Internet of Robotic Things: Its Domain, Methodologies, and Applications

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Abstract

Robotics involves design, construction, operation, and use of intelligent machines that possess the ability to sense, compute, manipulate, and navigate environments to monitor events and execute an appropriate course of action. Internet of Things (IoT) on the other hand is a fast-developing novel technology consisting of group of uniquely addressable heterogeneous smart objects or tiny devices (things) interconnected via the Internet to share and process data from different sources. IoT is designed with the goal to "connect everything and everyone everywhere to everything and everyone else." The two technologies, IoT and robotics, have evolved into Internet of Robotic Things (IoRT) by the creation of a synergy between the two. IoRT aims at enhancing the current IoT with active sensing and actuation from robotics. This idea opened a novel opportunity for collaboration between IoT and robotics applications and research communities. However, most application domains of IoT and robotics have not fully explored the use of IoRT. This chapter discusses the (potential) applications of IoT-aided robotics in different domains, explaining how robots can extend the capabilities of existing IoT architectures to make them more knowledgeable and smarter; discuss some of the challenges in the full realization and application of IoRT; and lastly proposes an IoRT architecture for smart library management, an area that has not received much attention in the research community.

Keywords

Robotics • Internet of Things • Internet of Robotic Things • Application of IoRT • Actuation

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1 Introduction

Internet of Robotic Things (IoRT) is the merging of two technologies, Internet of Things (IoT) and Robotics (Afanasyev, 2019; Simoens, 2016; Grieco et al., 2014; Whitesides, 2018; Batth et al., 2019; Simoens et al., 2018; Ray, 2016; Sethi & Sarangi, 2017; Vermesan et al., 2017). Robots have been extensively used in solving problems and making them smart by building into them artificial intelligence so that they could be autonomous as much as possible. The need to make robots know about the existence of other robots in their environment so that they could collaborate to handle more complex tasks brought about the multi robot system (MRS) which requires machine-to-machine (M2M) interaction. On the other hand, Internet of Things (IoT) is a fast-developing novel technology consisting of group of uniquely addressable heterogeneous smart objects or devices (things) interconnected via the Internet to share and process data from different sources. IoT is designed with the goal to "connect everything and everyone everywhere to everything and everyone else". IoT has been used in various area such as healthcare, military, industrial processes, business as well as smart city.

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Since MRS needs interaction between constituent robots and IoT provides a ready medium for interaction, it is only natural for the two technologies to be merged in order to form a powerful computational and communication platform for executing robotic task both in programmable form and autonomously. This merger is what birth IoRT.

The individual technology has found application in different domains with some level of intersection. Robots have been employed to perform important functions, such as human assistive operations, healthcare delivery, industrial processes, military supports, and rescue management, monitoring, and environmental and equipment regulation (Grieco et al., 2014; Batth et al., 2019; Simoens et al., 2018; Sethi & Sarangi, 2017; Thusabantu & Vadivu, 2019; Scilimati et al., 2017). Also, IoT has been used in healthcare and smart environments such as homes, offices, and even factories. Thus, IoRT which is a combination of the two is applicable in all of these domains and provides a system that is smarter and more autonomous. Although this combination is an advancement to both worlds, the new breed comes with new challenges which need to be addressed in order to fully realize the potentials inherent in IoRT and even make it applicable in more wide and complex domains.

In this chapter, the two areas of IoT and Robotics are discussed. Then, IoRT is presented as a multidisciplinary technology that merges the two areas. The application of IoRT is presented, and some of the challenges that inhibits its full realization are discussed. The applicability of IoRT in educational libraries is also explored given that this area has not been given attention as others that are discussed in the chapter.

The chapter is organized as follows: Sections 2 and 3 present the concepts of IoT and Robotics, respectively. Section 4 discusses IoRT as a combination of IoT and Robotics. Section 5 presents some of the notable application of IoRT in the domain of smart environments (homes, offices, and industries), healthcare, and military including civil policing and rescue operations from disasters. Some of the challenges in the implementation of IoRT are discussed in Section 6, while Section 7 presents a proposal of the application of IoRT in library management. Section 8 concludes the chapter and highlights a further study on the empirical investigation of the use of IoRT in educational library.

2 Internet of Things

Internet of Things (IoT) is a paradigm which involves the interconnection of devices, often heterogeneous, with the capabilities of tracking, sensing, processing, and analyzing of information passed in the network. It offers a new environment in which sensors and other actuators seamlessly communicate with each other and their environment (Gubbi et al., 2013). The connected devices are smart and have sensing abilities and unique identification through the use of Radio Frequency Identification (RFID) technology. In RFID technology, electronic product codes are encoded in RFID tags which can be used to track smart objects in IoT.

IoT is basically based on the integration of sensors, RFID tags, and communicating technologies. Other components include embedded systems, mobile computing, cloud computing, low-price hardware, and even big data in order to provide computing functionality, data storage, and network connectivity for equipment that hitherto lacked them. One of the main capabilities of IoT include ability to collect and analyze data about the physical world and use the results for inform decision making and to alter the physical environment. Thus, it addresses traceability, visibility, and controllability of smart objects. IoT has had several applications which include environmental monitoring, healthcare service, manufacturing, inventory, and production management.

There are several IoT architectures which differ in the number of layers as a result of the level of granularity depicted in the architecture. At the early stage of IoT development, a three-layer architecture depicted in Fig. 1 suffices. The three layers are the perception layer, the

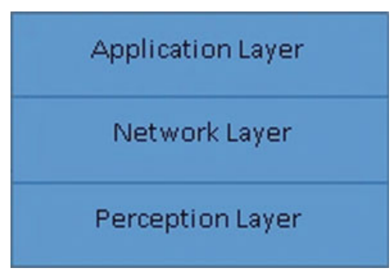


Fig. 1 Three-layer IoT architecture

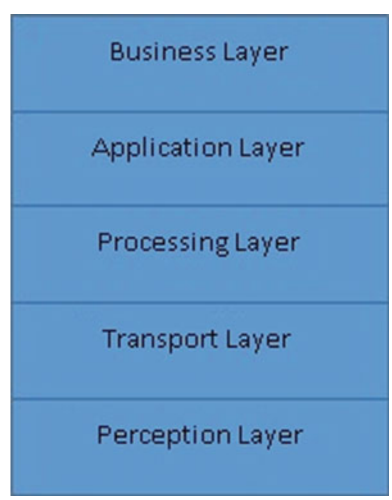


Fig. 2 Five-layer IoT architecture

Table 1 IoT architecture layers and their functions

S. No.	Layer	Function
1	Perception	This is the physical layer that comprises sensors that perceive and gather information from the IoT environment, i.e., senses available smart objects
2	Network	This layer is responsible for connecting smart objects, transmitting sensor data/information, and connecting to network devices and servers
3	Transport	Comprises of networks that transmit sensor data from the perception devices to the processing layer devices. These networks include Bluetooth, RFID, NFC, 3G, 4G, and even LAN
4	Processing	This layer is responsible for storing, processing, and analyzing. This layer uses technologies such as database, cloud computing, mobile computing, and big data analytics
5	Application	Defines the various areas in which IoT can be applied and responsible for delivering application specific services to users
6	Business	This layer manages the application models, business models, and user security

network layer, and the application layer. A more comprehensive architecture is depicted in Fig. 2. Table 1 presents the descriptions of the layers (Sethi & Sarangi, 2017).

3 Robotics

Robotics is a multidisciplinary field that comprises majorly science, engineering, and technology geared toward the development of mechanical robots that efficiently and effectively perform most human actions. The goal of robotics is to design intelligent machines that can assist humans in day-to-day activities and for engineering processes. Advancement in technology provided the platform for modeling robots to execute tasks that mostly require precision and that are repetitive and tedious in nature. There are several operations and places that robots can be applied, and these include firefighting, manufacturing plants, surgical assistance, delivery services, cleaning, heavy object lifting and movement, searching and information gathering, and detecting objects such as landmines in warfronts. Thus, some of the popular areas where robotics are useful are manufacturing, logistics, homes, travels, and healthcare.

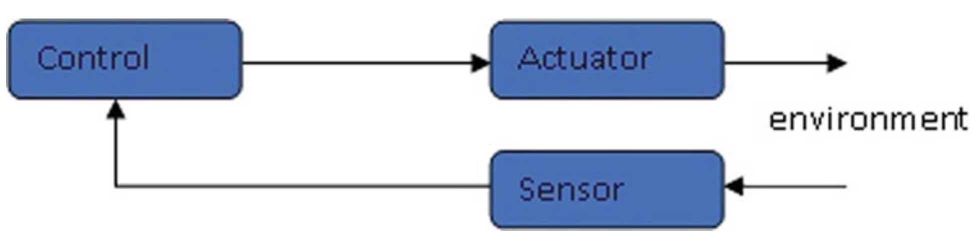
The advent of artificial intelligence (AI) has seen the development of intelligent robots that can learn from their environment while performing their tasks. Some of the notable application of AI robotics is in the development of drones that aid emergency response operations, law enforcement, and even search and rescue operation. They (drones) can be used to collect information such as source of wild fire outbreak, location of kidnappers and hostages, or the level of impact of the damages caused by disaster situations. Roomba is a vacuum cleaner robot that can adapt to its given environment by mapping it out while cleaning floors. Robots can also be made to adapt to working with humans, taught by humans by way of moving them around during the tasks, and they can adjust the amount of force applied to handling objects in their environment.

Besides manufacturing, robots have found applications in other sectors such as security, education, entertainment, and healthcare. One of the common attributes of robotics that has contributed to its applicability in these sectors is that they are programmable to perform their task, thus making them to be easily amenable to perform different task with little resemblance. Other common attributes of robots include: They consist of some level of mechanical construction which is determined by the nature of the tasks for which they are designed, and they also consist of electrical component as well.

Mostly, the robotic system consists of three components which are: control, actuation, and sensors. This is depicted in Fig. 3.

As shown in Fig. 3, the control is responsible for the connection of action into perception in an intelligent manner. The actuation has the capability to exert an action, in terms of locomotion and manipulation. It also provides and

Fig. 3 Components of robotics



animates the mechanical system of the robots. The sensory is responsible for perception, acquiring of data on the internal status of the mechanical system, and the external status of the environment (Siciliano, 2010).

Types of Robots

Robots come in different shapes and sizes depending on the nature of the task they are designed to carry out and the environment in which they will operate. Some robots usually mimic the structure of the original entity, most often humans or their parts, which carry out the task the robots are designed to perform as a substitute. For instance, car assembling robots are modeled after human arms to carry out tasks such as welding and screwing of car parts during manufacturing. Robots can be grouped into two main categories (Tzafestas, 2018): the service robots which are designed to render assistive service to users in an indoor environment such as homes and offices; and the field robots which are designed to operate outdoor in field where the environment is unstructured and have less constrained. The field robots are further classified into marine robots designed to operate under water; ground robots, operate on ground surface; and ariel robots design to fly and operate in the airspace. Another classification of robots includes the following five categories:

Preprogrammed robots: These are robots for controlled environments and monotonous task. Details of the tasks and environment are foreknown comprehensively, and they are tailored to work as programmed. A typical example is the mechanical arm on automotive assembling line. This arm mimics the human arm, and it performs the task more efficiently and repetitively without getting fatigued (Gawli et al., 2017).

Humanoid robots: As the name implies, they are robots that are physically and/or behaviorally human like. A typical example of this category is Sophia and Atlas of Hanson Robotics and Boston Dynamic, respectively.

Autonomous robots: These are robots that operate independently of humans, i.e., they require no human supervision, they are intelligent enough to control themselves. An example if Roomba, the vacuum cleaner robot that uses sensors for roaming and mapping out its environment while cleaning.

Tele-operated robots: Unlike the autonomous robots, tele-operated robots are controlled by humans. They are often designed to operate in complex environments and difficult circumstances. Typical examples are drones used to detect landmines in battlefield, robots for performing surgery, and underwater robots for fixing pipe leakages.

Augmented robots: These are robots used to complement or replace the human capabilities that may be deficient or lost. Some typical examples are prosthetic limbs for the physically challenged and exoskeleton robots used for lifting heavy objects.

4 Internet of Robotic Things

As it can be guessed, Internet of Robotic Things (IoRT) sometimes referred to as Internet of Things Robotic is a merging of the concept of IoT and Robotics in which IoT serves as the smart context in which robots operate thereby making robots smarter than they ordinarily were in carrying out designated tasks. This integration of robots into smart environments makes the robot to be aware of their environment and communicate with other things besides their fellow robots. Given this new context awareness and the autonomous capability of some robots, they become more knowledgeable and smart in carrying out more complex tasks (Simoens et al., 2018).

Although there is no universal definition of IoRT yet, some studies have attempted to provide definitions. A comprehensive definition is given by Ray (2016) as follows:

> A global infrastructure for the information society enabling advanced robotic services by interconnecting robotic things based on, existing and evolving, interoperable information and communication technologies where cloud computing, cloud storage, and other existing Internet technologies are centered around the benefits of the converged cloud infrastructure and shared services that allows robots to take benefit from the powerful computational, storage, and communications resources of modern data centers attached with the clouds, while removing overheads for maintenance and updates, and enhancing independence on the custom cloud-based middleware platforms, entailing additional power requirements which may reduce the operating duration and constrain robot mobility by covering cloud data transfer rates to offload tasks without hard real time requirements.

IoRT Architecture

Studies in IoRT have attempted to give a high-level architectural view of the landscape of IoRT. Figure 9.4 depicts the landscape of IoRT, showing the specific roles of robots and IoT, their main functions, required technologies. and applications to function and application domain (Afanasyev, 2019).

As shown in Fig. 4, robots in IoRT are the intelligent agents that carry out actions sensed and communicated via the IoT component of the system. The robots need to possess some abilities to be able to carry out their vital role in the system. Simoens et al. (2018) discussed the key abilities of the robots which include both the basic abilities of robots and a set of high-level abilities that make the robots to be smart in performing their roles. The basic abilities include: perception ability, to be able to collect environmental information for awareness and location within its environment; motion ability, to be able to move from one point to another within its usually dynamic environment; and manipulation ability, to be able to process information and change its environment as and when required. Other abilities that are high level include decisional autonomy ability, to be

Fig. 4 IoRT landscape. *Source* Afanasyev et al. (2019)

able to take decisions independently and intelligently; interaction ability, to communicate with other "things" in its environment to ensure the smooth execution of their task: for instance to avoid collision with other object, the robot needs to map out the environment and identify the location of other objects; cognitive ability for learning and reasoning using the perceived data/information collected from the environment.

As a system, the features that the IoRT should have are configurability and dependability. In terms of configurability, the system should be amenable to carry out different but related tasks, i.e., it should be adaptable for different environments. In terms of dependability, the system should be resilient, and its failure rate should be tolerable. Security is a key aspect to be considered in IoRT since it inherits the risk associated with the Internet–network hacking. Component integrity, authentication, and authorization must be ensured using strong cryptography models to prevent hackers from intruding into IoRT networks to cause malicious acts.

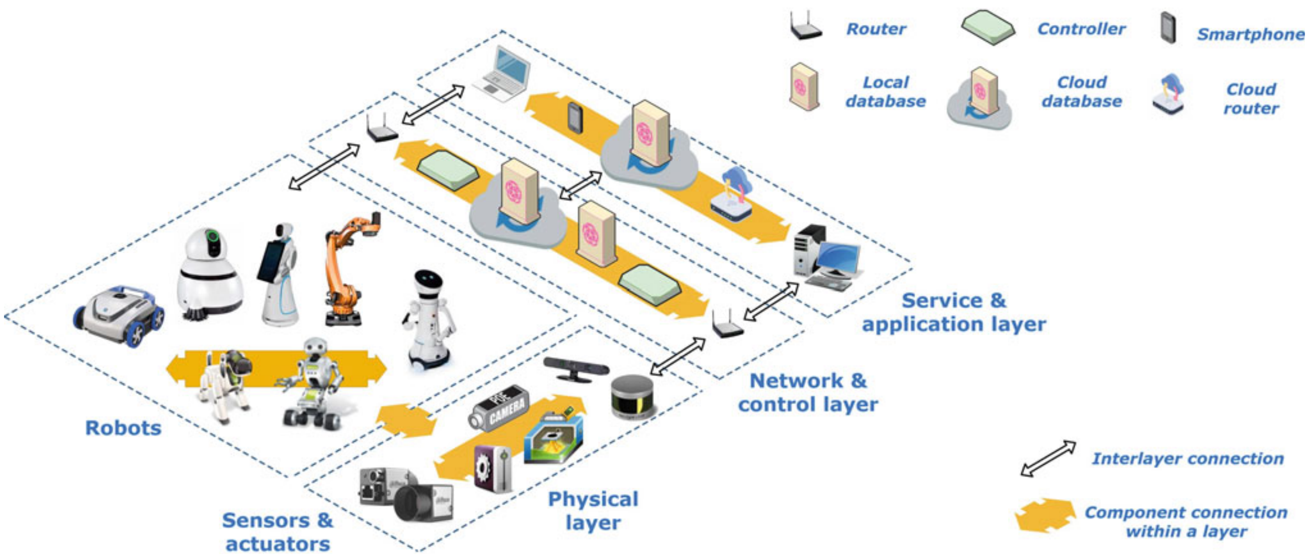


Fig. 5 IoRT architecture (Excerpt from Afanasyev et al. (2019))

Table 2 Roles of IoRT architecture layers

Layer	Role
Physical	This comprises the smart robots, sensors and actuators. The robots are intelligent agents that connect and communicate with other components, sensors are the hardware for perceiving the environment while actuators are the devices that implement intended actions such as switching components on/off, lifting objects, etc.
Network and control	This layer is saddled with the responsibility of interconnecting and managing the things in the environment using various network protocols and devices such as TCP/IP, Routers, Bluetooth, Wi-Fi, WLAN, RFID, storage medium and devices
Service and application	This layer provides the feature for programming and configuring the IoRT system including the robots, sensors and actuators as well as controls

Also, (Afanasyev et al., 2019) proposed a three-layer IoRT architecture that comprises the physical layer, network and control layer, and the service and application layer. Figure 5 and Table 2 present the three layers and their roles, respectively.

In Ray (2016), a more detailed architecture for IoRT with five layers was presented. Figure 6 presents a view of the layer while Table 3 gives the role of the layers.

Another architecture layer was presented by Hardmeier (2013). It is an expanded communication protocol for IoRT application that depicts a five-layer protocol and the associated technologies for each of the layers. Figure 7 depicts this IoT protocol stack layer for IoRT applications.

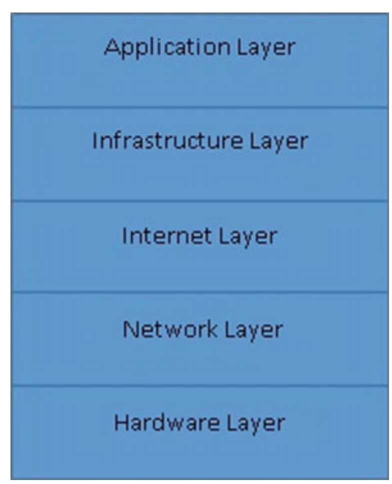


Fig. 6 Five-layer IoRT architecture (Ray, 2016)

5 Applications of IoT Robotics

IoRT has found applicability in various domains. It is applicable in most of the areas where robots have been used and areas where IoT have also been applied. Application of IoRT creates smart environments which include smart home, smart office, smart factory, and smart city. Other notable areas where IoRT are been applied are healthcare (especially telemedicine and eHealth), industry assembly, policing (search and rescue), and military. Grieco et al. (2014) depicted an application framework showing how IoRT can be utilized as shown in Fig. 8.

Table 3 Five-layer IoRT architecture

Layer	Description
Hardware	This is the lowest layer of abstract that comprises of the physical objects such as the robots, sensors, actuators, and even smart phones
Network	This level of abstraction describes the various network connectivity that can be leveraged for the connection of the robotic things. This includes: telecommunication networks such as 3G and 4G, Bluetooth, NFC, WiMAX, and Z-wave
Internet	This layer defines the Internet connectivity required for IoRT, especially the communication protocols that are suitable for robotic communication such as IPv6, UDP, MQTT, CoAP, XMPP, uIP, DTLS, AMQP, LLAP, and DDS
Infrastructure	This layer is considered the most vital, providing some cloud-based computational facilities and middleware for the operation of IoRT. These infrastructures include machine-to-machine-to-actuator cloud platform support, robotic cloud platform support, IoT cloud infrastructure, IoT business cloud services, and big data services
Application	This layer is the top most layer and provides the abstraction for configuring and programming the IoRT system to meet user-specific needs and requirements

Source Ray (2016)

Fig. 7 IoT communication protocol for IoRT application

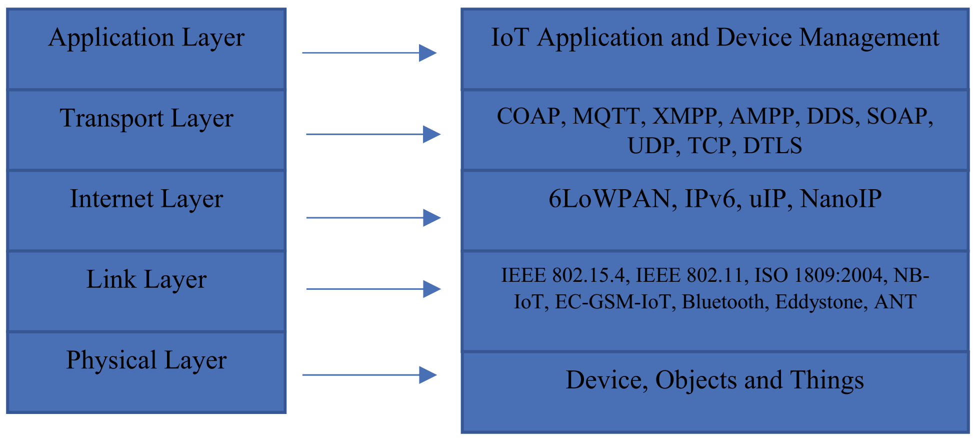
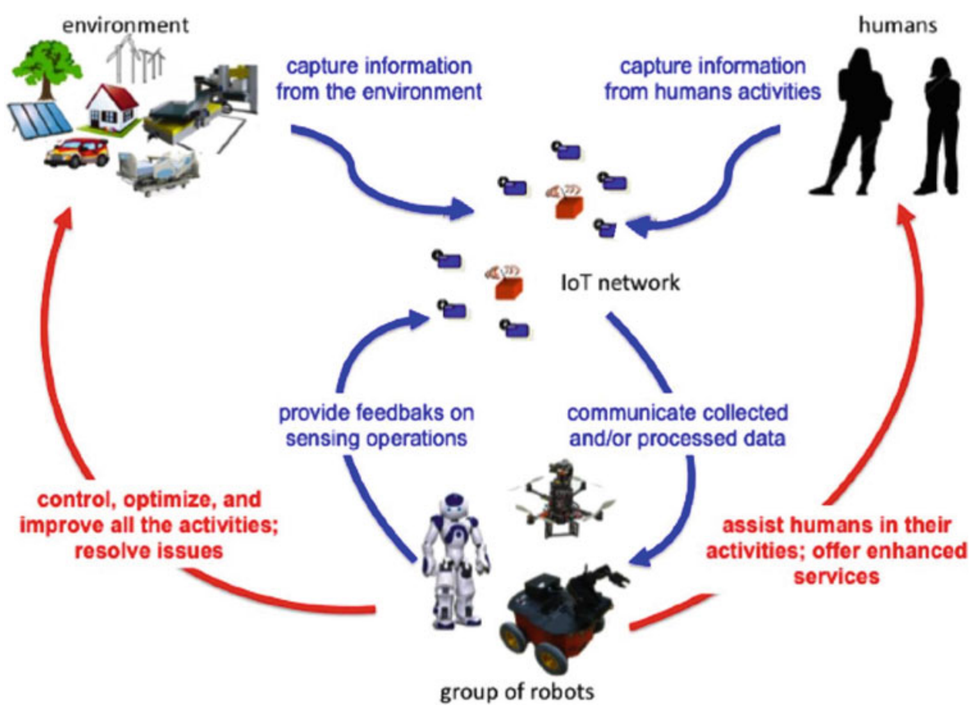


Fig. 8 An application framework of IoRT. *Source* Grieco et al. (2014)



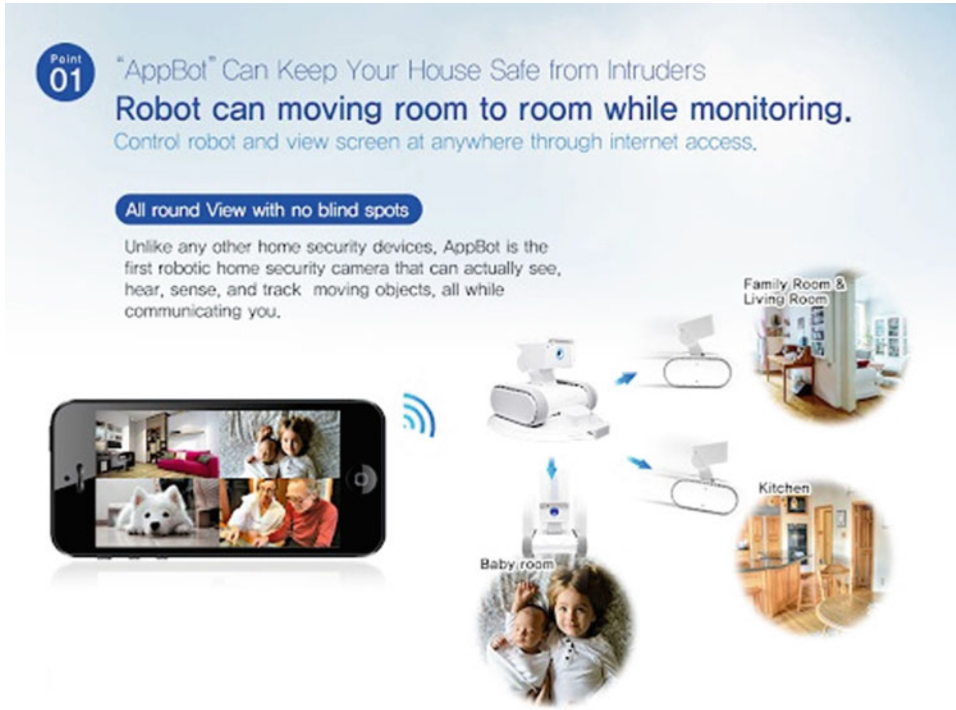


Fig. 9 AppBot riley home security and monitoring robot

5.1 Smart Environment and Industry

Smart home and office include the use of IoT and now IoRT for efficiently performing home and office task such as environmental temperature and humidity regulation, household chores, scheduling and reminder system, and even personal health and remote patient monitoring. Also, smart robots can serve as assistants in office meeting scheduling and logistics. Smart factory can include smart robots that control and monitor manufacturing processes via M2M communications and coordination, performing task such as environmental condition monitoring and regulation, heavy object lifting, location and mapping, and even complex and safety-critical tasks that otherwise are risky for humans.

Smart homes as relates to IoRT entails the engagement of robots in home management to carry out domestic tasks such as cleaning, washing, monitoring, and control. Roomba is a robot designed to clean indoor environment. AppBot Riley, depicted in Fig. 9, is a typical monitoring robot that can be used for both indoor and outdoor home security (The Prism Group, 2020); to monitor the activities of children indoor. The robot is equipment with camera for live streaming and can move about within its environment.

Manufacturing industry has seen the application of robots to perform tasks that are energy-intensive, risky, and require high level of precision and accuracy. A typical example is the assembling arm used in car manufacturing, see Fig. 10. Making the robots in the industry smart requires the IoT technology among others. Other key technology needed also include M2M for communication between robots without having to consult a central location or server. With smart objects and sensing devices in the environment, robots can be made to perform even more complex tasks and in a cooperative manner involving more than one robot at a time, working in consensus to carryout operations without making conflicting decision and actions. The areas where IoRT is applicable in industries include:

Fig. 10 Robots assembling cars in Chennai plant

1. Autonomous movement of industry equipment when needed
2. Industry environmental condition measurement and regulation (such as furnance temperature measurement and

control, detection and possible elimination of toxic chemical in the air in facility areas)
3. Management of facility energy requirements such as electricity
4. Access control management for safety and security
5. Prediction of failure and disaster to mitigate them before they occur and management of disastrous situation if they occur.

Grieco et al. (2014) presented a comprehensive scenario of the applicability of IoRT in the airport operation and management; highlighting the technological and computational requirements for the implementation of an airport IoRT—see Fig. 11. Robots in the IoT context can be made to man or assist humans in airport check-in, boarding, luggage, security, and even emergency situation management.

Interestingly, the application of IoT-aided robots in the food processing and production industry for production of health food is being considered. The production of special type of food for persons with, say, diabetes and heart disease was explored by Bader and Rahimifard (2020).

5.2 Healthcare

Healthcare delivery is one of the major domains where IoT and Robots are being applied to assist caregivers or as caregivers to efficiently deliver timely and effective services. The inclusion of robots into telemedicine, eHealth, and mHealth technology increases capacity to deliver healthcare to patients both in-house and remotely to places where needed. Figure 12 depicts some applications of robotics in healthcare delivery.

The figure, respectively, shows a robot used to assist patients with motor problem, robotic arm for performing surgical operations, and Zora, a caregiver robot that can be used in nursing homes (Adams et al., 2018). These robots and more with IoT will tremendously enhance and increase the healthcare delivery capacity of health worker both remotely and in-house. Some of the areas where IoRT is applicable in healthcare are:

1. Remote patient monitoring (RPM)
2. Assisting patients with motor disabilities to perform recovery exercises

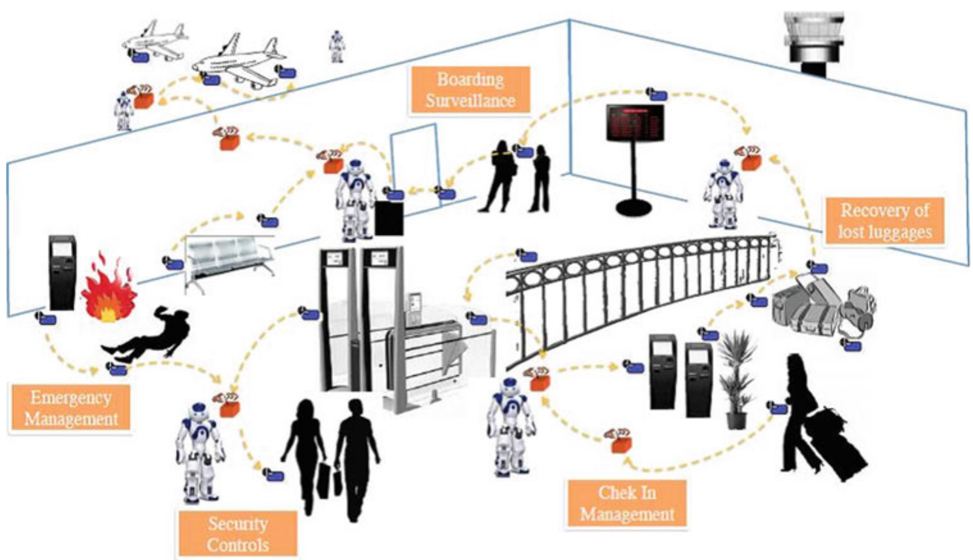


Fig. 11 Smart airport with IoT-aided robots. *Source* Grieco et al. (2014)

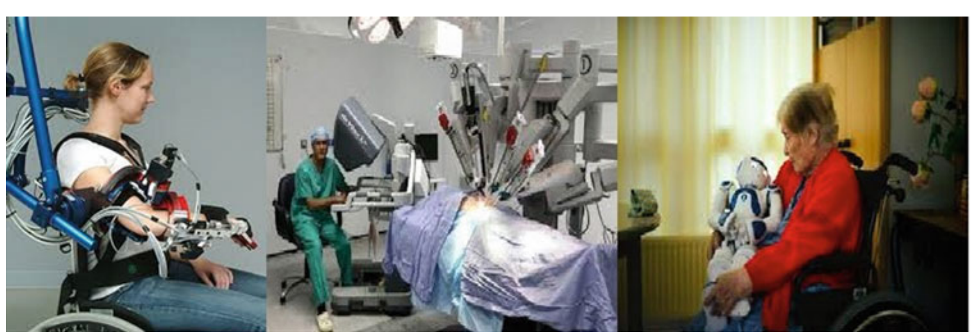


Fig. 12 Robotics healthcare

Fig. 13 BigDog designed by Boston dynamics

3. Management of drug storage, discovery, movement, and delivery as well as its administration to patients.
4. Emergency assistance
5. Hospital environmental condition and medical equipment monitoring and regulation
6. Management of safety and security within hospitals.

Networking and mobile computing technology provides a good medium for the implementation of healthcare IoRT. The use of wireless body area network (WBAN), RFID, Bluetooth, etc., as well as mobile technology (3G, 4G, and 5G) and mobile devices create connections for robots for remote sensing and communication, i.e., robots can connect to other "things," receive and send data to one another, process the data, and take actions based on acquired information using these technologies.

Aside accessibility to healthcare, efficiency and timeliness in healthcare delivery, IoRT will also be highly useful in pandemic situations such as the COVID-19. Robots can be used to remotely and virtually attend to patients to ensure physical distance to avoid physical contact in order to fight the spread of infectious diseases.

5.3 Military and Policing

IoT and Robotics as individual technology have been used in the military ecosystem (Ha et al., 2019) and security in general. For instance, IoT are applied for detection and prevention of intrusion, detecting presence of chemical, biological, and explosive devices. Yushi et al. (2012) presented a high-level Military IoT (MIoT) architecture. The architecture comprises a sensing layer that captures data/information from human, materials, equipment, and devices in military environment; and information layer that shares collected information among military personnel, equipment, and application. On the other hand, robots have been intensively used in military operations and experiments. One of the notable applications is in unmanned vehicles such as in unmanned ground vehicle (UGV), unmanned surface vehicle (USV), unmanned aerial vehicle (UAV), and unmanned underwater vehicle (UUV). Building intelligence into robots has seen the design and development of BigDog, a four-legged robot that can operate in complex and rough environment carrying military equipment and highly resilient to noise—Fig. 13. Military drones are unmanned and tele-operated form of robots that are used in spying operations and even enemy targeting and execution. These robots have found use in military and policing operations such as area (e.g., border) surveillance and mine detection on combat fields.

Merging the capabilities of IoT and Robotics into IoRT which makes the robots to be more knowledgeable and intelligent greatly enhances the application of these technologies in the military ecosystem. Thus, based on the respective application of these two technologies, IoRT are applicable in the following areas of military operations:

1. autonomous detection of harmful chemicals and biological weapons and ground mines; and safe storage and deployment of nuclear weapons,
2. autonomous control of military vehicles and aircrafts with little or no human intervention,
3. provide assistance in both policing and war operations,
4. securing military facilities by providing role-based access control (RBAC) and restriction to sensitive and risky environments.

Besides the high-end military application of IoRT, it is also applied in civil policing and rescue operations. Police–civilian altercation that often lead to shooting and killing of either police officers or civilians can be avoided by deploying IoT-aided robots to interact with civilians at road checkpoints and home thereby eliminating the chances for shooting and/or killings due to provocations. Also, safety at mining sites can be assessed by deploying robots to examine them before engaging humans to perform mining operations. In case of disaster, robots can also carry out rescue operations.

Fig. 14 Application of IoRT in educational library

6 Challenges in Implementing IoRT

Some of the key areas where research is focused in the full actualization of IoRT application include interoperability in heterogeneous context and distributed computing environment; energy usage optimization (Rajendran & Lourde, 2016); autonomy of robots and things using artificial intelligence (AI) (Alsamhi et al., 2019)—specifically usage of machine learning (ML) algorithms in autonomous decision making by robots; security using measures such as cryptographic algorithms for confidentiality, authentication, and authorization, and integrity of IoRT components to prevent intrusion, identity theft, and other cyber security attacks which are inherited from the Internet aspect of the IoRT framework.

M2M and human–robot interaction (HRI) have attained a mature stage where they can be applied to solve the problem of communication between "things" in a distributed environment. Data sharing in IoRT or its constituent technologies is on anytime basis and has to be timely. Edge computing and big data are considerable in handling and sharing data in complex communication (Thusabantu & Vadivu, 2019). M2M interaction also requires some level of cognitive autonomy of the robots and other things in the IoRT environment which can be achieved using AI/ML.

IoRT environment must be secured against hacking—cyber security threats from the connectivity component of the IoRT—since networking forms the backbone for the IoRT operation and it (networking is susceptible to cyber attacks). The robots and other "things" in the IoRT environment must be authenticated and authorized to carry out functions within the IoRT settings, and the communication links must be protected from eavesdropping and hijacking by using point to point secure communication protocols. Some of the measures that are amenable to IoRT security are network security digital certificate and signature but must be adapted to function in a distributed environment.

In the adoption and/or adaptation of existing technologies for the implementation of IoRT, computational complexity in terms of time and space must be considered in order to avoid problems associated with latency delay in processing and communication (Micoli, 2019). Robot and things are limited in both computational speed and memory, thus computational algorithms and data structures that are efficient in time and space usage must be used in building the IoRT environment.

7 IoRT in Libraries

Educational or academic library is one notable area where the application of IoRT is possible but has not be considered like other smart environment discussed in Sect. 5.1. IoT application prototypes and models have been proposed (Wójcik, 2016; Brian et al., 2014), and robots have been considered for use in libraries (Pujari & Deosarkar, 2017), but the merging of IoT and robotics has provided the opportunity to further make libraries smatter by engaging smart robots in an autonomous manner. Library catalog and collection stack management in physical libraries is a very vital part of the tasks that librarians do. In the context of IoRT, robots can be made to autonomously assist librarians in performing these tasks; patrons can interact with robots to borrow and return print documents (books). With sensing and actuation, IoRT can be applied in library environmental condition and regulation. Also, using the Internet, remote communication between libraries can be implemented. Figure 14 presents an architectural view of a smart library environment using IoRT.

8 Conclusion

IoRT is a technology that has come to revolutionize industrial processes, healthcare delivery, military, security, and most ways of human life and activities. A world where autonomous robots and every vital objects and things can communicate both remotely and in-house to carry out majority of the tasks been performed by human and standalone machines is envisaged. IoRT is being applied in developing smart homes, offices, industries (Industry 4.0), and military operations. Although, it is an improvement on IoT and robotics as individual context, IoRT also comes with technological challenges. Efficient algorithms and computational models need to be in place to ensure the autonomy of robots and the security of the network and communication in IoRT. The algorithms and computational models must be distributive to be usable in the IoRT environment; centralized computation and communication will pose serious problems in the application of IoRT for the future. As future direction, the application of IoRT in libraries will be explored further with a view to implementing IoRT in education library.

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