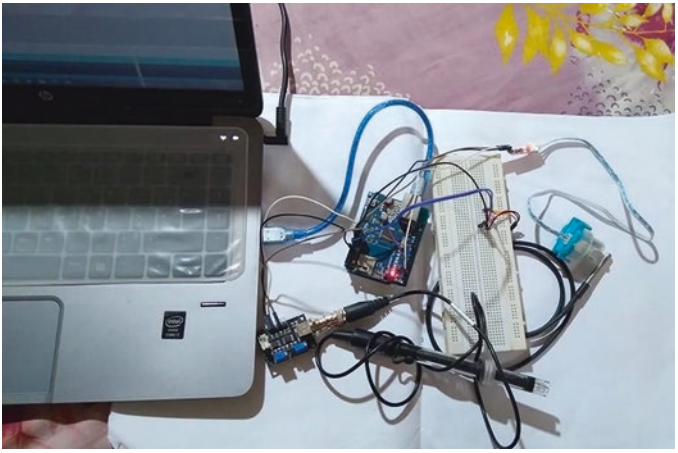

Fig. 2 Combined circuit with all the sensors

3.3 Monitoring Unit

Data can be monitored in a web app with digital devices. The web app shows the processed data in a graphical meter for a user-friendly view in both phone and laptop/desktop environments.

River Water Sample: The river water sample for this study is collected from "the Padma," one of the major rivers of both Bangladesh and India. This river flows almost 120 km, and the confluence with the Meghna river then meets the Bay of Bengal. This particular water sample collection location is in Rajshahi city, the northern part of Bangladesh.

Pond and Drinking Water Sample: Pond water, as well as drinking water samples, is collected from another part of Bangladesh, Jamalpur district, Melandah upazilla, Malancha village. In this particular place, villagers usually use tube-well water as their primary drinking water source, so we have collected the sample from 10 different tube-well as the drinking water sample in this study.

4 Results and Discussion

After processing, the final outcome is visible in a web app shown in Fig. 3, where different sensor and its corresponding output are shown, respectively. However, the standard value and the inputted value from the sensors are compared to get the analysis. The standard value used in this study is shown in Table 6.

From every source of the water, data was tested a large number of times. Table 7 shows the ten data samples from actual test results.

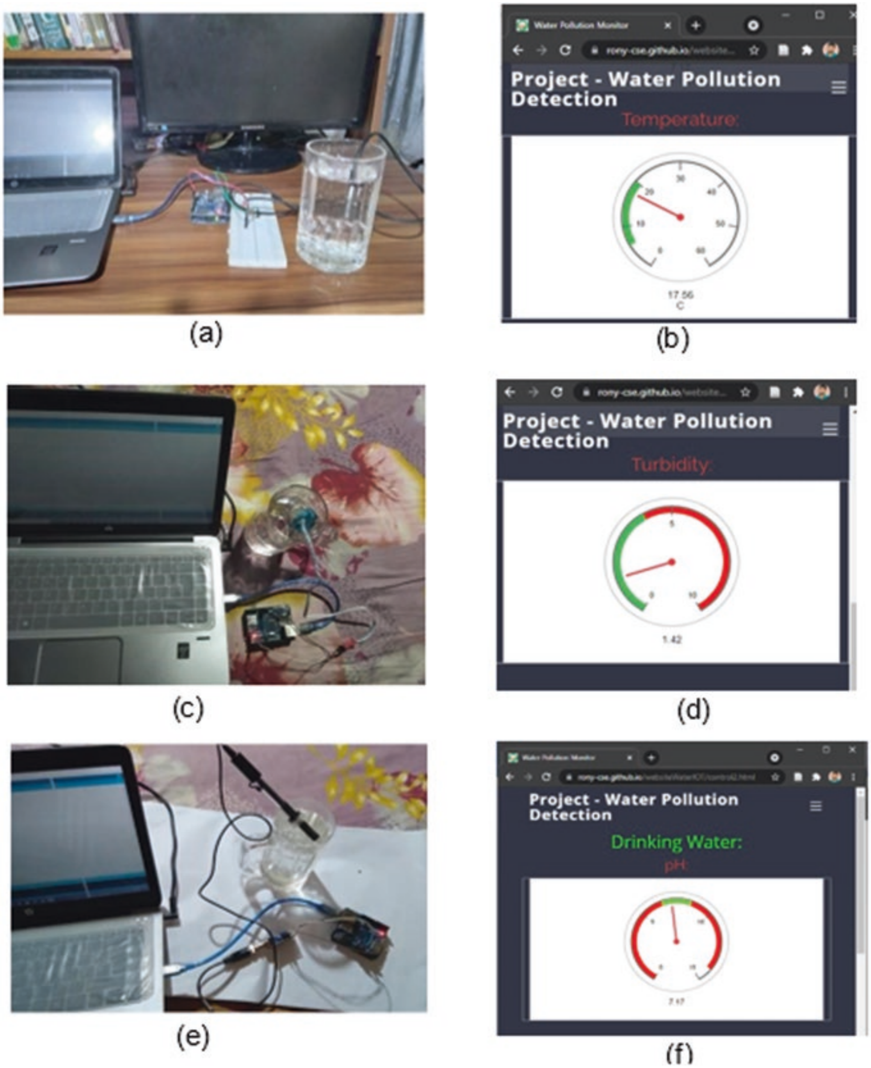

Fig. 3 (**a**) Temperature sensor testing. (**b**) Temperature sensor output monitoring in web app. (**c**) The turbidity sensor testing. (**d**) Turbidity meter monitoring in web app. (**e**) pH sensor testing. (**f**) pH sensor output monitoring in web app

Table 6 Standard of different water quality

	Drinking water [28, 29]	Pond water [30]	River water [31]
pH	6.5–8.5	6.5–8.5	5–9
Temperature	6–20 °C	20–23 °C	<32 °C
Turbidity	<4 NTU	<30 NTU	<10 NTU

Table 7 Sample data from actual test results

created_at	entry_id	field1 (Temperature)	field2 (pH)	field3 (Turbidity)
2021-07-14 13:38:05 UTC	1	17.62	6.02	1.26
2021-07-14 14:38:07 UTC	2	17.5	6.01	1.07
2021-07-14 15:46:32 UTC	3	17.56	6	1.92
2021-07-14 16:38:05 UTC	4	17.75	6.09	2.65
2021-07-14 17:46:37 UTC	5	17.56	6.93	2.75
2021-07-14 18:37:50 UTC	6	17.69	6.42	2.22
2021-07-14 19:46:02 UTC	7	17.69	6.48	1.15
2021-07-14 20:37:53 UTC	8	17.56	7	2.4
2021-07-14 21:39:58 UTC	9	17.5	7.27	1.54
2021-07-14 22:37:52 UTC	10	17.62	7.24	2.97

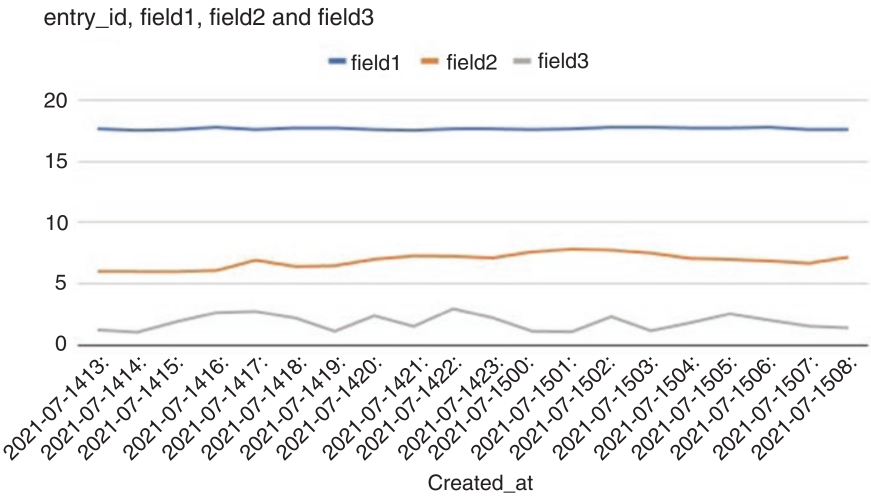

Fig. 4 Graphical view of table data sets

A chart from Table 7 is shown in Fig. 4 to present a graphical view of the data set. All the data are from one single source, so the changes are tiny changes in data points.

5 Conclusion

This study showed an IoT-based water quality and pollution monitoring model that collects different water quality parameters using sensors and store them in a cloud database. A graphical water quality meter of those parameters is shown by comparing the data that are stored in the cloud and data from the standard value. Multiple water samples from different places and sources were tested, and the system showed the expected result. Water samples from almost ten tube-wells, one pond, and rivers all around Bangladesh were tested during this study. Water is one of the most vital substance. Therefore, a water quality monitoring device like this one is highly needed to ensure water safety. However, there are a few limitations in this study that need to be addressed in the future; for example, in the thingspeak server, the data refresh rate is limited. As a result, data can be written once every 15 seconds. Besides that, for future work, long-range data communication and compact size module designing can be done.

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Participatory Citizen Sensing with a Focus on Urban Issues

Hana Kopackova

1 Introduction

The concept of participatory citizen sensing (PCS) emerged in 2006 with the first publications about citizens serving as sensors [1, 2]. A wide spread of PCS systems was further enabled by the mass exploitation of smartphones, which lowered time demand and brought new capabilities (e.g., built-in camera, GPS locator, and other devices). Despite the popularity of PCS systems, their deployment is even now rarely accompanied by a clear vision, investigation of success factors, potential pitfalls, and measurable outcomes. The aim of this chapter is to bring a comprehensive view of this contemporary phenomenon.

The first issue in this domain is the vague definition of the PCS concept. We can find many different terms with similar meanings, making orientation in this field complicated. This subchapter brings clarification and definition of the PCS concept (Table 1).

The first distinctive PCS feature from other concepts is the sensing activity, which means collecting data. This feature separates it from e-participation and citizen sourcing. Although both terms cover participatory activities of citizens, they may involve other activities than data collection. For example, citizens can be a source of action, ideas, material, opinion, etc. PCS tools are, therefore, a special case of e-participation and citizen sourcing.

The second distinctive PCS feature is the consciousness of the sensing. The word "participatory" in the PCS name expresses that people are aware of data gathering and that the data will be processed somehow. This feature excludes PCS from

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Table 1 PCS-related concepts

Related concepts	Explanation of the relationship	Sources
Live sensors, citizen sensing, Crowdsensing	People act as sensors gathering data, but the gathering can be unconscious.	[3–5]
Citizen sourcing, crowdsourcing	The purpose is to take some action in public interest. Sensors may not be part of the solution (co-creation).	[6, 7]
E-participation	Broad concept covering all forms of civic engagement, enhanced by the e-government 2.0.	[8, 9]
Citizen science, extreme citizen science	Citizens gather data for research purposes.	[10–13]
PPGIS, VGI, CGI, Geocollaboration	It covers all information systems designed for the public to gather spatial data. Geographic data are a necessary part.	[14, 15]

citizen sensing based on social networks, where people do not know that their data (Tweets, Facebook, Reddit, or other posts) will be mined. An example of such unconscious sensing was put forward by Ayora et al. [5], who described streaming API to distill tweets based on hashtags.

However, sometimes it is not easy to adhere to this categorization. For example, cities can make profiles or discussion groups on social networks to promote citizens' participation [16–18]. In this case, citizens intentionally publish their opinion, comments, or report problem issues on social networks with the awareness that their posts will be gathered and mined.

Data collectors (local governments, scientists) can even combine conscious and unconscious sensing to evaluate data's timeliness, importance, and relevance. The example can be found in Anantharam et al. [4]. They extracted traffic events from Twitter and 511.org (incidents reporting) events over San Francisco. This experiment showed that posts on social networks, especially Twitter, can be used as a complement to PCS.

The division line between conscious and unconscious citizen sensing can be even more blurred. For example, reporting tools, which are used knowingly, also gather data that users may not be aware of (frequency of use, issues watched, type of device, etc.).

A third distinctive feature of PCS is the possibility to use spatial data. Concepts of PPGIS (Public Participation Geographic Information System), VGI (Volunteered Geographic Information), CGI (Contributed Geographic Information), and Geocollaboration expect the gathering of geographic data. Although data gathered by PCS mostly have a spatial component, it is not necessary. The data can refer to the whole city or defined territory.

Summative Definition of PCS *Participatory citizen sensing (PCS) is defined as an open call, meaning that the task is offered to the public. The task is specified as sharing data, either personal or other types of data related to the territory. Participatory sensing explicitly means intentional sharing of data in contrast with opportunistic sensing, when data are collected in an automated manner without user involvement. Sensing equipment provides the government, third party, or citizens to use their own.*

The rest of the chapter is divided into two parts. The next section focuses on current trends in PCS tools through the lens of applicable domains, motivation of citizens, and demands for technical solutions. The third section introduces a case study evaluating the quality of citizen reporting tools used in the urban environment to report non-emergencies. The presented case study covers 13 Czech regional capitals.

2 Fundamental Issues of PCS Concept

This section is based on the review held in April 2021. Articles were gathered from the Web of Science using keywords (participatory citizen sensing, citizen sensing, citizen science, citizens as sensors, citizen engagement sensors).

Compilation of sources after duplicate removal brought 756 papers. Abstract reading lowered the number to 206, which was further reduced to 104 papers available for download and thematically correct. The review should answer three questions:

1. In which areas are PCS used?
2. How are citizens recruited and motivated?
3. What issues must be solved on the technical level?

2.1 PCS Domains

The review showed that most PCS projects focus on nature and ecology (air pollution, noise, water and soil quality, biodiversity, etc.). The second most frequent topic considers urban issues (traffic, condition of roads and sidewalks, litter, street lighting, illegal activity, etc.). Finally, extreme events (floods, hurricanes, earthquakes, epidemy, etc.) are another PCS domain, which is popular.

Description of PCS domains leads us to different outcomes that initiators expect. The first expected outcome is the generation of knowledge. This outcome is especially true for citizen science. The second expected outcome is problem solution, which is highly visible in urban space. Finally, the third outcome is less specific and covers the exchange of information and fun.

2.1.1 Nature and Ecology

Nature and ecology cover the biggest category in the review, which consists of 43 papers. The most common project in this category is air quality measurement. Measurement methods differ according to the equipment that citizens use. Most studies used dedicated stationary sensors placed in the garden, porch, sheds, inside, etc. [19–24]. For example, Brienza et al. focused on gathering of different air pollutant data (i.e., Ozone (O_3), carbon monoxide (CO), and nitrogen dioxide (NO_2)) in cooperative manner [20]. Through uSense, a user can monitor the air quality near her/his house, just by placing a small sensor node in her/his property, for instance in a garden, a balcony, a window sill, or hung to an outside wall. Basically, the node periodically measures—through proper sensors—the concentrations of some airborne pollutants. Then, the obtained data are sent to the uSense database via the Internet, and are made accessible to all the other uSense users. This way, in a cooperative fashion, each user contributes to monitor part of the city. Similar results brought dedicated mobile devices placed on bikes, cars, busses, or the participant's body [25–28]. Hybrid approaches combine data from mobile and stationary sensors [25, 29, 30]. A completely different way of data collection is represented by smartphone applications, which mainly support collecting qualitative data in the form of reporting – smoke sensing, smells [31, 32]. However, smartphones can also be equipped with gas sensors [33].

The second most frequent topic is noise measurement using also stationary devices, mobile devices, and smartphone applications. The difference is in the frequency of use of smartphone applications, which is much higher [33–41]. This situation is understandable as the microphone is the necessary equipment of smartphones, whereas gas sensors represent additional costs, as they need to be professionally installed and calibrated. However, examples of dedicated sensors were also found [41–43].

The monitoring of the quality and quantity of water, whether fresh or marine, is another topic in this field. A technically simple solution for freshwater monitoring is from Africa. Citizens send SMS messages via standard mobile phones to report the lack or poor quality of water at a public water point: "no" for no water and "dirty" for dirty water [44]. Another example from Africa focuses on monitoring of wells and river flow [45]. Five monitoring wells are manually dipped every two days with a dip meter and the rain gauge is measured daily at 9 am by reading the level of the internal graduated cylinder. The river gauges are monitored daily at 6 am and 6 pm by reading the river stage from the permanently installed gauge boards. Hard copy records of measurements are provided by community monitors on a monthly basis to the Dangila woreda office, where they are transferred to an Excel spreadsheet and forwarded to the research team. Citizens acted as sensors also in the experiment of dams mapping. In this case, participants used reporting applications on their smartphones to report dams, locks, or other obstructions on rivers [46]. Algal blooms on lakes were monitored with reporting application CyanoTRACKER [47]. Marine Debris Tracker mobile app was used to monitor litter and debris in the ocean [48].

Wildfires and forest preservation are other topics of PCS research. Forest Fuels Measurement Application was designed for the public to visually classify fuel conditions (the amount of wood debris on the ground surface, height and the closure of conifer crown, and understory vegetation coverage), aided by reference images and illustrations [49]. The Forest Fire reporting (FFR) mobile application aims to tackle forest fire incidents at the preliminary stage [50]. The forest department tested the solution, but it is possible to use it also by the public. Different approaches to forest preserving offer the Relasphone Measurement Application that implements the digital relascope, augmented with metadata and computed forest variables to get forest inventory data, including basal area, tree species, tree height, and age [51].

Biodiversity is an essential topic for the preservation of the world and life as we know it. Various studies have addressed the monitoring of endangered species, and PCS can be a powerful tool in this research as the amount of gathered data can be significantly expanded. For example, the BAYSICS project from Germany monitors plants, animals, trees, and allergens [12]. Collaborative investigation of species through soundscapes was used in Dema et al. [52] as acoustic sensing is a noninvasive approach to monitor species and the environment. Observation and reporting were used in the following example that focused on amphibians and reptiles [53]. Participants monitored road-kills of amphibians and reptiles along 97.5 km of tertiary roads covering agricultural, municipal, and interurban roads as well as cycling paths in eastern Austria.

2.1.2 Urban Issues

Solving urban issues is the second most common PCS domain, in which citizens can help improve the quality of life in urban and even rural areas. The specificity of this domain is that citizens gather data considering the man-made environment. The most frequent approach in this field is the use of smartphone applications that use GPS coordinates and cameras to capture problematic issues complemented with textual description. Types of issues that are solved mainly by these apps are non-emergencies (damaged benches, mess, broken pavement, uncut grass, landfills, potholes, broken lights, or abandoned vehicles). Examples of these applications are CityCare [54], SeeClickFix [55], Be Responsible [56], CityWatch [57], City Probe [58], Amsterdam reporting app [59], and CitizenConnect [60].

Transportation in cities is often a problem as many people commute to work; that is why some PCS tools are focused on this area. For example, the MITOS platform combines dedicated stationary sensors with citizen sensing in the form of free text or predefined messages (e.g., “heavy traffic,” “too much noise,” etc.) and/or images [61]. A different approach was brought by Barnwall et al. [62], who used data from Waze (reporting app for traffic events) to predict the accuracy of users’ reports.

Issues of the road surface such as potholes and bumps, which are closely connected to traffic flow, affect driver safety, fuel consumption, and road maintenance costs. Although urban reporting applications mostly cover reporting of potholes in textual form, some cities use more sophisticated ways of data gathering. For example, the combination of microelectromechanical systems (MEMS) accelerometers in smartphones and GPS allows for road surface condition assessment [63, 64].

Another problem in cities is queuing, whether those are queues of people or cars. Wang et al. [67] presented CrowdQTE, a mobile crowdsensing system for real-time queue time information for different scenarios. In places where people wait in a line, accelerometer sensor data is collected to automatically detect the queueing behavior and calculate the queue time. In places where people do not wait in a line, the participants manually report the queuing status. Technologies for smart buildings are also representants of PCS. They can be used to measure the humidity level at homes [65] or manage energy consumption [66]. A particular type of PCS project, which is more rural than urban, was introduced in Poland. The project aims to preserve the cultural landscape and natural environment together with the activation of their residents. A dedicated application LC-CApp (Land Consolidation-Crowdsourcing Application) was created in the GIS environment. This app offers a possibility to supplement data used in land consolidation works by adding the perception level based on lived experience, preferences, associations, and memories of the local community members related to their local area [68].

2.1.3 Extreme Events

The use of PCS in extreme events can be preventive, emergency, or both. The information about past events helps researchers and local governments prepare contingency plans and preventive measures. Data gathered by citizens (video, photography, description) are beneficial in this process. These data can be used, for example, to calculate the water depth. Singh [69] and Sy et al. [70] describe the projects where citizens were asked to indicate the water depth affecting their houses during historical flood events by localizing this information.

Sensing applications can use more than form, camera, and GPS. For example, smartphones' accelerometers can also be used to measure the strengths of shakes. Faulkner et al. [71] described CSR (Community Sense and Response system), which exploits accelerometers in smartphones combined with dedicated devices to monitor earthquakes.

Early warning flooding systems FloodCitySense in Birmingham, Brussels, and Rotterdam were described in Veeckman and Temmerman [72]. Although this project brought some success, at the same time, it draws attention to the problems that can occur when using these technologies. The following reference shows what problems a similar project may encounter. In the case of Birmingham and Rotterdam the activities stopped after the experimentation phase. This was mostly due to technical performance issues of the low-cost sensors, the low perceived data quality of the crowdsourced flood reports, lack of integration with existing systems and the high perceived efforts involved in data control and validation of the crowdsourced information. The original way of disaster data collection is described in Di Felice and Iessi [73]. They used reporting application TwitterEarth with the predefined form (GeoReport). This application is participatory because people know that their posts will be collected, even if they use Twitter as a collecting medium. A unique hashtag is generated for reports from a given territory in order to retrieve the data quickly. Each GeoReport can concern only one warning, written by selecting either the field Damaged Asset or Damaged Infrastructure.

One more example of PCS in extreme events is from the recent past and present. PCS can be used to trace contacts during pandemics. The example is Singapore [74], but most countries applied any type of tracing PCS either at the national or local level. Contact tracing means that citizens diagnosed with the virus fill the form; a user's data are collected from their phone, centralized, and redistributed to others. The app uses Bluetooth for communicating between devices over short distances. When two phones remain in proximity, TraceTogether uses Bluetooth to exchange temporary ID numbers between the apps on the two phones. Citizens using this app are informed about infected people nearby, so in the case they feel some symptoms, they can be treated earlier.

2.2 Citizen Involvement: Recruitment and Motivation

The implementation of PCS systems needs acceptance on the level of initiators (researchers, local government) and the level of citizens. The willingness of the initiators to accept citizens as qualified partners is the first assumption for the successful start of the implementation. Nevertheless, they can just offer the PCS tools to citizens, which is only the supply side. Real success happens when citizens adopt these tools, get used to them, and are satisfied with their results.

Many papers in the review addressed citizens' motivation and recruitment, mentioning either monetary, non-monetary, or both incentives, e.g., [75, 76]. As monetary incentives, we can take real money and virtual money, credit, or some other reward that is perceived as valuable by citizens. Different approaches to setting the price can be found in the literature. Static incentive means that the price for a task is estimated in advance and stays the same for all participants. On the other hand, dynamic incentive means that the price changes based on the minimum amount of money a participant is willing to accept for a sensing task. Another distinguishing feature is the entity that determines the price. According to this division, we can see a user-centric model and a platform-centric model.

1. User-centric model: Citizens offer the price for which they are willing to undertake the task. Lee and Hoh [77] introduced a reversed-auction-based incentive mechanism called "RADP." Participants in this scheme sent their incentive expectations to the platform, and those with the lowest expectations are chosen as auction winners to carry on the sensing task. Krontiris and Albers [78] adapted the RADP model with more dimensions, especially with the quality of data participants can offer. They argued that it is unfair for participants when the platform only considered their bidding prices but entirely ignored the data quality. Other types of auction models were also introduced for assigning sensing tasks – threshold-based auction [79] or reputation-based incentive mechanism [80].
2. Platform-centric model: Initiator of the sensing task sets the price to maximize the profit. For example, Khazankin et al. [81] offered participants a defined

amount of reward if they can finish the task in a given time. Participants could "book" a task if they assumed rewards and allotted sensing time attractive to them. A different approach, described in Luo and Tham [82], can give the platform more decisive power. In contrast to the Price-Decision-First model described so far, participants' data were uploaded without knowing the price, thus giving the platform more privilege to allocate payment (Data-Upload-First model). The platform encouraged participants to provide more sensing data for the rewards given to participants with more contributions. Reddy et al. [83] experimented with five different settings of payments. The experiment was held on campus for 5 days. Participants were asked to take photos of outdoor waste bins' contents and optionally add a label to the photo. MACRO payment promised individuals 50 dollars for involvement in the study, MEDIUMμ, HIGHμ, and LOWμ involved 20, 50, and 5 cents per valid submission respectively, COMPETEμ payment was based on ranking among peers determined by the number of samples taken (which was reset daily) and ranged from 1 to 22 cents per valid submission. COMPETEμ members had access to all participant ranking/submission numbers in real-time on the phones. The total pay out for the micro-payments was capped at 50 dollars per participant. As a result, the MACRO payment group collected the lowest number of photos (1291), the highest percentage of them was invalid (7%), but they added the highest percentage of labels (70%). Compared to that, COMPETE payment group collect the highest number of photos (5256), the average percentage was invalid (6%), and they added the lowest percentage of labels (6%). Other price models were among these extreme variants.

Monetary incentives represent only one form of incentive mechanism. Citizens' motivation is often activated by nonmonetary incentives as social interaction, access to other users' data, the possibility to learn new things, gain prestige, enjoyment, or just pure altruism. This statement is especially true for citizen science as proved by Koss [84] – motivation incentives were "want to protect the coastal environment," "sense of achievement," "meet new people," "being part of the group," and "feeling good about myself."

Another example from coastal citizen science was reported by He et al. [85], who verified that environmental citizen science could deepen the connection between people, place, and ecosystem. Their research showed that both altruism and self-interest are powerful motivators in initial and continued participation. Moreover, volunteers who remain engaged adopt the mission of the program as their own.

Ganzevoort and van den Born [86] studied which experiences in nature are incredibly memorable and impactful for participants to motivate them in future research. They proved that surprise in discovering the biodiversity and learning were the two most prominent participants' experiences. In contrast, only a few respondents expressly referred to their contribution to science and conservation through submitting collected records.

A popular approach to recruiting more participants for PCS tasks is the use of gamification. For example, Sirbu et al. [87] describe the AirProbe web game, a map management game, where participants (Air Guardians) annotate the map with AirPins – geo-localized flags tagged with an estimated or perceived pollution level. In addition, Martí et al. [88] described the NoiseBattle prototype to move around a city, taking noise samples. The city is split into cells of a grid, so the user can conquer the cells by taking more and better measurements than other users in the area. The sounds that can be sent to the rivals are used to show the power obtained by the sender of the noise. The rivals have the option of re-conquering previously conquered cells by performing better quality measurements or more recent measurements. Comparison of gamified and non-gamified PCS approach presented Palacin-Silva et al. [89] for capturing lake ice coverage data in the sub-arctic region. They found out a much higher number in gamified approach, participants under this approach were much active, and the dropout in this group was significantly lower. Although they found that gamification affected the participants' engagement positively, the user experience was the same. This statement is in line with Nacke and Deterding [90]. They concluded that adding simple visual manifestation of gamification elements or deterministic mechanics to the interface is not enough without considering other aspects of engagement. Similarly, Aoki et al. [91] brought a critical view on citizen science. They emphasized the complexity of the sensing task and the fact that participants' interests need to be sufficiently aligned with the desired science outcomes to get expected results.

Different perspectives for citizen involvement were proposed by Willet et al. [92], who focused their attention on the problem, how to make sensing tasks easier for novice participants. Their solution was to break analysis tasks into discrete mini-applications designed to facilitate novice contributions. This strategy helped novice users to identify relevant phenomena and generate local knowledge contributions.

2.3 Procedural Issues and Technical Solutions

PCS systems differ according to domains, various providers, and technical solutions. However, we can find elements, which occur in all PCS systems. A use case diagram capturing the most common functional elements is depicted in Fig. 1. There are four actors (users, participants, data collector, and administrator). This division means roles but not necessarily different people. Data collectors can also gather data, which means they are in the role of participants. as Also, the role of administrator and data collector can be combined in one person (organization).

The essential functionality of any PCS system is the **gathering of data**, which can be regular (data are gathered at defined time intervals for a given period) or irregular (data are gathered when necessary). This difference affects the requirements of technical equipment and battery life. Requirements on battery life are

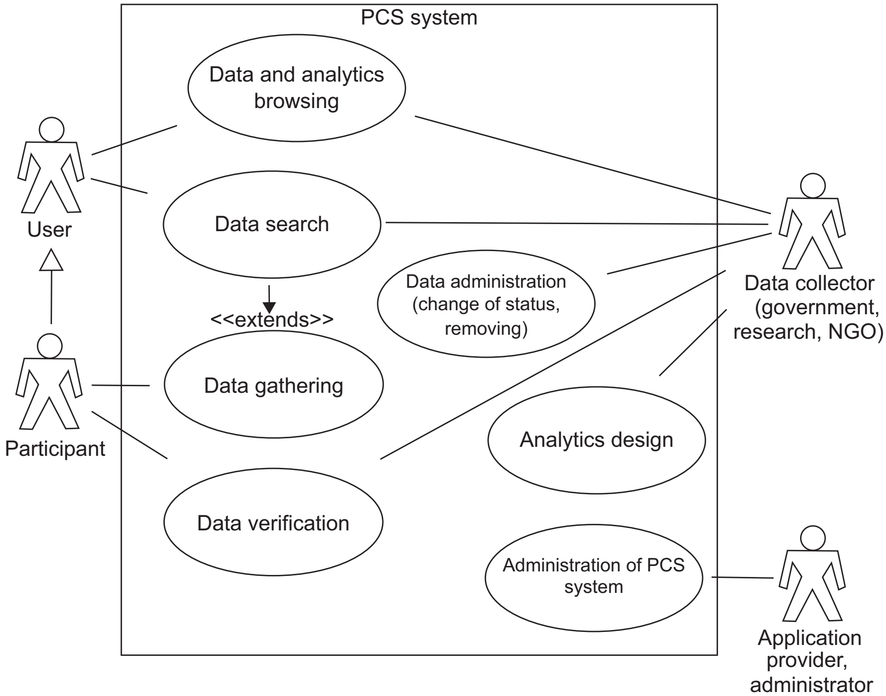

Fig. 1 Functional elements of PCS systems (use case diagram)

significantly higher for regular data gathering. Technical equipment for citizen science projects needs to be more sophisticated (e.g., sensors for CO_2, NO_2, PM2.5, humidity, etc.). On the other hand, technical equipment requirements for reporting systems are pretty low. They need mostly smartphone cameras, microphones, and GPS location in combination with the form-based application.

The data gathering process also differs in demands on how active the participants must be. In regular data gathering, participants mostly give their consent to data collection and check that everything works (battery life, connection). Irregular data collection is usually more dependent on participants' activity (take a photo, fill the form, or check if there is already some data about the same issue, upload data, etc.). There are two most frequent problems related to data gathering: privacy and data quality. While participants are primarily interested in the possibility of maintaining privacy, the data collector requires a high quality of the collected data. These two requirements are closely connected but in contradiction; therefore, the scientists try to find a way to transmit each observation with sufficient anonymity. At the same time, the data collector de-anonymizes the data with acceptable accuracy.

Perez and Zeadally [93] summarized contemporary approaches to privacy protection in crowdsensing applications and divided them into two classes: hiding the identity and hiding contextual facts. Based on this review, they proposed the Privacy-Enabled ARchitecture (PEAR), a layered architecture that consists of four abstraction layers (communication, anonymization, security and privacy, and processing).

1. Hiding the identity: Metadata, such as network addresses/identifiers (e.g., IP addresses, MAC addresses, and cookies) needed by network protocols to send and receive data, can be used to reveal the identity of participants. Protection mechanisms can use, for example, double encryption via brokers [94], peer-to-peer (P2P) anonymization networks [95], utilization of disposable network identifiers such as pseudonyms [96], the use of anonymization networks [97], group-based signatures [98], or data aggregation [99].
2. Hiding of contextual facts: Associate aspects considered private by participants include inferring contexts such as places, activities, behaviors, and/or health state based on the collected data. Protection mechanisms include, for example, k-anonymity, l-diversity, t-closeness, or their combination [100–103]. Different approach represents the attribute-centric scheme introduced by Abrar et al. [104]. Another privacy approach for measuring air pollution was proposed by Markert et al. [105]. They proposed to combine Private Proximity Testing and an anonymizing MIX network with cross-sensor calibration based on sensor rendezvous.

A new approach to privacy protection, which gives decisive power to participants, was introduced by Pournaras et al. [106]. They proposed a self-regulatory information-sharing model with the supply–demand system supported by computational markets. Citizens make incentivized but self-determined choices about the level of information they are sharing. That results in an equilibrium between privacy preservation and accurate analytics.

Data search is primarily independent functionality for users (participants or not) and data collectors. Nevertheless, it can be part of the data gathering function unless it is desired to duplicate the data.

Sufficient data quality is a necessary requirement on data gathered by PCS in order to use this data for aggregation, display, analysis, and decision-making. However, as most campaigns do not pay participants for the data, their motivation to improve data quality is not high, especially if it takes additional effort (time, walking, equipment, etc.). Some participants may send wrong data nonintentionally (malfunction of a sensor, wrong position, mistakes made by insufficient knowledge of software and hardware, etc.). In contrast, others can sabotage the sensing process by sending false, corrupted, or fabricated data. Therefore, data **verification** mechanisms must be employed either at the side of the participant, data collector, or both.

One group of verification mechanisms is implemented as a trusted platform module (TPM), which is a hardware chip responsible for authorized access to sensors and data upload that resides on the participant's device [107, 108]. However, although TPM secures participant authentication and data integrity by encryption, it cannot ensure that appropriate data collection procedures are followed. Moreover, the price of TPMs, which are currently not manufactured for the mainstream market, is relatively high.

Another way to enhance data quality at the participant level is to provide thorough training, prepare introductory materials, and incorporate help and additional reminder mechanisms into sensing software (e.g., the question “Are you sure your microphone points to the sound source of the sensor device?”).

Reputation is another concept helping to provide accurate data. Reputation-based trust assessment methods are applied to the participants, who can influence their level by their contributions. Trust systems can be designed as centralized, collaborative, or hybrid [108]. Centralized trust systems use trust servers that receive all contributions and feedbacks, calculate and maintain the score, and distribute it to all participants. Collaborative trust systems treat all nodes as a source and sink simultaneously, thus using their computation power and storage capacity to calculate and maintain the reputation score. The hybrid approach combines both types.

The last type of data verification is focused on the side of data collectors. In reputation systems, collectors can assign a higher weight to data collected by more reputable participants. However, in equal contributions, collectors need some other mechanisms to verify the data and select only accurate ones. One possible way is to let more participants gather the same data and then compare the data quality. In reporting systems, this way can be very successful as more people can point out the same problem, thus assuring data collectors about the problem’s urgency. Finally, the most demanding but sometimes necessary way of data verification is a manual data check.

Data collectors are also responsible for **data administration and maintenance**. All the invalid data must be removed, and the status of the data must be updated according to changes. This activity can be demonstrated on urban reporting PCS systems. When citizens report some issue, then the status of the report is submitted. After verification, the status is changed either on rejected, in process, or transmitted. When the process of repair is done, then the status changes to finished. By publishing the report’s status, the local government can inform its citizens about its actions. In return, citizens strengthen their confidence in the local government if they see their needs are met.

The last important feature of PCS systems is the possibility to prepare an **analysis** of gathered data. Either this option is valid only for data collectors who then distribute the results or the system is prepared for simple analytics even on the user’s side (selecting data defined by date, location, topic, status, etc.).

3 Citizen Reporting of Issues on Public Infrastructure (CRIsPI)

This chapter introduces a case study evaluating urban reporting systems used at the municipal level in the Czech Republic. Cities often try to introduce smart initiatives that link together citizen participation and the efforts to improve the quality of life in the city. Citizen Reporting of Issues on Public Infrastructure (CRIsPI) is such an initiative focused on reporting of non-emergency incidents.

A study held in 2018 proved that 22.8% of municipalities with 1000 inhabitants and more use one or more types of urban PCS [109]. All municipalities above 50,000 inhabitants provide at least one PCS tool, whereas small cities use mostly none. Particular interest in this study was given to regional capitals, which evaluated the accessibility of citizen reporting systems in 13 Czech regional capitals.

The evaluation process covered finding city web pages and searching for information on how to report a non-emergency incident. If the search was done within 1 min, the searchability was evaluated as high; if the time necessary was higher but still under 5 min, then the searchability was medium. Longer time means low searchability. Possible non-emergencies covered: damaged benches, mess, broken pavement, uncut grass, landfills, potholes, broken lights, or abandoned vehicles. The coverage of topics was divided into three categories: HIGH (>5 topics), MEDIUM (3–5 topics), and LOW (<3 topics). Another criterion was the presence of visual geolocation (YES/NO) and the form of display of sent reports (MAP/LIST/NO).

As the data from 2018 can be obsolete now, the study was replicated with the same procedure in May 2021 to see what changed for 3 years (see Table 2). It must be considered that the global situation with COVID-19 does not favor investment in technologies that do not solve acute problems. So little if any progress in the adoption of this type of technology is expected.

Table 2 Evaluation of CRIsPI tools used at regional capitals

	Category 2021	Coverage of topics	Visual geolocation	Display of sent reports	Search-ability	Category 2020
Plzeň (Pilsen)	A	HIGH	YES	MAP	HIGH	A
Brno	A	HIGH	YES	MAP	HIGH	B
Olomouc	A	HIGH	YES	MAP	HIGH	C
Liberec	A	HIGH	YES	MAP	HIGH	A
Pardubice	A	HIGH	YES	MAP	HIGH	B
České Budějovice	A	HIGH	YES	MAP	HIGH	A
Ostrava	B	HIGH	YES	LIST	HIGH	B
Praha (Prague)	B	HIGH	YES	NO	HIGH	B
Jihlava	B	HIGH	YES	NO	HIGH	B
Karlovy Vary	C	HIGH	NO	LIST	HIGH	C
Zlín	C	HIGH	NO	NO	HIGH	C
Hradec Králové	C	LOW	NO	NO	HIGH	C
Ústí Nad Labem	C	–	–	–	–	C

3.1 Category A: Reporting Systems with Full Functionality

This section cover six cities (Plzeň, Brno, Olomouc, Liberec, Pardubice, and České Budějovice) with reporting systems that offer all necessary functions in high quality:

1. Coverage of topics is high (at least six out of eight types of issues are covered).
2. Reporting systems use GPS or visual geolocation (location of the issue can be selected by clicking on the map).
3. Display of sent reports on a map.
4. Searchability of reporting system is high (easy to find by Google search or there is a link at municipal pages).

Three regional capitals (Plzeň, Brno, and Olomouc) use their own mobile application and desktop webGIS solution to show the location of incidents and their status or report a new one. While Plzeň scored the highest in 2018, so they did not change anything, Brno and Olomouc did not get such a high score. In the last evaluation, Brno had lower coverage of issues (roads, streetlights, and suburban forests), which improved. Now it is possible to report all emergencies, display them on the map, and use the search function through location, type, or status. Olomouc in 2018 used only electronic form without the possibility of geolocation of reported issues and did not display sent reports. All cities now use dedicated custom-made solutions, which they administer themselves.

One city in this group uses a third-party solution (Marushka® map application server) that is not dedicated to citizen reporting. Instead, it is a map server based on GeoStore® component technology with the possibility of cartographic presentation of data. The city of Liberec use this solution for the evidence of municipal property, and one of its functionality is the display of incidents in the map and the possibility to report new one. The description of the issue is displayed after clicking on the object in the map. However, it is impossible to filter issues according to issue type, as it is possible in Plzeň, Brno, and Olomouc. The solution supplier is Geovap, but the administration of the geoportal is up to the city of Liberec. The solution did not change between 2018 and 2021.

Two cities use DejTip, a mobile application operated by a third party, related to a broader area than the city, and specialized in reporting. Pardubice, České Budějovice, and some Prague districts use this mobile application, allowing users to take a picture, select one of the categories, and add a comment. The server then locates a tip to the appropriate municipality based on the position of the GPS phone, completes the report of the nearest address, and passes it to the appropriate municipality. The municipality participating in the program receives an email twice per day, or it can have an admin interface for sorting messages. DejTip web pages show the map with the content of reports and their status. The solution is the same as in 2018.

3.2 Category B: Reporting Systems Violating One Condition to Full Functionality

Three cities (Ostrava, Prague, and Jihlava) do not display reported issues in a map, but they comply with all other functional requirements. For example, the city of Ostrava displays reports in the form of a list, whereas Prague and Jihlava do not display reports at all. Ostrava, Prague, and Jihlava cities have the same reporting system as in 2018.

3.3 Category C: Reporting Systems with More Functionality Issues

In this category fall four cities (Karlovy Vary, Zlín, Hradec Králové, and Ústí nad Labem) violating more than one functional requirement. The best in this category is the city Karlovy Vary. The problems are that it does not offer geolocation for reporting new issues and displays reported issues only in the form of a list. The city of Zlín uses the electronic form without geolocation and does not display reported issues. City Hradec Králové uses a similar electronic form with the same problems. In addition, this city has a reporting system only for problems with streetlights. The worst score has city Ústí nad Labem, which does not offer its citizens any tool to report non-emergency issues.

4 Conclusion

Participatory citizen sensing is a young and dynamic discipline bringing new possibilities as well as challenges that need to be solved. Internet of things for smart environments is mostly studied from the point of view of technical challenges and developments. This chapter also dealt with technical issues, but it applied a more holistic view of this phenomena. This approach is rather rare, which confirmed the literature review presented in this chapter. No publication in this review brought a comprehensive study of PCS tools and combined different views on this topic.

This chapter showed the main direction of development, the domains in which PCS is used and the possibilities of motivating citizens. All presented information is up to date in 2021, but we can expect rapid development in future. The direction of future research will depend on the overall global situation. If the COVID-19 pandemic continues, then we can expect a development toward better tracing and overall healthcare PCSs. If the situation improves, the trend toward citizen science should continue.

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Design Strategy of Multimodal Perception System for Smart Environment

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1 Introduction

With the rapid development of artificial intelligence (AI), Internet of Things (IoT), big data, 5G, and other technologies, the information society we live in is gradually evolving into a smart society, and our living space is also starting to transform towards the direction of intelligent empowerment. Since the global outbreak of the COVID-19 pandemic in 2020, people have been forced to endure self-isolation at home for extensive periods and thus, have become increasingly aware of the need to improve the quality of life, as well as the intelligence level of their living spaces.

As an important branch of the applications of intelligent technologies, Smart Environments can not only create sustainable building spaces by enhancing energy efficiency but also facilitate the inhabitants' daily lives by positively impacting their emotional states [1–3], acting as a healthy environment conducive to their well-being. In our previous studies, we investigated the essential elements that create a building space in a smart environment. Drawing on the characteristics of smart products proposed by Wolfgang Maass [4], we have constructed a framework outlining three basic capabilities of a smart environment [5] as follows: first,

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context-awareness, that is, the ability of the smart environment to perceive and understand the surroundings and the states of the users; second, behavioural adaptation, that is, the ability to optimise the building space according to the users' needs and the external environment; and third, social connection, that is, the ability to promote the exchange of information and interconnection between smart environments and smart devices. Among these three capabilities, context-awareness is the basis for developing smart environments because it determines the intelligence level of the environment and the potential for upgrading.

2 Related Works

Building context-aware smart objects has been extensively studied in academia. Installing sensors on smart objects is the most frequently used method to enhance their information-acquisition ability [6–8]. The choice of sensors varies depending on the function of the smart object [9, 10]. For example, Georgios Galatas suggests the use of multiple RFID tags and Kinect cameras in the living space to facilitate the understanding of users' behaviours by the environment itself [11]; Pratool Bharti et al. added gyroscopes and Bluetooth sensors detecting acceleration, temperature, humidity, and air pressure to smart bands, so they can analyse the users' positions and behaviours in space [12]; Houssem Eddine Degha et al. managed to empower the built environments with context-awareness by monitoring the energy usage in different rooms with sensors [13].

Many scholars have also attempted to improve the context-awareness corresponding to a particular function segment of the space by investigating the characteristics of space users [14, 15]. António Teixeira et al., for instance, set up multiple means of perception, such as voice and gesture recognition to better serve the elderly's needs [16]. D. Kavitha et al. propose an IoT and situational awareness technology-based approach for monitoring health and wellness information for patient populations [17]. Quanfeng Luo targets the students in educational spaces, proposing the use of several information acquisition methods, including keyboard, mouse, pen, and voice, to better understand the specific types of students' behaviours [18]. Li-Shing Huang et al. also focus on how to build a context-aware intelligent system architecture for classrooms with a smart classroom prototype, a technology integration model, and supporting measures for smart classroom operation [19]. M. Swarnamugi analyses the most suitable service model for the system in the IoT environment and how to provide more efficient services through context-aware technologies for the intelligent transportation space [20].

Moreover, some scholars have proposed theoretical frameworks to enhance the context-awareness of smart environments in a complex system of scenarios [21–23]. Nuno Almeida argues that the perceptual system of an architectural space should consider the information collected by various devices in addition to sensors situated in the space [24]. Banos et al. suggest a method of deriving high-level context-awareness from a sensory dataset comprising recognitions of low-level contexts (i.e. simple activities, emotions, and locations) as it allows the perceptual system to identify and analyse an individual's emotional state at a given time in space [25]. Gallardo et al. propose to model the time, location, and behaviour during human–computer interaction to infer users' future behaviour and possible preferences [26]. Lin Zhao et al. argue that a smart home with situational awareness can be built by constructing a sensing system with five levels: temperature sense, gas sense, infrared sense, light sense, and security sense [27].

Although existing studies have proposed methods for enhancing the context-awareness of smart environments, there is still limited research about systematic classification of different types of context-awareness and systematic strategies for establishing such awareness in a given space from a design perspective.

3 The Context-Awareness System in Architecture Space

Considering that context-awareness aims to enable the built environments to achieve an ability equivalent to that of humans to perceive and process information of the surrounding environment, the construction of such awareness for smart environments may be approached with reference to the formation principle of similar awareness in humans. From the perspective of cognitive psychology, the perception of our surroundings depends on a set of processes in the perceptual system by which we recognise, organise, and make sense of the sensations we receive from environmental stimuli [28]. Developing context-awareness is a three-stage process: starting with the lower-level sensory data, the information, which may be in a disorganised state, is mapped from the external object to the subject through the sensory organ; next, on the cognitive level, the raw information from the previous stage is relayed to the brain, then, filtered, analysed, and processed to form new, organised information; finally, compared with past cognitive experiences, the perception becomes recognisable, comprehensible signals or images to the subject, thereby, influencing the individual subject's possible actions or behaviours.

Concurrently, constructing context-awareness in smart environments also requires a similar two-level process: the first level, that is, the sensory level, is built by adding sensing elements (i.e. electronic sensors), which act as sensory organs and form perceptual channels to the building space, thus, accomplishing the process of mapping information from external stimuli to the interior environment. The second level, that is, the cognitive level, is achieved by adding a central processor, which functions as the brain of the smart environment to further filter, analyse, and process the raw information collected through the sensory organs. It, thus, transcribes the received contextual information into meaningful signals comprehensible to the smart environment to further build the possibility for the behaviour of the building.

Therefore, this chapter will discuss the methods of constructing the context-awareness system in an architectural space from sensory and cognitive perspectives. First, it will explore how a smart environment can develop sensory organs and perceptual channels on a sensory level. Then, it will examine the possible factors that influence the effectiveness and efficiency of the brain of the environment to process the information collected by the perceptual system and their solutions, thereby establishing a framework and corresponding design strategies for the perceptual system of the smart environment.

4 Perceptual Systems in Smart Environments

The establishment of smart environments is the process of equipping the building space with sensory organs, that is, receptors of sensory information. Various sensory organs are the basis for capturing information; for example, vision requires the eyes to collect lights emitted by the surroundings, while hearing requires the presence of the ears to receive sound waves. By analysing and synthesising the sensory information captured by each sensory receptor, the brain generates a comprehensive cognition and builds a holistic image of the external space. Likewise, the perceptual system of architectural space also involves different sensory organs, which are, in this case, various embedded sensors, to gather information from surroundings and form an understanding of the external environment with the aid of the brain of the environment. According to the five basic sensory systems of humans, the perceptual system of smart environments can also be divided into five categories: visual, auditory, haptic (partially mimicking the somatosensory system that includes proprioception and haptic perception), olfactory, and gustatory. Nonetheless, as the olfactory and gustatory senses both reflect the sensation of odours and flavours, the study tentatively integrates the olfactory and gustatory systems into the odour system when building the sensors.

4.1 The Visual System

Vision is the perception of objects in the environment through the light they emit or reflect [29]. The visual system includes the eyes, the connecting pathways through to the visual cortex, and other parts of the brain. The eyes are used to detect the variables of contour, texture, spectral composition, and transformation in light. In humans, vision is based on the information extracted from visible electromagnetic waves in the external environment by the eyes and the processing of visual information by the brain. In this sense, visual processing may be richer in other organisms capable of capturing ultraviolet and infrared radiation. In architecture, the visual system can capture various types of electromagnetic wave information in the surroundings via different optical sensors, such as light intensity sensors, gesture sensors, cameras, and so on, and analyse the information recorded by the sensors to finally form valid visual perception using implanted algorithms.

The visual system produces the most amount of information, which is most easily captured from people's daily lives. The visual system of the built environment can be divided into three parts according to the complexity of the visual information and the difficulty of the brain's cognitive functioning: the perception of static, three-dimensional information regarding the environment (e.g. intuitive image information such as lighting, colour, depth), the perception of the dynamic information relative to the temporal dimension of the environment (e.g. movement and deformation), and the perception of symbolic information about the environment (e.g. identifying the categories of objects in the environment, human emotions, and other information related to previous experiences) [30].

Perception of Static Information

The acquisition of physical information about static objects or surroundings in the third dimension is the basis of the visual system. Although the dimensionality of this type of information is relatively homogeneous, the analysis of even the simplest kind of optical stimuli may help the architecture form a perception of the built environment—we can still sense the light intensity with our eyes closed and form a perception of our surroundings, although this information is entirely transmitted by the optic nerve. For a given architecture, a single light sensor would suffice to detect the light intensity of the environment and thus help determine whether the building space is being used, whether the real-time lighting environment meets the users' needs, whether adverse effects such as glare are produced, and so on. When groups of light sensors are installed, the building has a visual ability comparable to an insect with compound eyes. Just as a cell phone screen forms image information through pixel arrangement, the aggregated information from groups of light sensors can help the building acquire visual information similar to greyscale images, which can help the building to determine the shape, boundary, distance, and even type of objects in the environment.

In fact, human vision is based on the uptake of visible light, but the latter is only a small part of the natural spectrum. In addition to the vision created by visible light, the visual system of buildings also processes infrared or ultraviolet light, which is not visible to the human eye. In the design of the architectural space installation Ca-Fi Robot, infrared sensors were used as the visual channel of the installation (Fig. 1).

The installation is equipped with three main types of vision sensors: infrared pyroelectric sensors, infrared distance sensors, and infrared obstacle avoidance modules. The visual system of the installation is created by integrating the information captured by the three types of sensors, each with its distinctive responsibilities. Infrared pyroelectric sensors collect the infrared light of a fixed range of wavelengths in the environment, which is an indirect measure of temperature based on the principle that people emit infrared rays due to their body temperature. They are widely used in environmental detection, where people are present. Infrared range sensors emit a fixed wavelength of infrared light into space and calculate the time it

Fig. 1 The Ca-Fi Robot installation

takes for the infrared light to bounce back to the sensor to analyse its proximity to various objects in space. The infrared obstacle avoidance module works similarly to the infrared distance sensor in that it also emits a fixed wavelength of infrared light into the environment to detect the presence or absence of objects in the environment. The difference is that the infrared obstacle avoidance module intelligently detects the presence of objects within a very small range but cannot determine the distance of the object; the infrared distance sensors can determine the distance, although they are slightly slower, but cannot identify whether the object is a person; the infrared pyroelectric sensors can determine whether someone is present but not the location of or the relative distance to the person. Therefore, the three must cooperate to determine whether there is someone in the space, the distance of the person from the installation, and the location of the person through the multi-angle arrangement of the infrared obstacle avoidance module.

Perception of Dynamic Information

The perception of dynamic changes in the temporal dimension of the environment is a way of perceiving movements based on changes in the position or shape of objects at different points in time in the environment. Perceiving movement in the ambient time dimension allows the built environment to pay more attention to the objects in motion in space and be prepared to respond to these objects. The perception of movement in the ambient time dimension requires the visual system to function over a continuous period. For example, the state of the environment can be visually captured between fixed intervals of time by installing cameras in the building, and these images at different points in time can be compared to locate the changes for analysing which direction the objects in the space are moving towards and what motion they are performing. For example, an installation named Keywin (Fig. 2), which takes on the prototype form of a window, employs an eye-tracking

Fig. 2 The Keywin installation

sensor as the visual channel that continuously records the relative position of the user's pupils to determine the direction of their gaze and compares the pupils' positions at different points in time to map the trend of eye movement. The installation receives information about the direction of the user's gaze through the eye-tracking sensor and responds to this information at a specific position on the window. When a person gazes at a point on the window, the ice cracks in this area of the window are rotated and reconfigured into a combination of rectangles, thus, allowing the user to see without being blocked by the window ribs and feel as if the window ribs are the view frame of the landscape outside. In this sense, the Keywin window acts not only as a tool responsible for transmitting the landscape but also as a part of the interpretation of the landscape.

Perception of Symbolic Information

Symbolic information refers to the form of abstract information that requires people's experience to be extracted into a concrete expression of meaning based on visual information. In the case of visual-based symbolic information, which may be a person's age, level of appearance, emotional state, and so on, to process such information, it is necessary to first discover the patterns in a given characteristic by studying a sufficiently large sample of images. Using human age detection as an example, the computer first analyses images of faces marked with different ages and finds the general patterns in the pictures based on the arrangement of features such as colour values and greyscale values for each pixel in the image; it, then, learns a method to determine the age of a portrait picture and deduces the age of the person in an unseen picture by applying this method. Nowadays, thanks to the popularisation of image recognition services, the work of extracting and perceiving symbolic information about the environment can be directly subcontracted to the cloud server, and the API can be recalled to help designers implement the corresponding functions quickly, easily, and concisely. The interactive installation *Flipped Space* chooses to use the camera as a sensor to capture real-time image information of the site and uploads this information to the cloud (Fig. 3). Using the cloud image recognition server, it processes symbolic information and generates a perception with help from facial recognition and emotion recognition technologies, thus, providing its users with a personalised spatial experience. For example, when a person appears

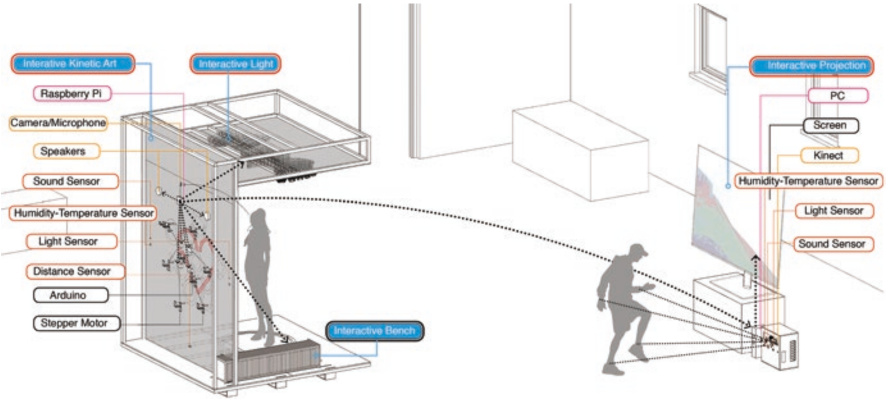

Fig. 3 Sensory and interactive system for Flipped Space

in the space, the installation uses facial recognition to determine whether the person has appeared in the space before; if so, it retrieves the user's basic information from the database, such as name and preferences. Then, based on this existing information, the user is provided with personalised chat content to help them feel connected. Simultaneously, the user is provided with an ambient light colour design that influences their mood positively according to their mood changes and the theory of colour psychology. In addition, the installation can also analyse whether the user has made meaningful gestures through the cloud server. When the user expresses affection for a heart gesture, the installation will respond by displaying a heart-shaped pattern on the wall.

4.2 The Auditory System

Hearing is a response to vibrating air molecules [29]. It is formed when the cochlea stimulates the auditory cells after receiving vibrations from the air. Depending on the frequency, intensity, and medium of the vibrations, the sound waves will have different characteristics, leading to different tones and even languages. The establishment of an auditory system in smart environments can be divided into two types: the perception of the physical realities of sound and the interpretation of linguistic encoding [30].

Perception of the Physical Realities of Sound

Owing to variations in frequency and intensity, sound itself encompasses a lot of information, such as pitch, loudness, and rhythm. This information can be further extracted and used as an element to activate interactive behaviours. In the design of

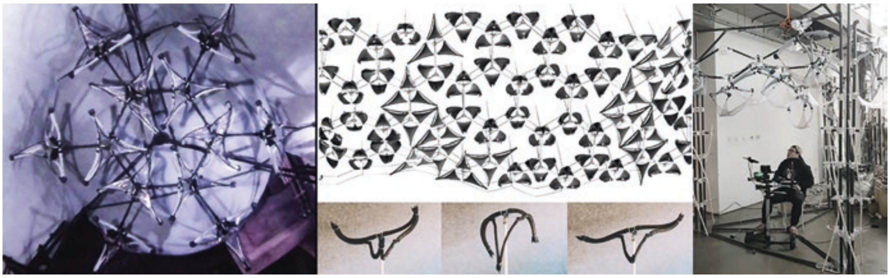

Fig. 4 The Klyntar955 installation

the interactive installation Klyntar955, sound is used as the main design element to facilitate the initiation and continuation of interactive behaviours (Fig. 4). The goal of the design is to create an ambience for the singer to perform. This installation can automatically analyse the mood of the songs played by the singer so that the built space can automatically resonate with the rhythm and melody of the song, thus facilitating the singer's performance. The audio sensor module acts as an auditory channel for installation. The installation collects music information through small microphones placed on both the left and right sides, as well as analyses the music at seven different frequencies with a frequency divider. The rhythmic state, beat, and pitch of the music are inferred through analysing the arrangement and combination of the sound intensity at each audio stage. The installation, then, matches these rhythms with movements of the air muscle components in the installation; for example, with heavy bass, the air muscle appears to bend significantly, and with high pitch, the air muscle vibrates in small increments. Thus, the installation space exhibits a sense of rhythm that reacts to music.

Interpretation of Linguistic Information

Human language encodes abstract information that must be interpreted through acquisition. Languages enable people to communicate information directly and efficiently. They are formed based on the fact that each word is pronounced with different vocal-cord vibrations, resulting in different sound sequences, which can, then, be interpreted by humans in the form of linguistic information [31–33]. Therefore, by running the recurrent neural network (RNN), Long Short-Term Memory (LSTM), Gated Recurrent Unit (GRU), and other algorithms [34, 35], the built environment is programmed to identify the words represented by each sound wave to interpret the encoded linguistic information. The application of natural language processing technology in intelligent buildings and the interpretation of linguistic information can help the built space accurately understand the users' needs and intentions, as well as proactively offer them personalised solutions and services.

The interactive installation *Flipped Space* is also designed to have embedded language recognition systems. The installation is equipped with a microphone acting as a perceptual channel for linguistic information, and the information encoded in the user's speech is interpreted by a cloud server, which analyses the captured sound data when there is a sudden increase in loudness. The linguistic encoding is relayed to the language database of both the local central processor and the cloud in order to find the best matching response, and the feedback is conveyed to the user through speakers and other components of the installation to meet their demands. For example, when the installation picks up the anger or annoyance of the person in the space, it adjusts the lighting to blue to calm the user down, and when it detects emotions of joy and happiness, it adjusts the lighting to pink to prolong the positive emotions. When the installation perceives the space to be in a lively, dynamic state, it adjusts the lighting to a colour pattern changing at a certain frequency to mirror the personal sentiments into a shared space (Fig. 5).

4.3 The Haptic System

When cells in the skin or muscle tissue of a living creature are squeezed and deformed, a tactile sensation results from the deformation. Given that the sense of touching is found in every cell and is the largest sensory channel of the human body—the skin—it is the most direct perception of contact with external objects [36]. As touching is the most extensive and reliable form of perception, people's judgements about external objects or environments tend to be based on haptic perceptions [37]. Many visual perceptions, such as the perception of roughness and the perception of shape and size, are based on the sense of touch [38, 39]. The building space can establish its direct haptic system by physically sensing the pressure, capacitance, resistance, and so on, as well as its indirect haptic system that detects intangible factors such as temperature, humidity, air pressure, and electromagnetism [30].

Fig. 5 Flipped Space adjusts the lighting to a colour pattern changing at a certain frequency to mirror the personal sentiments into a shared space

Direct Haptic System

A direct haptic system refers to the process of direct physical contact between a person and the environment. The building space determines the meaning expressed by the touch by calculating the magnitude of multiple forces by analysing the physical deformation of the sensing elements. Broadly speaking, traditional buildings contain many haptic receptors, such as light switches and the use of remote controls. For smart environments, such haptic systems can also be pressure sensors placed on the surface of the building space, and the number of people in the space and the characteristics of their behaviour can be analysed by modelling the pressure value felt on the surface.

One may consider the interactive installation *Leaf–Wrap–Weave* as an example (Fig. 6). The concept of the installation is to provide a shaded area with privacy for users in urban spaces to relax. The installation creates a haptic system by placing pressure sensors on the seat. When someone sits on the installation, the sensors detect an instantaneous rise in pressure and activate the bending of the top branch of the installation to create a semi-enclosed private space. The installation may also adjust the amplitude of the bending of the branch and leaf elements according to the pressure exerted, changing the scale of the semi-enclosed space to adapt to different user characteristics.

Indirect Haptic System

Indirect haptic systems monitor intangible information about the user and environment in the architectural space. In people's daily lives, we observe the phenomenon that we can perceive the existing physical properties of an object despite the lack of direct contact with the skin. We can sense the heat and humidity of the flames and fountains, even without touching them. Most of this indirect contact depends on air, which is the so-called medium of information transmission. The type and physical attributes of an object can be identified by sensing airflow conditions. Smart environments rely on indirect haptic systems for activating interactive behaviours, such as the perception of the strength of the wind, the temperature level, and the strength of the magnetic field.

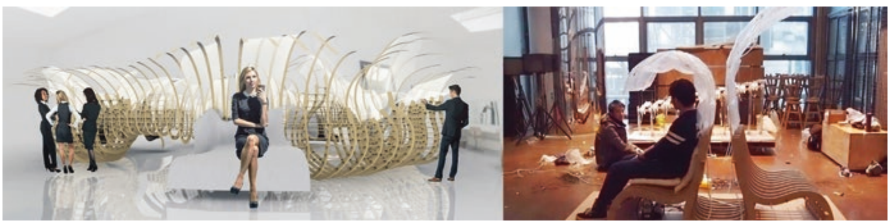

Fig. 6 The Leaf–Wrap–Weave installation

Fig. 7 The Interactive Pavilion

In the design process of the *Interactive Pavilion*, the building operates on an indirect haptic system consisting of temperature, humidity, and wind sensors (Fig. 7). The cabin can control its form and turn on different sensing devices according to the changes in the external environment perceived by the indirect haptic system. When the outdoor temperature is between 16 and 29 °C, the three walls of the cabin will open at different angles to enable natural ventilation and view of the outdoor scenery; when the outdoor temperature is below 16 °C, the walls will automatically close and activate the coiled floor heating system for heating; when the outdoor temperature is above 29 °C, the walls will close and activate the air conditioning system for cooling; when it is windy or rainy, the building will also remain closed to prevent weather erosion. The cabin is designed with an indirect haptic perceptual system to ensure that it meets the functional needs of the inhabitants and achieves dynamic energy conservation.

4.4 The Odour System

Both smell and taste are produced from the reaction of proteins in the human body with one or more chemical elements in the external environment, which stimulates the nerve centres of the brain and constitutes a specific impression of this element. Different combinations of chemical reactions within human body fluids allow people to determine the flavour of an object or substance [40, 41]. For humans, the perception of smell and taste is accomplished through different perceptual channels, as smell is based on nasal cells and taste on oral cells. However, for architecture, both smell and taste can be seen as products of chemical interactions and can be unified into an odour system for smart environments.

The establishment of an odour perceptual system in a smart environment can help the built space quickly identify invisible safety hazards in the environment, such as gas leakage and food spoilage. It can also infer the behaviour of inhabitants and the contextual state of the space based on the distribution of odours in the smart environment. In addition, the smart environment can actively record the odour distribution status in the space, form an odour log, and reproduce and modify the odour in space to create an atmosphere for a particular scene in the future. In the design of the olfactory sensing device *OBean M1*, a set of 20 different odour sensor arrays—each having a strong electrical signal response to different odour molecules—are used to construct special chemical patterns for different substances (Fig. 8). Through the acquisition of the 20 different electrical signals, the temperature, and humidity information of the test environment, the *OBean M1* can detect and notify odours such as food, toiletries, garbage, and gas in the environment. The electronic nose can upload the collected odour composition data to the server, and by comparing it with the odour big data from the cloud server, it can precisely determine the specific category of this odour. For example, it can analyse the specific variety of apples, as well as locate and categorise the users who also have such odour, and form the user classification dataset of the odour dimension, which is convenient for building odour sharing and odour searching functions in future living.

The establishment of an odour system for smart environments can also be extended to the perception of people: the human body secretes a substance called pheromone, which is composed of chemical molecules similar to proteins. Similar to the way a dog can form a perception of a person through the sense of smell, a built space can also form a perception and understanding of its users through analysing pheromones. Analysing the composition ratio of different types of pheromones, it is possible to form a cognition of the physiological condition and emotional state of the human body, thus, helping the smart environment to form an intelligent building space with a healing colour that is oriented towards improving the user's physiological condition.

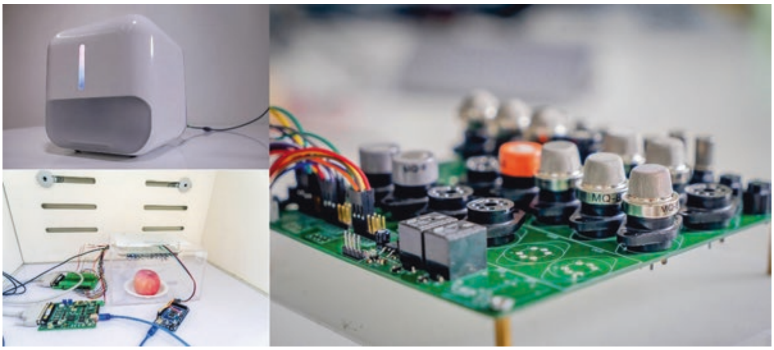

Fig. 8 A set of 20 different odour sensor arrays used to construct special chemical patterns for different substances

5 Smart Environment Cognitive System Construction

In the process of constructing the context-awareness capability of the smart environment, the information collected from various sensory channels needs to be analysed and processed to turn into valuable and meaningful signals and complete the cognition and understanding of human behaviour in the smart environment. In this process, the context-awareness capability of the smart environment needs to focus on the following two aspects of the cognitive system construction. First, the cognitive system needs to reduce the information noise of each perception channel to enhance the information's effectiveness. In this process, in addition to the quality of the hardware of the sensors themselves, the location of the sensors of each perception channel in the building space is also an important factor affecting the information's effectiveness, which is also more closely related to the architectural design. Second, the cognitive system needs to deeply explore the potential mapping relationships between different dimensions of information to enhance the accuracy of behavioural decisions. In this process, in addition to selecting the appropriate machine learning algorithm for each sensory channel information, it is also important to integrate and process the multimodal information of different perception channels to increase the robustness of the system. Therefore, the following section will focus on the design strategies for optimising the distribution of various perception systems in the environment and for the information processing of cognitive systems.

5.1 Design Strategies for Optimizing the Distribution of Various Perception Systems

When optimising the distribution position of each sensory organ in the smart environment, the mechanisms of information formation and noise generation of each organ need to be considered. In this process, we can borrow the distribution of human organs to generate a strategy for optimising the distribution of perceptual systems in a smart environment. To better represent the relationship between human sensory organs and human perception of the environment, the brain science field has developed the 'Sensory Homunculus', an abstract image of a human being formed to express the proportional relationship between human senses and the areas of the cerebral cortex in charge of the senses [42]. The 'Sensory Homunculus' shows that vision and hearing are located in the brain at a point scale, while touch, smell, and taste are located at a zoned scale, corresponding to the physiological structure of our body organs.

Vision, which is based on light, receives information from a small sensory point, but, as it is located near the highest position of the head, it can acquire a wide range of information, even from the farthest distance in all kinds of human perceptual systems. However, vision is isolated and directional, and we cannot see objects behind one thing or other directions while gazing in one direction. Therefore, the distribution of the visual system for intelligent space requires a multi-point layout, depending on the type of information collected about the target. The visual sensors for environmental data should be placed as high as possible so that the global environment can be seen, and the visual sensors for face-to-face interaction with the user should be placed at a position even with the human line of sight to ensure that the user's micro-expressions and postures can be clearly observed. Simultaneously, when arranging the visual sensors, it is important to place them in a place free of glare and reflection to prevent parallax caused by light to increase the accuracy of visual information.

Unlike the linear propagation characteristic of light, the propagation of sound information is multi-directional. Regardless of where the sound is emitted, it spreads in all directions and dives into the ear. To receive sound in a wider and more efficient way, our ears are located on both sides of our head, close to parallel to our mouths so that we can achieve a maximum sound reception field and prevent sound from being absorbed by too many obstacles in the transmission process. Simultaneously, people can also distinguish the location of the sound through the difference in the intensity of the sound received by the two ears, allowing a more sensitive sense of hearing. The smart environment auditory system distribution needs to make the sensor as close as possible to the location of the target sound source; for example, language collection sensors should be placed on the desktop or wall closer to the location of the human mouth. In addition, the sensors need to consider multi-directional multi-point placement, which can, in turn, eliminate environmental noise by analysing the situation of the sound received by different sensors and determining the location of the sound source by comparing the intensity of the sound received by different sound receivers.

As the closest and most intimate sense of perception, it requires direct contact between our haptic organ (i.e. skin) and a substance to create a perceptual stimulus based on temperature and pressure. Haptic sensation requires direct contact with a substance; thus, the area of the haptic organ needs to be large because of its limited accessibility. Our skin, as the largest organ in our body, guarantees that the entire body is covered by the tactile organs. Through this large-area and low-dimensional information recognition, we can establish a more authentic sense of scale and distance. The haptic system of a smart environment is also the most extensive area coverage of information in access to space. All physical interfaces in space can be designed as haptic sensors. This haptic sensor is not presented as a 'point', but as a 'surface', helping the space to know the size, position, strength, hardness, and other multidimensional information of the relevant things in the environment.

The senses of olfaction and gustation occupy the second-largest compartment in the brain after the sense of touch. Unlike vision, hearing, and touch, which rely on physical reactions (either displacement, reflexes, or vibrations) to establish perception, the odour system is based on molecular-chemical reactions to create perception. Physical reactions only change the state of the substance, while chemical reactions change the content of the substance and create new substances. The senses of olfaction and gustation usually require a pure environment, and their sensitivity depends on the difference between the stimulus and the environmental factors; for example, if people are exposed to an odour for a long time, their sensitivity to the odour will decrease. Therefore, in the smart environment, the arrangement of odour sensors should be placed in a location with fewer surrounding odour interference sources; simultaneously, the interfering chemical substances should be decomposed in time to prevent the problem of induction failure of sensors.

In general, the design of a perceptual system in a smart environment needs to optimise the location of perceptual sensors according to the characteristics of various perceptions to ensure that the sensors can have a broad and effective range of perception. Second, the arrangement of sensors should minimise the interference of signals; for example, visual sensors should be arranged in a position with no obstruction; auditory sensors should be arranged in a position where noise has less influence; haptic sensors should be arranged on the exposed plane; odour sensors should be arranged in a position where odour changes are obvious, and so on. Furthermore, the arrangement of the sensing system should meet the ergonomics requirements; for example, the microphone for talking with people should be arranged at the height of the head and neck as much as possible, and haptic sensors for interacting with people should be arranged at the height of their limbs as much as possible.

To address these distribution strategy principles, we conducted an experimental project called Future Habitat to optimise the distribution of sensors in different perceptual channels. We selected a two-bedroom apartment and placed four different types of perceptual systems in the space (Fig. 9). For the visual system, multiple RGB cameras, depth cameras, and infrared cameras were placed on the ceiling of the foyer, living room, study, kitchen, and other common areas for collecting information to fully understand the properties, shape, location, and movement trajectory of various items in the room. Cameras were also placed at eye level at the make-up table and the TV stand to capture human expressions. For the auditory system, we arranged array microphones on the desktop and walls of each room from multiple angles so that the volume and audio changes of each microphone could be analysed to precisely locate the sounding objects and analyse the language information. For the haptic system, capacitive pressure-sensitive flooring was installed throughout the room to collect information about the user's position, gait, and movement trail in the room, while pressure sensors were placed on the sofa to detect the pressure distribution of the user's sitting position proximally to analyse their physiological and emotional state. For odour systems, electronic nose sensors were placed in the living room, bedroom, kitchen, and bathroom, where the air circulation is fast, to detect odours in the space, such as rotten food, abnormal breath, and so on, for determining the air quality status and the health condition of the occupants in the space.

Among the collected information, the purpose of information cognition shows a high degree of overlap. For example, the perception of human emotions can be simultaneously evaluated using visual, auditory, and haptic information. The accuracy of the information analysis generated by different perceptual channels will differ and even contradict each other. At this time, the brain of the smart environment is needed to intelligently analyse and recognise multimodal information.

Fig. 9 Placement of four different types of perceptual systems in a two-bedroom apartment

5.2 Design Strategies for Information Processing of Cognitive Systems

In addition to optimising the spatial layout of the perceptual system with different modalities, the complex data collected by the sensors need to be learned and analysed for transforming it into meaningful cognitive information about the spatial situation. This process requires deep data mining and learning by constructing appropriate algorithmic models to achieve accurate analysis and cognition of specific behaviours or emotional states in a scenario.

Design Strategies for Unimodal Information Processing

First, for each modality of cognitive data, a suitable algorithmic model needs to be selected to analyse and process the data to improve the accuracy of the information of each perceptual channel. For different perceptual channels and different cognitive goals, the algorithmic models selected by the system will be vastly different. For example, the convolutional neural network (CNN) model is superior for visual information interpretation, whereas the RNN model is more accurate for linguistic information interpretation. Even the data size for the same type of feature can affect the choice of the data analysis algorithm model. For example, in our experiments on electronic nose odour data analysis, we tried both k-nearest neighbour (KNN) and artificial neural network (ANN) algorithms to analyse and identify different odours. It is found that when the amount of training data is limited, the KNN algorithm with simple principles and few parameters is preferred, and when the amount of training data is large, the ANN, which is suitable for learning complex data representations, is preferred [43].

Simultaneously, the choice of algorithmic models and the selection of features vary for different scenarios. For example, a user's emotional state in a smart environment is an important factor affecting spatial usage. The most common and accurate emotion recognition method is camera-based facial expression recognition. However, in a large building space environment, people are usually in the movement mode, and the camera is often unable to see the user's facial expressions clearly, which objectively reduces the accuracy of the user's emotion recognition. Therefore, in this scenario, the analysis of a user's gesture changes to form the cognition of their emotion will significantly improve the effectiveness of spatial emotion cognition. Our previous research has shown that a gesture-emotion computation method based on the bidirectional recurrent gated unit fusion neural network (BGRU-FUS-NN) can effectively determine eight different emotional states by observing human gestures [44]. By using virtual reality (VR) devices to allow users to experiment with some scenario tasks, the study redefined 19 human motion key points by collecting users' non-performance action data and converting that data into 3D coordinates of the corresponding skeletal points. Based on the existing basic features, advanced dynamic features are added to construct an 80-dimensional feature list that can describe the limb motion more accurately. Based on the fusion neural network model, we propose a BGRU-FUS-NN model by using gated recurrent units (GRUs) instead of long short-term memory neural networks (LSTM), adding layer-normalisation and layer-dropout, as well as reducing the number of stacked layers. By classifying emotions based on the valence and arousal emotion models, the cognition and determination of the eight categorised emotional states of excitement, happiness, pleasure, sedation, fatigue, sadness, anxiety, and nervousness are effectively formed.

Design Strategies for Multimodal Data Processing

In most cases, the context-awareness of smart environments is not based on single-modal behaviour perception but requires a comprehensive perception of multimodal behaviour patterns in a complex scene system. In this process, accurately comprehending users' intentions is a challenge in improving the perception capability of smart environments. When constructing an intelligent cognitive system for the entire smart environment, it is necessary to face a series of problems, such as significant differences in sensor data structures, large data sizes, and conflicting data features. In response to this, this study proposes a system of algorithmic model frameworks for a multimodal perception system (Fig. 10).

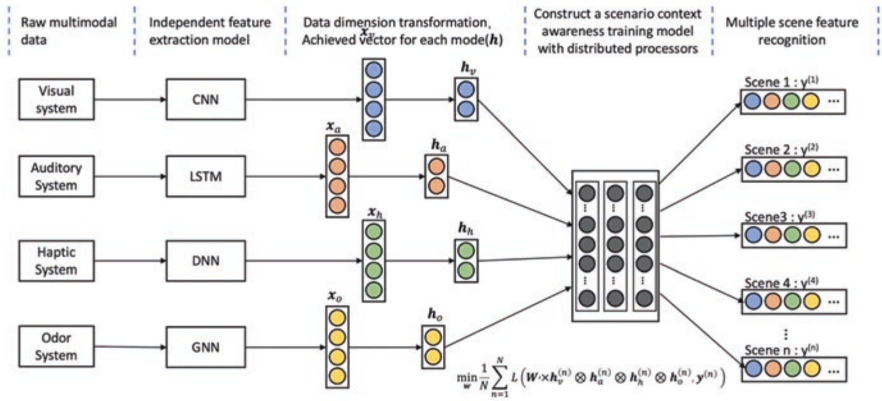

Fig. 10 Model frameworks for a multimodal perception system

First, there is the problem that the data structure of different sensors varies greatly. The types and dimensions of the data returned by different sensors vary dramatically, and the information calculation methods of each sensor also differ, which lead to the inability of the computer to analyse and process the data returned by each sensor according to a unified standard. Therefore, first, the CPU system in the environment needs to convert these multi-source heterogeneous data into a unified data form to facilitate the analysis and processing of further characteristics of multimodal data.

Second, owing to a large number of sensors inside the smart environment, the amount of data generated is huge, which leads to the formation of massive data sets in a short period. These data, if stored in the processors in a flat pattern, will inevitably result in slow data analysis and data recall speed. Therefore, the analysis of the data, in this case, needs to be processed in a distributed manner to improve the speed of data feature analysis and processing. For example, spatial data processing system can adopt 'Not Only SQL' (NoSQL) database construction method that supports multi-source heterogeneous massive data, Hadoop-based distributed storage system, and multi-source heterogeneous massive data storage and computing scheme based on HBase/Hive and MapReduce. By combining different databases, we can enhance the data processing speed and increase the data invocation methods by taking advantage of their strengths and weaknesses.

Third, the smart environment needs to construct the contextual features of the entire space comprehensively by extracting the data features fed back by each sensor. At this stage, it is necessary to use multimodal machine learning technology to fuse, organise, and analyse the information of each sensing system in the space for data mining. The multimodal cognitive data for a certain target feature must follow the principle of clearly identifying the data priority of the same feature and multidimensional fusion of different data features. The determination of data priority is related to situation type and target features. For example, a standard multimodal data fusion framework can be as follows: $\boldsymbol{h}_v$ is the feature vector of visual data processed by a CNN; $\boldsymbol{h}_a$ is the feature vector of auditory data processed by LSTM; $\boldsymbol{h}_h$ is the feature vector of haptic data processed by a deep neural network (DNN); $\boldsymbol{h}_o$ is the chemical molecule data of the odour processed by graph neural network (GNN) processed feature vectors; the fused features are the Kronecker product of multimodal features.

$$h_{fusion} = h_v \otimes h_a \otimes h_h \otimes h_o$$

Subsequently, $\boldsymbol{h}_{fusion}$ accesses the Fully Connected (FC) layer of the neural network, and the last layer is the scenario-specific user behaviour demand prediction layer, whose optimisation function is

$$\min_w \frac{1}{N} \sum_{N}^{n=1} L\left(W \times h_v^{(n)} \otimes h_a^{(n)} \otimes h_h^{(n)} \otimes h_o^{(n)}, y^{(n)}\right)$$

where N is the sample size, W is the model parameter of FC, L(•) is the loss function, and $\boldsymbol{y}^{(n)}$ is the label of the nth scene sample. In the process of multimodal machine learning, the model needs to be continuously optimised and trained by manual labelling and active learning so that the average difference between the predicted and true labels of all samples is as small as possible to achieve the goal of improving the accuracy of data analysis. This allows the smart environment to form an accurate cognition of user behaviour and emotional state for specific scenarios and build context-awareness for the smart environment.

6 Conclusion

This chapter discusses the design strategies related to multimodal perception systems in smart environments from two aspects: the type design of multimodal perception systems for smart environments and the design optimisation strategies for enhancing spatial perception systems. Regarding the design of multimodal perception system types, this chapter proposes building a human-like perception system for smart environments, forming a multimodal perception system with vision, auditory, haptic, and olfactory-gustatory senses, as well as illustrates the design methods of each type of sensory system in smart spaces with related design cases. In terms of design optimisation strategies to enhance spatial cognitive systems, this article illustrates the strategic principles from the perspective of optimising the spatial layout of perceptual systems and from the perspective of establishing multimodal data processing algorithm models. As an important direction for the future development of smart technologies, establishing a multimodal smart perception system will help smart environments explore an effective path to enhance the intelligence of architectural spaces.

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Cyberattack Measures in Smart Cities and Grids

Cevat Özarpa, İsa Avci, and Bahadır Furkan Kinaci

1 Introduction

With the development of information and communication technologies, cybersecurity problems in smart cities and networks are increasing rapidly. For this reason, increasing population, construction and mega investments, increasing energy needs in cities, and the need for smart grids come to the fore. However, this shows that the smart grid concept needs to be invested in and developed. With the frequent use of advanced network technologies used in smart cities, cyber risks and security vulnerabilities have come to the fore. Smart grids cover the areas of use of electricity, water, and natural gas networks, which are critical infrastructures of smart cities.

Anonymity and deniability are the facts that cyberattacks present an opportunity. It is also very difficult to identify the states and individuals behind these attacks. In such an environment, it is not possible to protect systems without mentioning absolute cybersecurity. For this reason, it is aimed to keep cybersecurity risks at a manageable and acceptable level. It is important to protect data in smart systems and to use them continuously. Cyberattack incidents should be handled with a holistic approach in smart grids and cities.

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Intelligent buildings are often part of a smart city project. Sensors can detect the deterioration of the building and can notify the authorities if necessary. Sensors can also be used to detect leaks in water mains and other piping systems, reduce costs, and help increase network efficiency. Also, smart city technology, in addition to job creation, energy efficiency, and sustainable use of space, increases the production and productivity of urban agriculture, including more fresh food for urban consumers.

While continuing to increase the population in cities, urban areas and infrastructure of these assets need to adapt to the increasing population by using them more efficiently. Smart city applications can enable these improvements, and cities can improve their operations and improve the quality of life of residents. From traffic lights to bus stops and even roads, all the elements that make up smart cities are interconnected, so they need to be protected from hackers. While cybersecurity techniques are designed to make it harder for hackers to work, those who run smart cities should always be on the alert. In this chapter, we will talk about what we need to do to prevent smart city software from being hacked by data thieves.

The process starts with smart grid and city applications, improving existing grids and making them smart. It enables to find and create new value from the existing infrastructure of networks and cities. This study aims to give general information about smart grids and cities and to explain the concept of systems. First of all, the concepts of smart city, smart grid, Internet of Things (IoT), and cybersecurity attacks in smart cities and networks are defined. The most common cyberattacks are given in smart grids and cities.

2 Smart Cities

Smart cities are human and nature-oriented and redesigned to provide maximum efficiency. In addition, smart cities have a framework that focuses on change, strategy, development and change, humans, and the environment in the management approach. For these reasons, smart cities are urban structures that have improved living standards by raising the living standards of society. These structures aim to use innovative and sustainable methods that reduce environmental problems. Moreover, it is based on creating new living spaces where the resources used are consumed efficiently and wisely. The smart city and grid, in other words, should provide human and social capital, sustainable economic support, and high lifetime value in classical and modern communication infrastructure. In addition, natural resources must be reasonably managed through competent management [1] (Fig. 1).

With the development of technology in recent years, smart grids have gained great importance by being widely adopted in many countries and cities. However, these new technologies have security disadvantages. Systems such as open data, education, IoT devices, smart agriculture, and smart energy form the basis of smart grids. However, it is very important to control and manage the structures in these smart grids (Fig. 2).

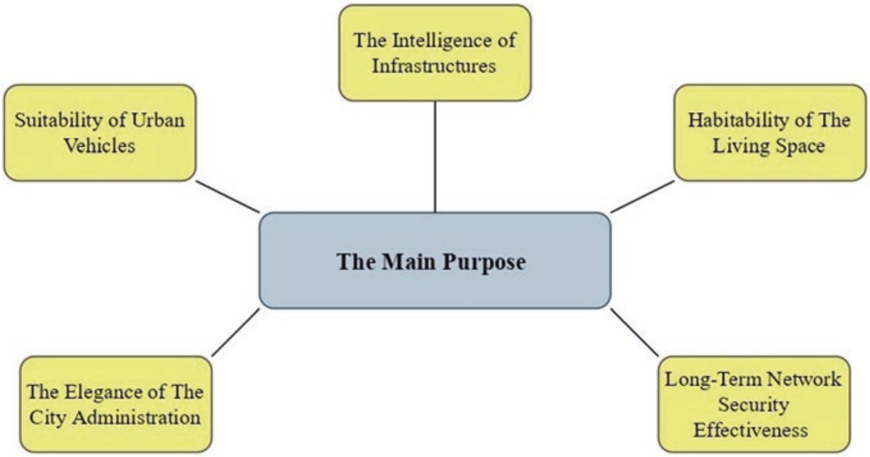

Fig. 1 The main purpose of developing and popularizing smart cities [2]

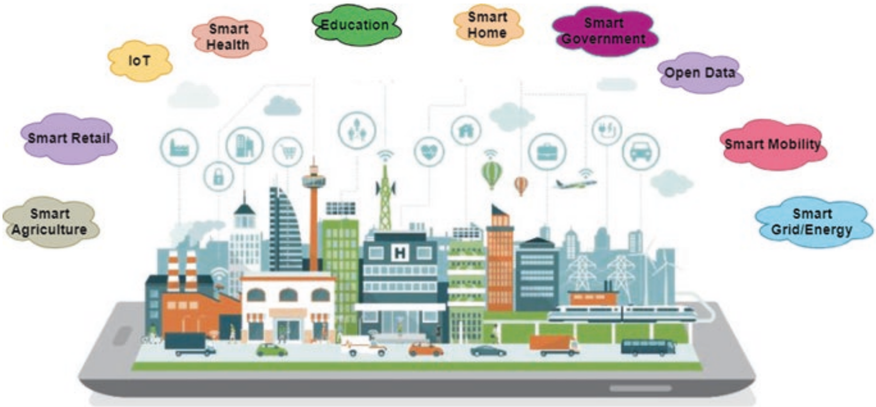

Fig. 2 Smart city overview [3]

The development of smart grids and cities and the prevention of security vulnerabilities that may arise in them is one of the most important issues. This study details the cybersecurity vulnerabilities of applications in smart grids and cities and the measures to be taken against them. These must necessarily require minimal precautions to be taken. It will be inevitable that there will be material and data losses in the face of measures not taken.

In addition to the emergence of new hardware and applications due to the changes in cyberattack methods and the development of technologies, an increase in security vulnerabilities is observed. In recent years, malware, distributed denial of service (DDoS), and advanced persistent threats have increased, especially among cyberattack methods. This study tried to determine the cyberattack methods that were detected and frequently used.

The continuity of all smart systems used in smart grids in terms of their operation and the availability of data, confidentiality, and integrity are the main components of information security. Furthermore, experienced personnel will be needed for the best management of these systems. The main components of success in the field of information security are people, technology, and the company. These are critical to the successful management of smart grids.

3 Smart Grids

Smart grids are an energy system that integrates the supply and consumption behavior of all market participants connected to them and aims to reduce loss and leakage, continuity in use, economic efficiency, and continuous data flow. Infrastructure services play an important role as an indispensable element of urban life. Control over these utilities became vital as the urban population grew. Population increases make it difficult to manage the use of information technology (IT) infrastructure, without software applications and made it impossible to manage [5].

ISO (which deals with the best management of physical assets by the International Organization for Standardization) argues that the management of infrastructure, as a whole should be systematic, risk-based, optimal and sustainable. Organization of systematic and interrelated movements manages assets and systems to achieve success and performance through a structure that is needed to control the risk and cost of organizational life cycle plans [4]. This requires intelligent networks for systematic monitoring.

The scope of the IEC 61850 (International Electrotechnical Commission) communication standard is based on the intelligent network protocol transformer. Otherwise, the same or different manufacturers use such non-parallel multiple protocols and interfaces [6]. The smart grid concept covers the use of information technology and communication systems, storage and consumption for the distribution and transmission system, and efficient, reliable supply of energy and materials through flexible management. In addition, the operating company has networks and wastewater systems designed for processes similar to information technology and electricity distribution in this sector, as well as processes for natural gas and water distribution [7].

In the classical network systems used today, problems such as power cuts, meter failures, low efficiency, and energy leaks can be detected by the subscribers by sending them to certain centers or by the work of distribution companies. In smart grids, on the other hand, these problems can be detected instantly and automatically resolved remotely without any interruption in service. Thanks to its real-time communication infrastructure, smart grids detect overloads, regulate energy flow directions, and contribute to preventing energy loss and leakage. At the same time, they manage the energy supply–demand balance and energy distribution, providing a fairer consumption price and more balanced resource use. Smart grids are more resilient to natural disasters and offer energy systems to distribution companies and consumers, which are quickly reactivated in the case of any natural disaster.

The working principle of the smart grid is based on the principle of managing the entire energy production and consumption infrastructure from a single center. Each of the natural gas, electricity, water, and telecommunication systems is managed from a single center within itself, and infrastructure management is carried out by ensuring the efficient operation of the systems. From this point of view, smart grids are the integration of computer and network technology into today's networks through geographic information systems. They process and interpret the data intelligently and manage the needs according to the data analysis they receive [8].

Smart grids, an essential component for smart cities, play a major role in bringing reliability, availability, and efficiency into the era. Testing, technology improvements, consumer education, standards, legislation development, and information sharing between projects will be critical in the transition from conventional grid systems to smart grids (Fig. 3).

In particular, the electrical grid, natural gas distribution is also very critical in a smart grid. The necessity to supply natural gas sustainably and efficiently requires smart network systems. The gas distribution network is a system that supplies

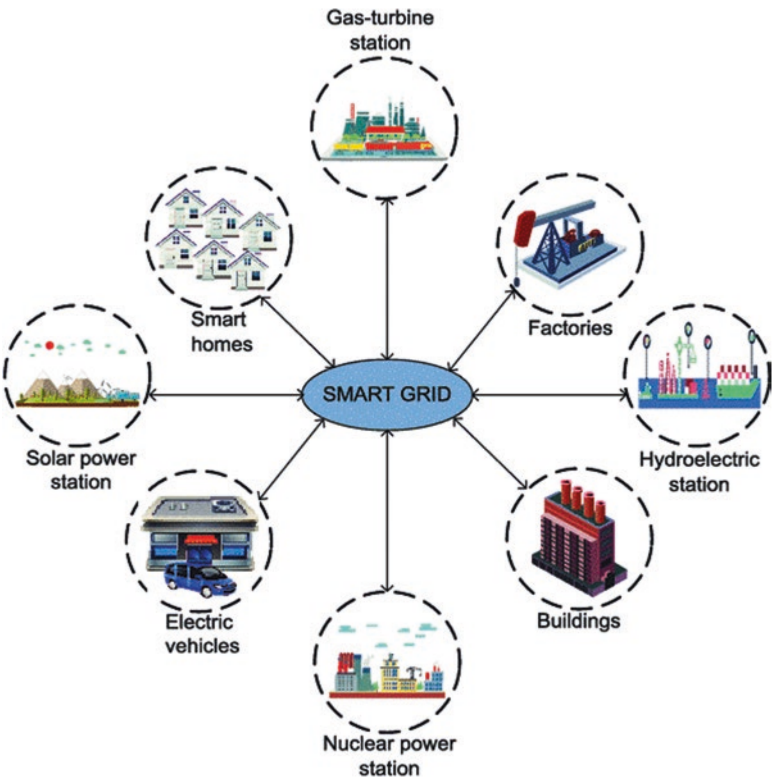

Fig. 3 Smart grid overview [7]

low-pressure gas from city gates to industrial, commercial, and residential buildings through pipelines of steel and polyethylene (PE) pipes at different pressure levels. Natural gas distribution networks consist of (i) Regulation and Metering Stations (RMS), (ii) mainline (steel) communication lines, (iii) regional stations and distribution lines, and (iv) service boxes and service lines. Due to critical safety issues in these systems, there can occur several cyberattacks. For instance, the set pressure and temperature levels of heating units can be altered remotely in the case of a cyberattack. This can damage the customer stations as well as the entire natural gas network [8].

An important element that effectively recognizes the full value of the smart grid process is its performance and capabilities to implement integrated, scalable, and interoperable engineering activities. In this new and more intelligent world, the customer's energy consumption of mobile devices, which can be watched via the Internet or a private home monitor, does the same things as meter data management systems. The counter also detects power surges and power outages, and the service will serve as a network sensor that can be used to connect or disconnect the remote connection [9].

The smart grid provides the integration of two-way communication between utilities and consumers through smart meters using Advanced Measurement Infrastructure (AMI). Thus, AMI is designed to provide real-time information on energy parameters such as prices, demand, capacity, and quality. If so, it would be surprising if the service company is properly navigating in terms of return on investment in an already deployed technology. Like all technological advances in energy efficiency, the smart grid has an important advantage to be noted and is highlighted in Fig. 4 [10].

Cybersecurity attacks are at the forefront of the difficulties experienced in smart grid deployment. Systems are protected against these attacks by using independent interfaces. It also provides energy efficiency and significant cost savings as an energy management tool called CISCO Energy Wise [11]. A smart grid system should have the following features.

Digitization means having a secure and fast digital platform for smart systems. Also, to be smart is to have good technology. Resilience, on the other hand, means that the developed intelligent systems can provide continuity without being affected by cyberattacks in the case of any abnormality. Personalization means tailoring customers to their needs. Finally, flexibility means that the smart grid is extensible, adaptable, and can work harmoniously within itself [12].

4 IoT in Smart Grids and Cities

In general, referring to the smart grid concept and the field of smart infrastructure, IoT applications in cities, transportation, industry, health, and other sectors are widely used. With the technologies that develop according to IoT application areas, its use has gained importance and provides significant convenience to human life.

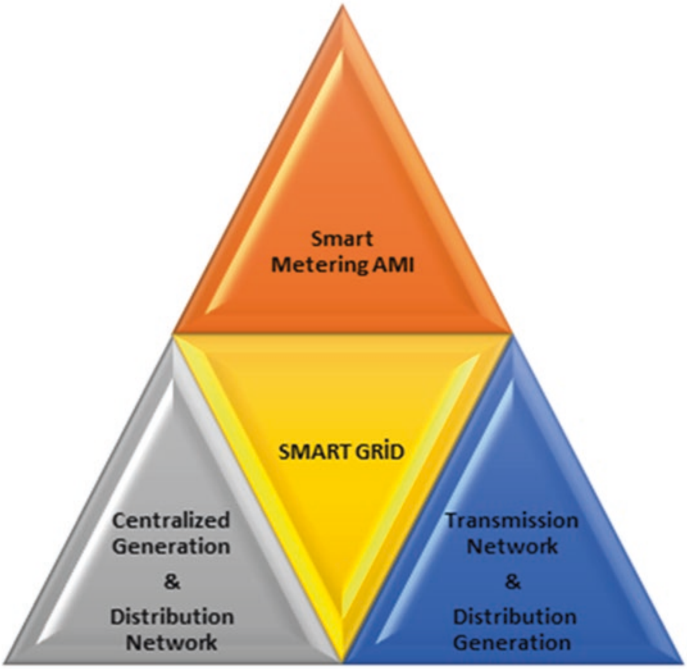

Fig. 4 The fundamental building block of the smart grid [10]

With the use of IoT devices, the security risks that will occur in the communication of data come to the fore. Studies in this area must be carried out and developments in this direction must be followed. All sectors and fields are given in detail in Fig. 5.

Smart cities use a combination of applications developed and interfaces created for the user to use devices, the IoT, and communication networks. The data collected by the communication of these devices with each other is stored in the cloud or on the server. With the development of these technologies, people's lives are getting easier. At the same time, the efficiency of both the public and private sectors is at the highest level.

5 Cybersecurity in Smart Grids and Cities

With advancing information technologies, cybersecurity threats have been an ever-increasing trend in recent years. From this point of view, it is clear that institutions strengthen their internal information security dynamics and place their strategic targets in the first place in terms of cybersecurity. In the field of cybersecurity, countries aim to protect computer networks in public and private sectors by following and adapting to international standards.

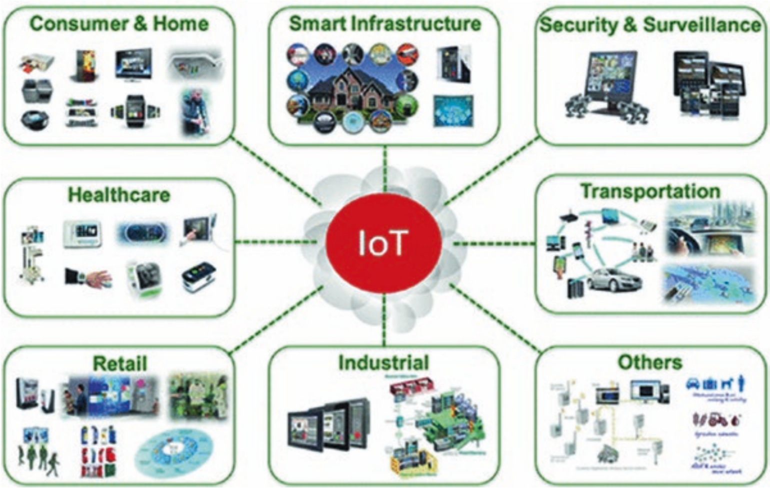

Fig. 5 Fields of application of IoT [13]

In terms of cybersecurity, no software application can guarantee companies a hundred percent security. For this reason, each institution should take its security measures, namely, technological, managerial, and education. Significant measures should be taken. For instance, employee information security awareness training should be done every year, the institution must have competent and senior experts in the field, and employment of cybersecurity experts to train the personnel, user, and system access logs should be kept: Cyber Incidents Response Team (CIRT), Cyber Security Center (CSC), Cyber Intelligence Center (CIC), and Software Security Testing Laboratory (Pentest Lab.) In order to respond immediately to cyber incidents, a Cyber Fusion Center (CFC) should be established, a corporate cybersecurity policy should be established, and the top management should support implementing them.

There are many sectors covered by smart grids and cities in Fig. 6. The exposure to cyberattacks against these sectors is shown as a percentage. Considering the impact of these cyberattacks, it is seen that the sector that has the highest risk and attacks with 26% is the energy sector [14].

5.1 Most Common Cyberattack Methods in Smart Grids and Cities

First of all, it is possible to define the subject threat in smart grids and cities, especially electricity, water, and natural gas. Looking at the smart city concept in general, it covers health, transportation, water supply, energy infrastructure, traffic management, waste management, and other services. A smart city can interoperate

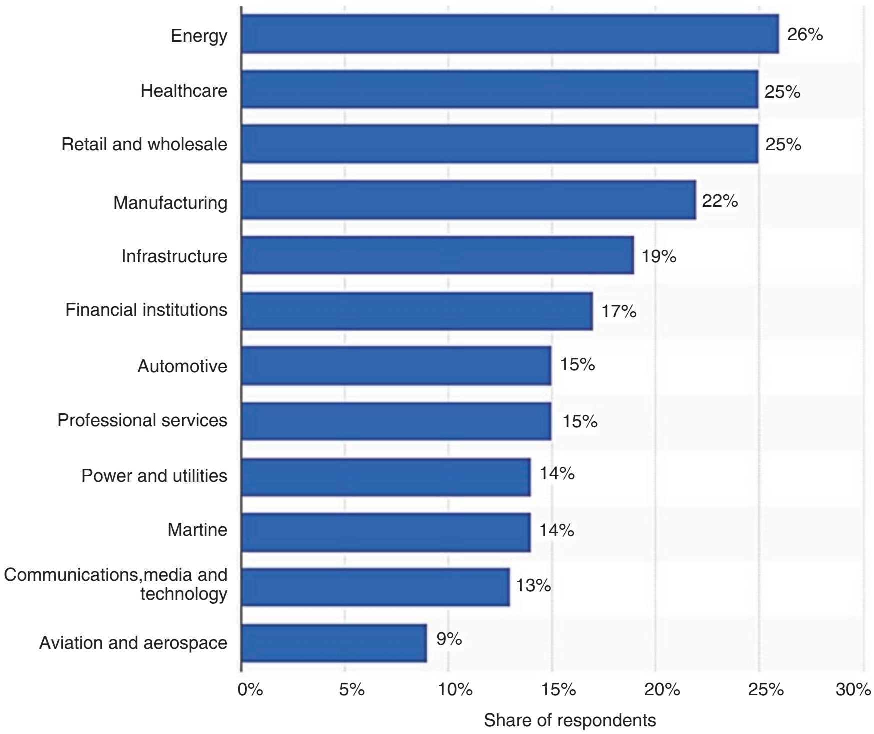

Fig. 6 Cyberattacks by sectors worldwide between 2016 and 2017 [14]

systems by establishing a mutual interaction between service providers and citizens. In this context, there are many concepts/methods such as cyber terrorism, cybercrime, cyber warfare, and cyber intelligence, each with different motivations, and different types of attacks. In this study, cyberattacks will be used for all of these methods. Cybersecurity violations intended to damage these structures are all functionally considered cyberattacks. In particular, this study investigates cyberattacks in smart grids and cities [15].

Cybersecurity aims to protect from external harmful applications, viruses infecting personal computers, advertisements from e-mails, and antivirus programs that need to be updated. In addition, when it comes to cybersecurity, one of the first things that come to mind is smart cities and grids. Because in terms of national security, loss of services in smart grids and cities can cause loss of life, large-scale economic damage, or weakening of national security. In particular, these systems are the most important assets to be protected in terms of cyberattacks. The main cyberattack methods are listed against smart grids and cities ([15–24]) (Fig. 7).

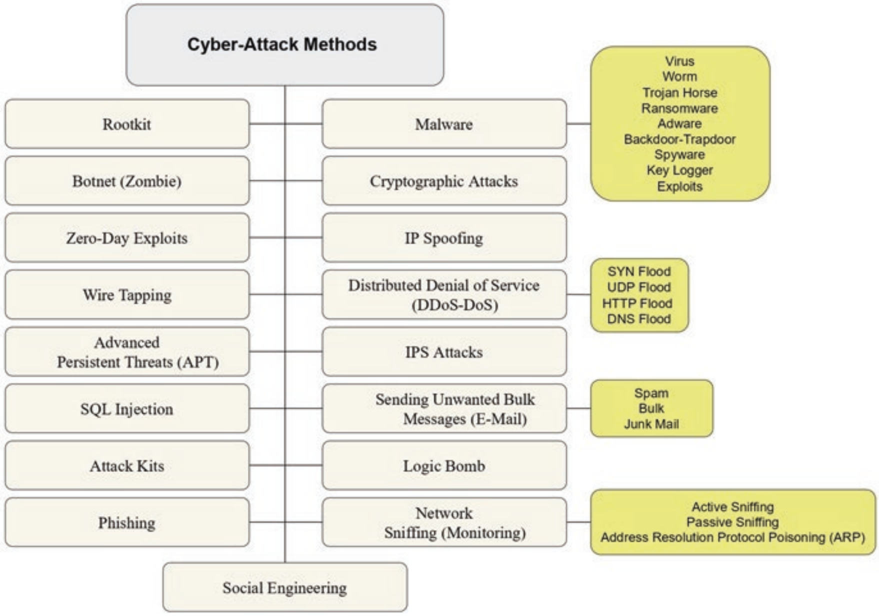

Fig. 7 The main cyberattack methods in smart cities and grids [2]

5.2 Measures Against Cyberattacks in Smart Grids and Cities

Some of the measures to be taken against cyberattacks in the smart networks and the main group of actions are shown in Fig. 8. The main groups given here have been determined based on the previous studies examined in the literature. In subsequent academic studies, these articles can be further expanded, and this chapter can motivate the studies to be carried out in this area.

The measures mentioned here must be given importance and attention in the critical infrastructures of state institutions and private companies. In addition, the mentioned cybersecurity measures motivated the creation of this article as a result of the studies and academic studies examined.

When building smart cities, they must take responsibility for understanding the systems they use and establish transparent relationships with the companies they support, from system construction to maintenance. In addition, every smart city should have trained cybersecurity emergency response teams to counter possible cyberattacks and their negative effects. Not knowing how to react to attacks can cause great confusion and stop normal city traffic. Therefore, serious cybersecurity strategies should be developed. But just as bacteria become resistant to antibiotics, threats can emerge with greater force to counter a change in strategy. Thus, each heightened security strategy often faces a new security threat. Therefore, security measures need to be constantly updated and monitored. For this reason, those who

Fig. 8 Overview of measures against cyberattacks smart grids and cities

want to be protected from attacks should always be one step ahead of hackers (Table 1).

Considering most of the identified attacks in general, they are among the most important issues that every institution should pay attention to. Because institutions and organizations do not want to be exposed to a cyber incident by experiencing a cyberattack, smart grids and cities can become more resistant to cyberattacks with technology.

Data that can be easily captured by taking advantage of vulnerabilities in smart systems such as face recognition over security cameras are used to threaten society. In particular, a system with a security vulnerability can be captured more easily than other systems. But, it is difficult to add a new system because all systems in smart cities work in an integrated manner. For this reason, the security strategy should be considered as a whole and at the same time, all security vulnerabilities should be minimized or even eliminated for each system. A security system is also required for the protection, monitoring, and control of smart grid and systems network traffic in cities. Firewalls aim to make systems more secure by preventing attackers from accessing data without authorization.

Table 1 Most common cyberattacks methods and measures [15–24]

	Most common cyberattacks methods	Most common measures
1	Distributed denial of service (DDoS-DoS) [14]	Determining cybersecurity performance targeted by top management and keeping performance records of all individuals.
	SYN flood	Determining the mode of action of the system to prevent unintentional disclosure of sensitive information related to the design, operations, and safety of the system.
	UDP flood	For third-party applications, patch management should be followed and a procedure or instruction should be prepared and followed up periodically.
	HTTP flood	The configuration controls and management of the software and hardware should be fully performed and monitored.
	DNS flood	It requires awareness to be resistant to cyber risks at all levels, from employees to senior management levels.
2	Botnet (zombie) [15]	The institutions should always keep risk management regulations against cyberattacks.
3	Zero-Day Exploits [16]	The institutions should always keep their inventory lists of information technologies against cyberattacks.
4	Advanced persistent threats (APT) [16]	Organizations should conduct personal access management on computers and servers.
5	Attack Kits [16]	Wired and wireless networks should be protected by strong authentication systems.
6	Sending unwanted bulk messages (E-mail) [17]	Institutions should perform event and log management.
	Spam	The institutions should conduct 24/7 emergency incidents and monitor management against cyberattacks.
	Bulk	Modem connections, local networks, connections with partners, internet, wireless networks, and satellite connections should be considered separately.
	Junk mail	To ensure a high level of cybersecurity, unnecessary network connections and unnecessary ports must be closed.
7	Network sniffing (monitoring) [18]	Institutions should use corporate networks and operational networks separately.
	Active sniffing	The security of SCADA systems used in smart grids and cities is mostly provided by the protection levels of the protocols produced specifically to communicate with the field vehicles and servers.
	Passive sniffing	Organizations should apply multiple access controls for user access to the internet and the applications in their network.
	Address resolution protocol poisoning (ARP)	Institutions should clearly define policies and procedures for cybersecurity and information security.
8	Malware [19]	Institutions should set up intervention teams against cyber incidents.
	Virus	The institutions should take the expert training of information security personnel and this training should be repeated periodically.

(continued)

Table 1 (continued)

	Most common cyberattacks methods	Most common measures
	Worm	Institutions should have penetration testing at regular intervals and keep their reports regularly.
	Trojan horse	In smart networks, standards on cybersecurity should be prepared and legally audited.
	Ransomware	Collaborative work should be done with universities, government, and private institutions on cybersecurity in smart grids and cities.
	Adware	Native and national software on cybersecurity should be developed in smart grids and the government should encourage this process.
	Backdoor-trapdoor	
	Spyware	
	Key logger	
	Exploits	
9	Rootkit [20]	
10	Cryptographic Attacks [21]	
11	IP Spoofing [20]	
12	Wire Tapping [22]	
13	IPS Attacks [21]	
14	SQL Injection [21]	
15	Logic Bomb [21]	
16	Phishing [21]	
17	Social Engineering [21]	

6 Conclusion

Cyber threats in smart grids and cities continue to grow day by day in an organized manner. Especially in terms of cyber incidents, the rate of attacks against the energy sector in the world is very high. Approximately 26% of cyberattacks worldwide are against the energy sector. Cyber threats and attacks have been detected in the energy sector, especially in natural gas, electricity, and water networks. Such attacks are expected to increase further in the coming years. However, the increase in the number of devices used in the concept of smart cities causes an increase in big data and wireless communication. The increase in the size of this data carries a high risk to ensure data security in terms of cyberattacks. Necessary security measures should be taken to reduce the risks of these cyberattacks, and cities should be made livable. Precautions to be taken should be preferred in terms of cybersecurity and newly developed hybrid prevention methods. Especially artificial intelligence and machine learning applications developed against new attack dimensions should be preferred.

Smart city leaders should be alerted, stating that many cities are not planning cyberattacks, although cities have plans for natural disasters such as floods and earthquakes as a result of research done by security research companies. Since the target of cyberattacks is a human-centered system, it is necessary to consider that they can lead to major events and to develop reasonable strategies against cyberattacks. As technologies improve in smart grids and cities, cyberattacks and vulnerabilities are also increasing. Therefore, in this study, cyber threat methods and solution suggestions are discussed in detail. It is shown that cybersecurity and information security are in every aspect of our lives, and it is recommended that institutions pay attention to the solutions given here. For this reason, the communication of the systems must be secure, the use of secure models, the protection of data, etc. In cases, the safety precautions given in this study should be taken into consideration. Finally, 17 cyberattacks were detected in smart cities, grids, and IoT systems used. However, measures that can be taken in these systems against cyberattacks have been given. Along with these measures, all stakeholders should cooperate among themselves and make suggestions for the measures to be taken against these cyberattacks. All countries should develop secure maturity models against cyberattacks for smart cities and grids. Moreover, investments should be made in this field, and joint work should be carried out by leading the way on these issues.

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