Robotic Technology, Artificial Intelligence and the 4IR Libraries

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Amos Orenyi Bajeh, Adeyinka Tella

Chapter 2
Internet of (Robotic) Things in Library System Automation

Abstract: The Fourth Industrial Revolution has brought about drastic changes in business processes and operations. The Internet of Things (IoT) and robotics are the key technologies leading this revolution towards full automation of management and service delivery, and the academic library is one of the prominent areas of application. Studies have shown the applicability of the IoT and robotics in the library management system and the benefits these technologies bring into the system. This chapter introduces the concepts of the IoT, robotics, and the Internet of Robotic Things (IoRT) which is an integration of the previous two concepts. The application of the IoT and robotics in the library business process and management is also presented. An IoRT based theoretical framework is proposed as a way forward for the automation of the library system for a better and smarter management and service delivery.

Keywords: Internet of Things, Robotics, Internet of Robotic Things, library management

Introduction

The technological revolution has brought about the automation of human activities and business processes to enhance productivity. Efficient and effective service rendering, gathering, storage, and processing of information resources are being impacted by technologies. The Internet of Things (IoT) as a technology has found diverse use in businesses, homes, and industries. Its application in library management is becoming comprehensive towards the Fourth Industrial Revolution (4IR). Smart library environment, library inventory, stack/rack, and collection management, as well as providing user personalized self-services, training, resource accessibility, and help have been impacted by the implementation of the IoT technology in the library (Abo-Seada, 2019; Bansal, 2018; Kaladhar & Somasekhara Rao, 2017; Qin, 2018; Renold & Rani, 2013; Shatte et al., 2014; Sheeja & Susan, 2019; Stefanidis & Tsakonas, 2015; Sun, 2014; Walsh, 2011; Brian et al., 2014; Cheng et al., 2016; Du & Liu, 2014; Evans & Sweeney, 2005; Fortino et al., 2016; Hahn, 2017; Hahn, 2018; Hoy et al., 2015; Khan et al., 2018; Massis, 2016; Miorandi et al., 2012; Nag & Nikam, 2016).

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Also, robots have been considered in the management of library settings (Pujari & Deosarkar 2017). The advent of the integration of the IoT and robotics into the Internet of Robotic Things (IoRT) has brought about a further revolution of the areas where the IoT and robotics have been individually applied. The IoRT provides more interconnectivity between things and robots for better service delivery and carrying out more complex tasks and functions.

This chapter discusses the concept of the IoT and robotics as individual technologies, their application in the library, and other areas as a source of inspiration. Taxonomy of the application of the IoT in libraries is presented, and a theoretical framework for IoRT-based library operation and management is proposed.

The remaining parts of the chapter are organized as follows. The second section introduces the concepts of the IoT and robotics as individual technologies. The third section discusses the concept of the IoRT and its applicability. The academic library system is introduced in the fourth section. The fifth section presents the core of the chapter by discussing the studies on the application of the IoT in libraries. Taxonomy of the IoT in libraries is also presented in this section. The sixth section presents and discusses the proposed IoRT framework for library management. The chapter is concluded in the seventh section with some areas for further studies.

The Internet of Things and Robotics

This section introduces the concepts of the IoT and robotics as separate technologies in our modern world. These two technologies are gradually revolutionizing daily living, business processes, healthcare, manufacturing, and even military and security.

The Internet of Things

The Internet of Things (IoT) is a paradigm that involves the interconnection of (heterogeneous) devices to provide the capabilities of sensing, tracking, processing, and analyzing information through the network of devices. It offers a new environment in which sensors and actuators seamlessly communicate with each other and their environment. The connected devices are smart and have sensing abilities and unique identification through the use of networking technologies such as Radio Frequency Identification (RFID) (Jabbar et al., 2017). Each of the smart objects in the IoT environment can be uniquely identified by an electronic product code (ECP) encoded in RFID tags and, through this, they (the smart objects) can be tracked within the environment.

Other technological components that may also be involved in the IoT include mobile computing, cloud computing, and even machine learning, as well as big data analytics in cases where huge data is generated and needs to be stored and processed. One of the main capabilities of the IoT includes the ability to collect and analyze data about the physical world and use the results to inform decision making and to alter the physical environment.

Several decades ago, the idea of inanimate objects engaging in any form of communicating would have been seen as fantastical, such as magic and/or science fiction (Abuarqoub et al., 2017; Walsh, 2011). Rose (2014, n.p.) posited that: "the Internet of Things is made possible through ubiquitous connectivity. An Internet connection allows the transmission of sensing and signaling information, the processing and storage of information, and the delivery of new services." Also Rowland et al. (2015)stated that: "the falling cost of sensing and computation means that there are more and more devices that are capable of capturing, and acting on, data about the world." Thus, the IoT addresses traceability, visibility, and controllability of smart objects. The IoT has had several applications which include smart environments such as smart home, smart campus, smart office, and smart city; healthcare; manufacturing; inventory; and production management (Abuarqoub et al., 2017; Agra et al., 2017; Xu et al., 2019; Yushi et al., 2012).

Several IoT communication protocol architectures have to be stated and they differ in the number of layers due to the level of granularity depicted in the architecture. At the early stage of IoT development, a three-layer architecture depicted in Figure 1 suffices. The three layers are the perception layer, the network layer, and the application layer. A more comprehensive architecture with a lower level of granularity is depicted in Figure 2. Table 1 presents the descriptions of the layers (Sethi & Sarangi, 2017).

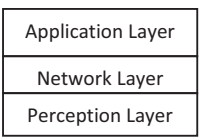


Figure 1: 3-layer IoT architecture.

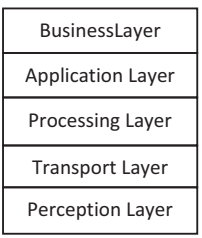


Figure 2: 5-layer IoT architecture.

Table 1: IoT architecture layers and their functions.

S/N	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 databases, 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.

Robotics

Robotics is a multidisciplinary field that comprises majorly science, engineering, and technology geared towards the development of mechanical robots that efficiently and effectively perform most human operations. The goal of robotics is to design intelligent machines that can assist humans in day-to-day activities. Advancement in technology provided the platform for modeling robots to execute tasks that are repetitive and tedious and require precision. These include tasks such as firefighting, use of manufacturing plants, surgical operations, lifting and moving heavy objects, searching, and gathering sensitive information, and detecting objects such as landmines on warfronts. Thus, some of the popular areas where robotics is useful are manufacturing, logistics, homes, travels, the military, and even healthcare.

The advent of artificial intelligence (AI) has seen the development of intelligent robots that can learn from their environment while performing their tasks. For instance, *Roomba* is a vacuum cleaner robot that can adapt to its given environment by mapping it out while cleaning floors. One of the common attributes of robotics that has contributed to its applicability is that they are programmable to perform their task, thus making them easily amenable to perform different tasks that have some resemblance.

The Robotic system consists of three components: control, actuators, and sensors. These components are logically configured into a loop depicted in Figure 3. The robotic system through its sensors(which serve as its interface with the environment) gets a signal from its environment. The signals are processed by the control and actions are taken through the actuators to cause the required changes to the environment.

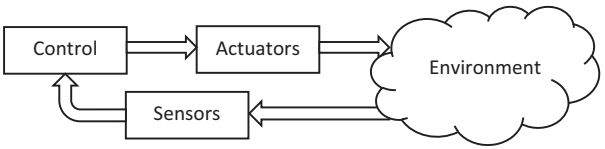


Figure 3: Components of robotics.

That is, the control is responsible for the processing of collected signals and generation of appropriate and intelligent output that will be used to control or perform an action on the environment, while the actuator can exert the action in terms of locomotion and manipulation on the environment by animating the mechanical system of the robot. The sensor is responsible for the perception, acquiring of data on the internal status of the mechanical system, and the external status of the environment (Siciliano et al., 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 tasks 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 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 outdoors, such as in a field where the environment is unstructured and is less constrained. The field robots are further classified into marine robots designed to operate underwater; ground robots, which operate on the ground surface; and ariel robots designed to fly and operate in airspace.

Another classification of robots includes the following five categories:

(i) Preprogrammed robots: these are robots for controlled environments and monotonous tasks. 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 the 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).

(ii) Humanoid robots: they are robots that are physically and/or behaviorally human-like, as the name implies. A typical example of this category is Sophia and Atlas of Hanson Robotics and Boston Dynamic respectively. Another example is Zora, the robot caregiver which often lead exercises and play games with humans in nursing facilities (Adams et al., n.d.)

(iii) 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 is *Roomba*, the vacuum cleaner robot that uses sensors for roaming and mapping out its environment while cleaning (The Prism Group, 2020).

(iv) Tele-operated robots: these are robots that are remotely controlled by humans. That is, unlike autonomous robots, these robots do not operate independently but are tele-guided to carry out their tasks. Typical examples are drones used to detect landmines on the battlefield, robots for performing surgery robots for earthmoving as part of military tasks (Ha et al., 2019), and underwater robots for fixing pipe leakages.

(v) 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.

Internet of Robotic Things

The Internet of Robotic Things (IoRT) is the merging of the IoT and robotics technologies in which the 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 aware of their environment and communicates 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 the IoRT yet, some studies have attempted to provide definitions. A comprehensive definition is given by Ray (2016):

> 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 allow 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 4 depicts the landscape of IoRT, showing the specific roles of robots and the IoT, their main functions, the required technologies, and the application domains (Afanasyev et al., 2019).

As shown in Figure 4, robots in IoRT are the intelligent agents that carry out actions that are 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. Cirani, Picone and Veltri (2015) discussed the key abilities of robots which include both the basic abilities of robots and a set of high-level abilities that makes the robots smart in performing their roles.

The basic abilities include:

- **Perception ability:** this is the ability to collect information for awareness and location within its environment.
- **Motion ability:** this is the ability to move from one point to another within its usually dynamic environment.
- **Manipulation ability**: this ability entails the capability to change its environment as and when required.
- **Decisional autonomy ability:** this is the capability to be able to take decisions independently and intelligently.
- **Interaction ability:** the ability to communicate with other "things" in its environment to ensure the smooth execution of its task. For instance, to avoid collision with another object the robot needs to map out the environment and identify the location of other objects.
- **Cognitive ability:** this is the ability for learning and reasoning using the perceived signals collected from the environment.

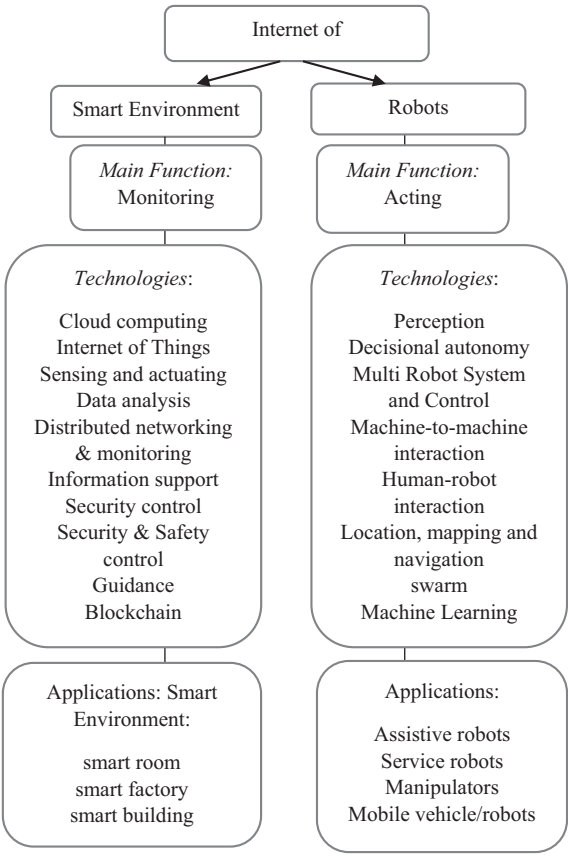


Figure 4: IoRT landscape (source: Afanasyev et al., 2019).

In addition to these abilities, the IoRT system needs to be configurable and dependable. In terms of configuring ability, the system should be amenable to carry out different but related tasks. That is, it should be adaptable to different environments. In terms of dependability, the system should be resilient and its failure rate should be tolerable. Furthermore, security is a key aspect to be considered in IoRT since it inherits the risk associated with 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.

Similar to IoT, several IoRT communication protocol architectures have been enumerated. Afanasyev et al. (2019) proposed a 3-layer IoRT architecture that comprises the physical layer, the network and control layer, and the service and application layer. Figure 5 and Table 2 present the three layers and their roles respectively.

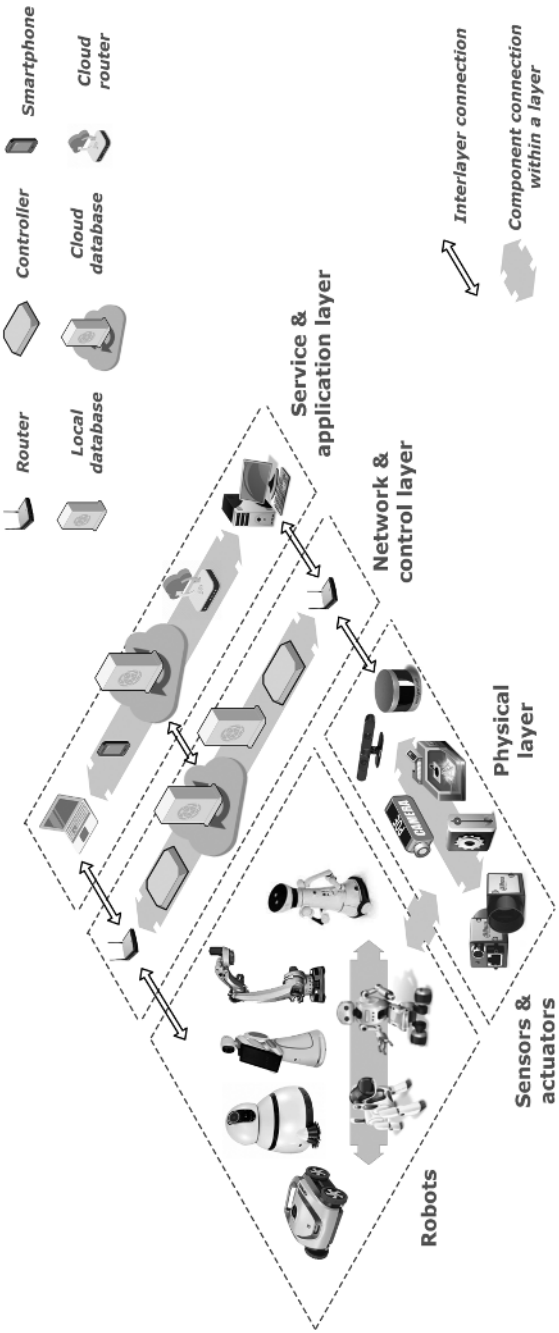


Figure 5: IoRT architecture (excerpt from Afanasyev et al., 2019).

Table 2: Roles of IoRT architecture layers.

Layer	Role
Physical	This comprises 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.

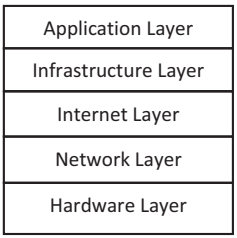


Figure 6: 5-layer IoRT architecture (source: Ray, 2016).

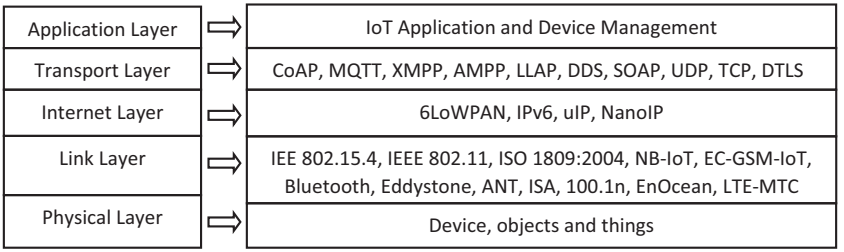


Figure 7: IoT communication protocol for IoRT application.

Some other layered and more detailed architectures of IoRT are given by Ray (2016) and Vermesan et al. (2017) as depicted in Figures 6 and 7 respectively. Table 3 describes the roles of these layers.

Table 3: 5-layer IoRT architecture (source: Ray, 2016).

Layer	Description
Hardware	This is the lowest layer of the abstract that comprises physical objects such as robots, sensors, actuators, and even smartphones.
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, Z-wave, etc.
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 topmost layer and provides the abstraction for configuring and programming the IoRT system to meet user-specific needs and requirements.

Applications of IoT, Robotics, and IoRT

Grieco et al. (2014) depicted an application framework, Figure 8, showing how IoRT can be utilized.

IoRT has found applicability in various domains. It is applicable in most of the areas where robots have been used and areas where IoT has also been applied separately. Application of IoRT creates smart environments which include: smart home and office; smart factory and smart city; healthcare; industry assembly lines; policing and military.

Grieco et al. (2014) presented a comprehensive scenario of IoRT in airport operation and management, highlighting the technological and computational requirements for the implementation of an airport (IoRT; see Figure 9). Robots in the IoT context can be made to man or assist humans in airport check-in, boarding, luggage, and security, and even manage emergencies.

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

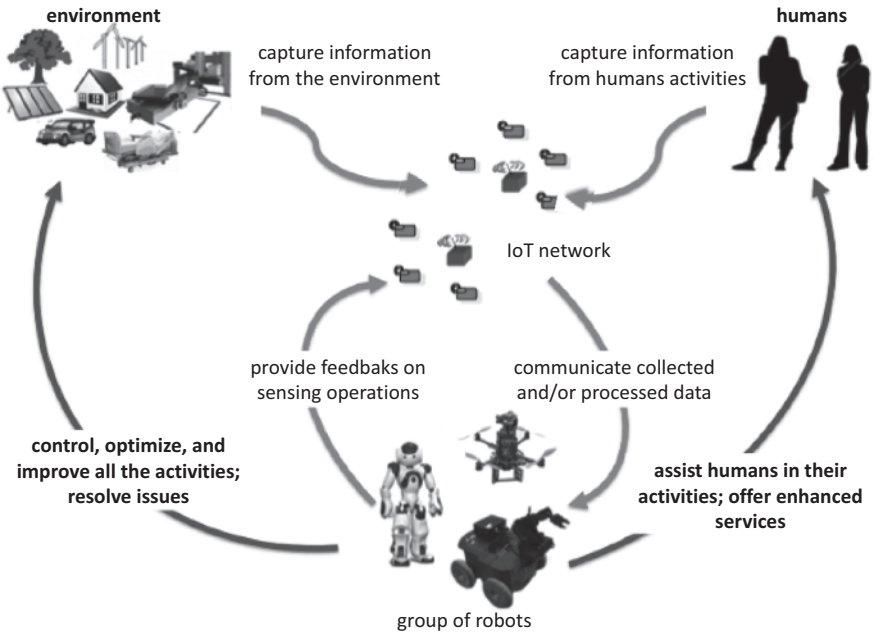


Figure 8: An application framework of IoRT (source: Grieco et al., 2014).

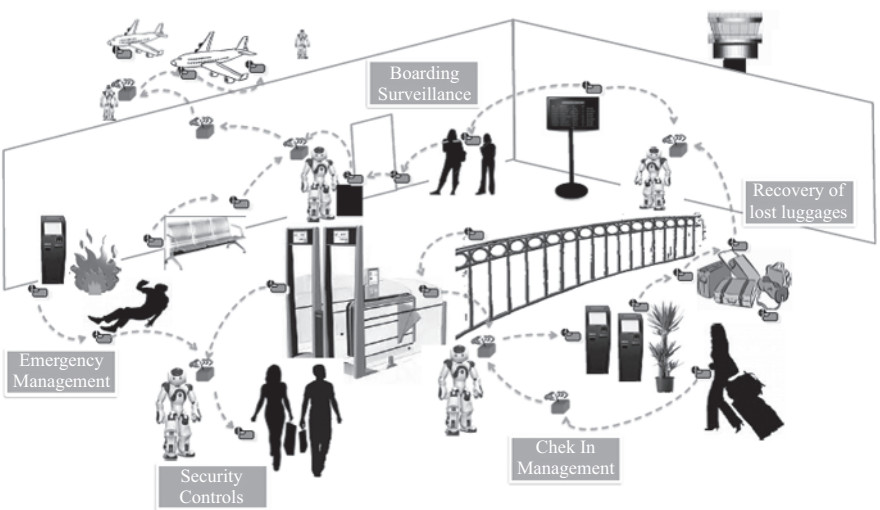


Figure 9: Smart Airport with IoT-aided robots (source: Grieco et al., 2014).

Academic Library System

The main services rendered by libraries can be viewed from two perspectives: mediating between users and information, and advisory services(Pew Internet, 2013; Qin, 2018). These can be further broken down into information sharing, cataloging, and providing bibliographic information to ease access to information and materials, making both traditional and online resources accessible in conventional settings and remotely via the internet. Furthermore, libraries and librarians are saddled with the responsibility of providing a conducive and equipped environment for library patrons as well as training them on the effective and efficient use of library collections.

Library stack management, as reported (Evans & Sweeney, 2005), involves the following functions:

(i) Developing collection storage master plans;
(ii) Developing storage standards;
(iii) Planning the acquisition of storage systems and the fitting out of storage spaces;
(iv) Monitoring collection growth in relation to storage capacity and layout;
(v) Planning collection moves;
(vi) Arranging the repair and replacement of storage equipment;
(vii) Managing the physical preparation of items to withstand shelf life;
(viii) Delivering and re-shelving requested items from storage, whether onsite or offsite and in public areas;
(ix) Tracking the location of collection items when they leave and return to the shelf;
(x) Ensuring the integrity of shelving order and sequences;
(xi) Identifying, analyzing, and resolving delivery failures; and
(xii) Continuously critiquing and improving storage and delivery systems.

As listed by Brown et al. (2006), the following are the activities in library collection storage:

(i) Strategic planning;
(ii) Measuring storage capacity;
(iii) Occupancy rates;
(iv) Monitoring and projecting growth of the collection;
(v) Adopting and using collection size standards;
(vi) Maintaining collection integrity;
(vii) Specifying storage equipment and layouts;
(viii) Procurement of storage equipment;
(ix) Installation of shelving; and
(x) Planning and managing collection relocations.

The advancement in the delivery of library services has been championed by the application of ICT in library systems. Tella et al. (2021) discussed the impact of ICT and identified the needed skills for librarians and ICT for professionals for the operation of modern library systems. This chapter is a contribution in this direction and proposes an IoRT model for library management.

IoT, Libraries, and Automation

In the Fourth Industrial Revolution (4IR), the Internet of Things (IoT) has been applied in several domains including smart environments (smart home, smart office, smart city, and smart industry – industry 4.0), healthcare, security and military, and the library is not an exception. Proposals for the automation of the various tasks of librarians have been made in the literature. This section presents some of these proposed models of IoT application in the library system and some applications of IoT in libraries.

Studies in IoT and Libraries

Fernandez (2015) examined how the IoT can facilitate library management given that it is a technology that most big IT companies such as Microsoft, AT&T, and DHL were investing in and developing; besides, it was projected that by 2019 the IoT would be the largest technology, creating over $1 trillion markets and impacting the way of life of businesses, homes, industries, healthcare, and even government.

The potentials of the IoT for library management were also examined by Pujar and Satyanarayana (2015) where the authors posited that the technology would add value to library services and improve the user experience of patrons. The areas of application of the IoT identified in the study included: accessing libraries and their resources; managing library collections; training library patrons; making recommendations to patrons based on interest; providing directions and location of resources to patrons; and managing library appliances and environmental conditions (e.g. temperature).

Hoy et al. (2015) discussed the concept of the IoT, its potential usage for library management, some major problems associated with IoT as a technology that could have an impact on its usage in the library, and highlighted some useful technologies that could enable IoT usage. The usage of IoT in the library could be seen in inventory control, mobile payments, ticketing and even registration, environment condition regulation, accessing resources easily, and the availability of

both content and physical facilities. The problems highlighted in the study include: security risk since the internet is susceptible to hacking and the IoT is not an attempt to mitigate it; it is an attempt to only bring in more "things" into the internet backbone besides the computer and its accessories; the problem of fragmented and slow progress due to lack of standardization of the technology since every IT company is independently developing its IoT platform and equipment to monopolize the market and make more profit; and the problem of social acceptance of the technology which does not necessarily solve the internet's problems but serves as another means for large tech companies to make more profits off users. The identified examples of devices/solutions that can enable the IoT in libraries include:

(i) Chui, a web-enabled doorbell that identifies visitors using facial recognition, which sends a video to house owners, and opens the door after verification. This solution is now christened truface (214 Technologies Inc., 2020).
(ii) Mimo, a technology that allows parents to monitor their babies through mobile devices, monitoring their sleeping and breathing status as well as body movement and even listening to them. The solution is no longer supported (https://www.mimobaby.com/).
(iii) Lion Tracking Collar, a technology by GROUND Lab that tracks the proximity of lions in Southern Kenya to safeguard herders and their herds without needing to kill the lions, thereby conserving wildlife(GROUND Lab, 2020).
(iv) GlowCap, a web-enabled and programmable device that reminds patients or users to take their medication as and when due. The caps fit onto pill bottles and produce both audio and visual reminders as programmed. It also has an automatic refill button and reminder as well (http://www.glowcaps.com).
(v) BiKN, a location finder that consists of the phone case and GPS for locating missing objects and even the phone as well, irrespective of the battery status. It is a system that allows iPhone users to track or relocate up to eight items at once (Coxworth, 2011).
(vi) Delphi Connect, a device designed for car tracking, engine diagnosis, and system control using smartphones. The device can be plugged into car diagnostic ports.

Nag and Nikam (2016) proposed a smart library architecture that is based on cloud computing, a magic mirror, and a pressure pad sensor that uses a wireless sensor network. Cloud computing provides remote access to services that would otherwise have to be hosted and maintained by users which is costly and demanding. Libraries can adopt cloud computing to access services such as access to online resources and repositories on a pay-as-you-go and subscription basis. The magic mirror consists of a display screen, a sensory device such as a camera,

and a server connected through a wireless sensor network. The sensory device can capture the image of books with patrons; the server processes the image and displays advisory information to patrons based on their book of interest. The pressure sensor pad is used to sense the presence of movement within the library facility to detect the presence of patrons and/or users. This information can be used to condition the room for users, for instance turning the lights and air conditioners on/off when users enter or leave facilities, thus saving energy. Figure 10 partly depicts the proposed architecture.

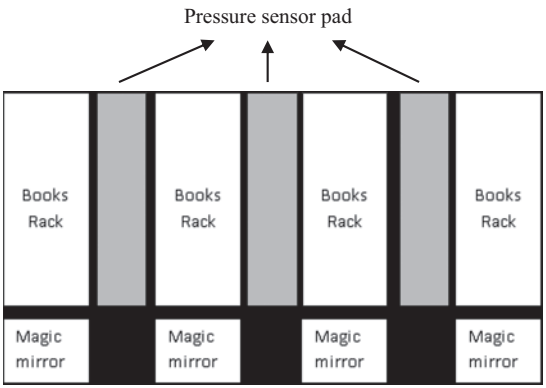


Figure 10: Nag and Nikam (2016) proposed smart library architecture.

Recommendation services based on user preferences and location within library buildings have also been studied and facilitated using the IoT. Hahn (2017) conducted a case study in which Bluetooth low energy (BLE) technology was used to implement inclusion of Bluetooth beacons in book stacks of an undergraduate library for a location-based recommender system. The system recommends online resources such as e-books and journals based on patrons' preferences and interests as they browse through stacks. The study showed the application and also implications of using IoT-based solutions in libraries – privacy and security issues were also highlighted. Also, Hahn (2018) implemented and evaluated an IoT navigation in library stacks and rooms to provide useful information that can guide decision-making by librarians to offer better services to patrons. IoT way finder and navigation support were evaluated through API log analysis. The analysis includes generating plots to show the locations of users within the library and how users search through library stacks. This information provides intelligent recommendations of library usage by patrons. Figure 11 is a heat map of a library showing the locations of users requesting a recommendation. According to the author:

"The heat map indicates the popularity of a specific section: the darker the red, the higher the number of points reported at that location, while a lighter blue indicates less popularity. A reveal filter of lighter areas is displayed for the location of recommendation support" (Hahn, 2018, n.p.).

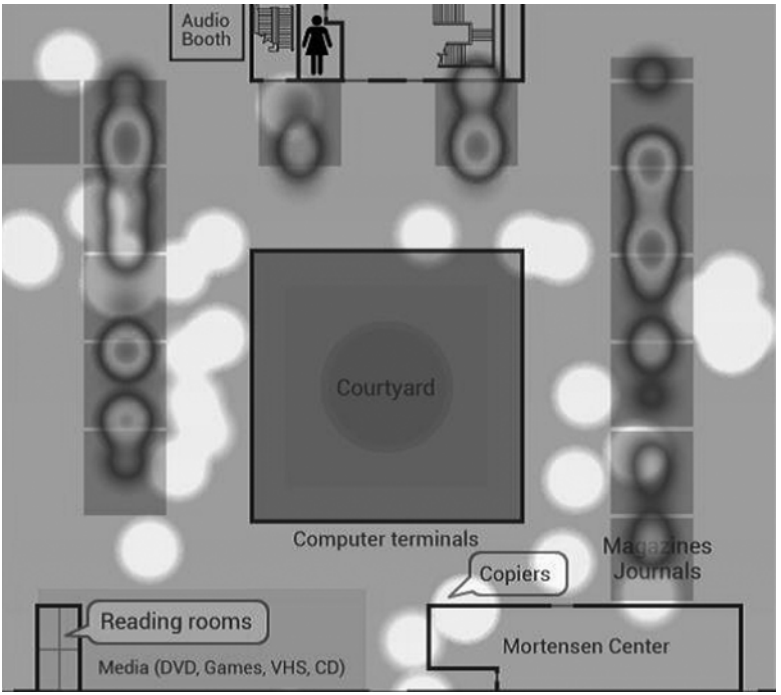


Figure 11: A heat map of the usage of the library (source: Hahn, 2018).

ICT and the IoT, in particular, are applicable in the automation of the two thematic areas of library services mentioned in section 4. Qin (2018) conducted a comparative analysis of the use of the IoT in commercial services with the range of modern libraries, and also IoT in commercial services with non-service library activities. The study identified five main areas of possible application of the IoT in library services and six areas of possible application in some other library services. Figure 12 depicts these areas.

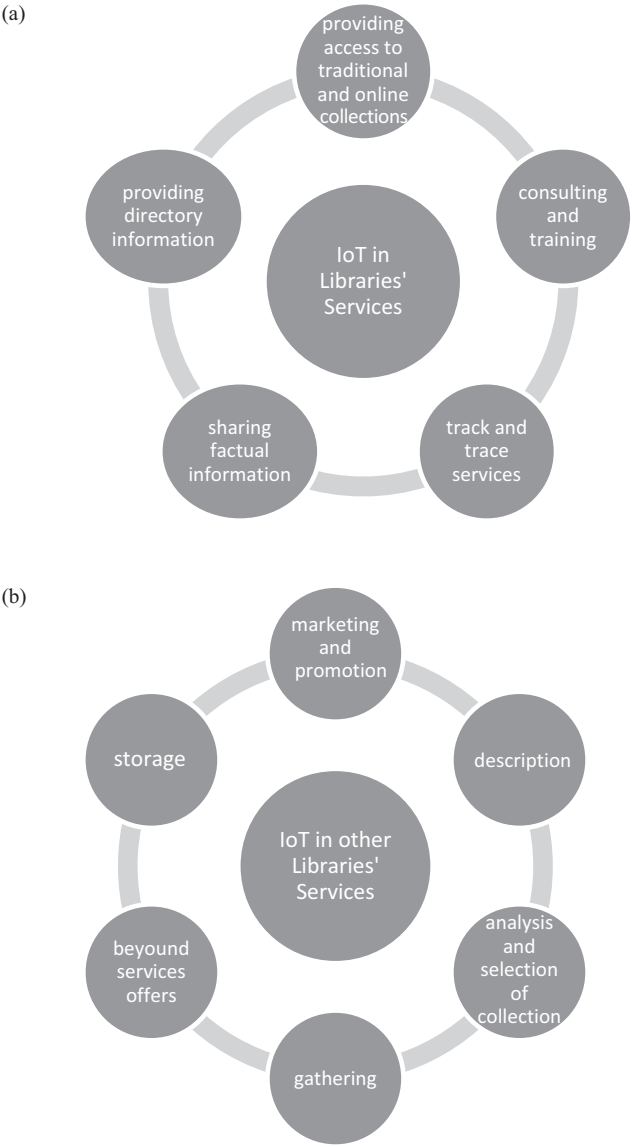


Figure 12: Applicability of IoT in libraries (a) core library services (b) auxiliary services (source: Qin, 2018).

The study listed specific areas where IoT is applicable in the libraries:
(i) tracking books;
(ii) organizing self-guided tours;
(iii) making interesting exhibits;
(iv) making contactless payments;
(v) checking the availability of equipment; and
(vi) providing detailed information on collections.

Wójcik (2016) examined the applicability of the IoT in library service delivery. The study identified the main areas in which IoT is used in commercial institutions and compared the findings with a profile of modern library services to see if the experience in the commercial institution can inspire the use of the IoT in modern libraries. The result of this analysis leads to the proposal of a theoretical model for the use of the IoT in libraries. Directory management and access to the collection can be revolutionized by the IoT. The main areas identified in the study where IoT is applicable include:
(i) searching locations of physical objects in the library
(ii) searching and location of electronic resources
(iii) providing advisory information based on users' preferences and interest
(iv) providing information and conducting training sessions
(v) managing library facilities and scheduling activities and patrons
(vi) facilitate the gathering, describing, analyzing, selection, and storage of resources in library stacks and stores

Ultimately, IoT will create smart environment for library operations.

Robots have also found usage in libraries. Pujari and Deosarkar (Pujari & Deosarkar, 2017) design an intelligent robotic library system that utilizes Wi-Fi, Zigbee, Radio Frequency Identification (RFID), barcode reader, infrared sensor, robotic arm and computer application. The automation and use of robot gives a platform for efficient and easy library management, reducing human mediation and thus, librarians can devote their time for other activities. The robotic arm can carry out the task of issuing out and returning collections efficiently. The computer application, using a database, coordinates the process of managing the library with the robotic arm. The wireless connection and identification components provide a unique identity for each of the objects (books and shelves) in the library and easy access to them for carrying out tasks such as library stack management.

Virtual/augmented reality has also been seen to be applicable in library automation. The existing implementation of augmented reality was lacking in context-awareness thus, Malhotra et al. (2014) and Shatte et al. (2014) proposed context-

aware solutions to library automation. Malhotra et al. (2014) proposed an augmented reality architecture for a context-aware library management system. The proposed system uses a unique visual code maker attached to the spine of books to provide access information about the books in the library. The architecture facilitates the efficient search for books within library collections by determining proximity to the book of interest. Shatte et al. (2014) developed an agent-based, mobile augmented reality prototype which was christened Libagent. The prototype facilitates collection sorting, searching and provides information about books and their whereabouts. The study experimentally determines the applicability and performance of the prototype and the results support the applicability of mobile augmented reality in managing the library.

Walsh (2011) examined the application of location-awareness technologies for the personalized learning environments in academic libraries. Among the technologies covered, the use of Quick Response (QR) codes at the University of Huddersfield was studied to determine its applicability. Others are the Global Positioning System (GPS) and RFID. The study observed that although QR codes can be used in libraries, RFID will give a better smart environment in libraries. While other experimental studies have considered the use of RFID, this study further considered using it for personalization of library environment in addition to stock circulation and control considered in other studies. Technologies, QR codes, and RFID, have their place in the smart library environment. Connecting print to electronic resources can be achieved using QR codes while RFID tags advisory services such as recommendation of books and providing comments on books. Also, personalized assistance, social networking and pick-up messages for library patrons can be implemented using RFID.

Employing Wi-Fi-based Local Positioning System (LPS) and Near Field Communication (NFC) tags, as well as an IoT smart library system that provides the functionality of locating and collecting books, was proposed by Brian et al. (Brian et al., 2014). The system uses the LPS to identify the location of any book of interest. This saves time in the searching for books from library stacks. Also, the system provides access to library catalogues; smart phones can be used to borrow and return library books. NFC tags in books, LPS, and users' smartphones communicate to locate the rack on which the book is located.

Markakis et al. (2013) experimentally designed low Specific Absorption Rate (SAR) smart bookshelves for the intelligent Library Management System (LMS) based on UHF passive RFID technology to replace a traditional barcode system. Antennas for communication were designed and tested in a library environment to maximize the readability of tags, localize items on the smart bookshelves, reduce spill-over energy to nearby shelves, and minimize SAR to library users. The system was evaluated to measure the radiation effect of near and far-field anten-

nas as well as cabinet and human interference and exposure to radiation. Also, the efficiency of book scanning was examined. The study showed that placing a microstrip antenna behind cabinet shelves reduces the spill-over electric field in the space of non-scanned shelves. IT also provides a good level of energy absorption by library patrons.

Khan et al. (2018) developed a graphical user interface (GUI) prototype, depicted in Figure 13, as a result of collecting the views of librarians and patrons through the Participatory Design (PD) approach. The prototyping includes the functionality of smart shelves, smart trolleys, and smartbooks. The study identified the main concerns of users (librarians and patrons) in the use and management of libraries. Some of the concerns include: searching and locating books, rendering help to users, managing patrons' book collections, and circulations. To address these challenges, applications on smart devices were suggested. The use of smart devices and objects in the library will reduce the problem associated with book tracking, misplacement, and loss by making the objects communicate their location and status. Data generated from the connections and communication can be employed by a data analytics system for managerial decision making.



Figure 13: GUI prototype of the smart library management system (source: Khan et al., 2018).

Patel (2019) proposed an energy-saving system that uses sensors and NodeMCU (an open-source IoT platform) to detect the presence of users in the library and control the usage of energy in the environment. Two sensors, passive infra-red (PIR) and a light-dependent resistor (LDR), are used for detecting the presence of humans and regulate electricity flow. The presence of the user triggers the switching on or off of electrical appliances such as fans and the source of power for user systems within the library room. The study implemented the proposed system and measured performance. The system reduces the wastage of energy by 41%.

Several other studies in IoT-based solutions for library management include Li et al. (2016) who designed and implemented an IoT-based system for library materials management using an android-based UHF mobile reader to facilitate resource management. Figure 14 depicts the architecture used in developing the system. The functions provided by the system include user authentication, inventory management, provision of self-help service to patrons, and resource searching, borrowing/lending, and return, as well as providing security assistance to librarians.

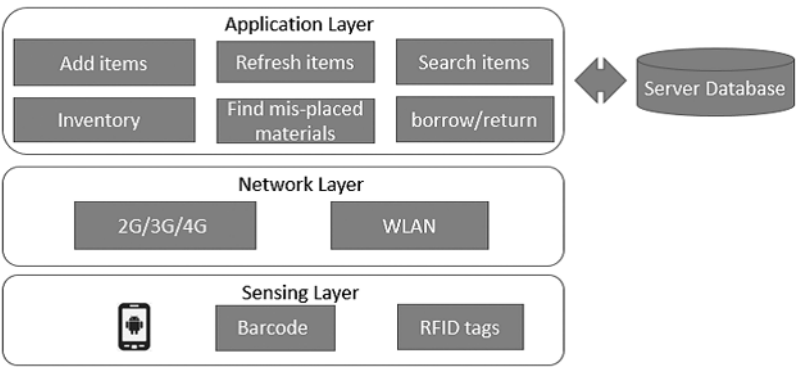


Figure 14: Library materials management system architecture (source: Li et al., 2016).

Renold and Rani (2013) developed a library management system (LMS) using a Motorola MC9090 with a RFID reader and tag with a unique electronic product code (EPC) to monitor and identify library patrons and resources within the library facility. This solution is implemented with a mobile app and can help in locating misplaced library resources, facilitating stack maintenance, and monitoring movement of library patrons and resources within the library, thereby enhancing the ease of access to resources, reducing the work required by the librarian to maintain library resources, and stacks. Figure 15 presents the architecture of the proposed solution.

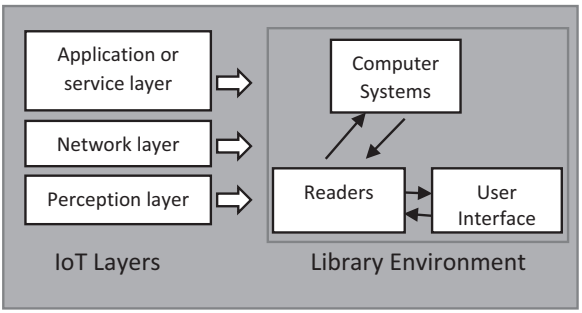


Figure 15: The architecture of RFID LMS by Renold and Rani (Renold & Rani, 2013).

Li (2014) also discussed how RFID can be used to provide an optimized library business process system for user self-servicing and a smart system for library management based on IoT. The system provides the following features in the library: self-borrowing, self-returning, smart inventory, intelligent query, a combination of books, and information system.

Noh (2015) determined the features of a Library 4.0 based on an extensive study of the concept and the applicability of web 4.0 to the library. The study proposed a library 4.0 model that can be adapted for different libraries. Some of the features of library 4.0, which are based on web 4.0, presented in the study are: intelligence-based, massive data processing, augmented reality, context-aware, cutting-edge displays, and infinite creative space. The study also identified the terminology for explaining library 4.0: intelligent agent, makerspace, context-aware technology, open-source, big data, cloud service, augmented reality, state-of-the-art display, and librarian 4.0. The study provides a foundation for future studies in and implementation of Library 4.0.

Besides the application of the IoT in the physical libraries and its resource management, the digital library (DL) has also been considered for IoT integration. DLs have distributed software infrastructures designed for the collection, usage, and management of digital resources as well as providing specialized services to users (Fortino et al., 2016). Fortino et al. (2016) discussed the integration of smart objects into DL besides the current resource types, such as text document, image, audio, video, and software. The study described a meta-model for cyber-physical smart object seamless integration into DL which complies with the DL reference model by the DL.org community. This integration is demonstrated through a case study conducted by the authors. Mohideen et al. (2017) discussed the evaluation of the quality of service (QoS) in a DL with emphasis on library information systems and RFID frameworks.

Stefanidis and Tsakonas (2015) used the SELIDA framework, an integration layer of standardized services that use the IoT for item traceability in library set-

tings using RFID (see Figure 16). The framework aims to provide tracing of RFID-tagged physical items among or within various libraries. The framework was used to implement library services such as checking in and out of library resources at different library facilities, as well as running different integrated library systems with few changes in the system. The study presented two case studies to demonstrate the implementation.

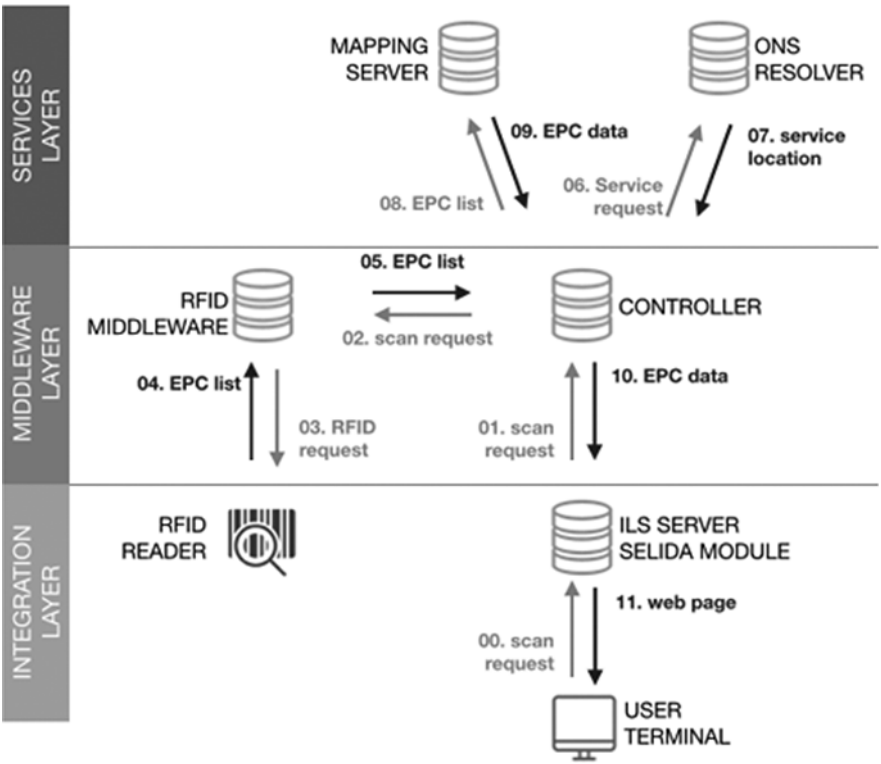


Figure 16: The architecture of the SELIDA framework (source: Stefanidis and Tsakonas, 2015).

Sheeja and Susan (2019) conducted a literature review of the IoT in academic libraries and identified the areas of library operations and management where the technology is applicable: (i) smart library building that includes optimal energy usage, environmental condition (temperature and lighting) regulation, and safety and security(Sun, 2014; Nie, 2017; Du & Liu, 2014); (ii) personalized services in which users are given recommendations based on their interests, preferences, and usage history (Wójcik 2016); (iii) locating books and other materials as dis-

cussed in Brian, Arockiam, and Malarchelvi (2014); (iv) library orientation and literacy to familiarize new patrons on the use of library; IoT can facilitate this education program; (v) smart circulation control where patrons can be informed of library holdings and the due dates in order to avoid payment of fines for late return; and (vi) inventory control where library resources can be traced in case of misplacement and/or mis-shelving.

Given that the IoT is an extension of the internet to include other things, it inherits the security and vulnerability issues associated with the internet. Library adoption of the IoT platform has also shown concern about the security and vulnerability of library patrons and their devices. A study by (Chickowski, 2014, n.p.) showed that "Nine out of 10 devices collected at least one piece of personal information through the device or related cloud or mobile app; and six of the devices had user interfaces vulnerable to a range of web flaws." To address this issue, libraries and librarians must continually be informed of IoT security issues and updates and educate their patrons on vulnerabilities and possible measures to mitigate them in the library settings (Massis, 2016).

Applications of the IoT in Libraries

Some of the real-life applications of the IoT in libraries are presented in this section. This is besides other applications of IoT in libraries that are at the experimental stage and yet to be published.

1. The iBeacon Application

BluuBeam and Capira technologies' application provides context awareness and a searching function to users in an easily comprehensible form. This application is built on iBeacon technology launched by Apple and it functions by sending information and location of items to patrons through their mobile devices and even makes recommendations based on their preferences. Over 30 libraries and museums, among which are the Orlando Public Library and the Orange County Library system, have implemented the application. Spotzer is another technology that uses the iBeacon technology for creating location-aware museums and libraries.

BluuBeam's technology comprises beams: lightweight, hockey puck-sized iBeacons that libraries can place in different strategic locations within their buildings. For instance, the Orange County Library System has 25 beams in its branches.

Although patrons were initially skeptical about the use of the application due to the requirement to allow identifying of user location, the ease of accessing resources and provision of valuable information by the app has made patrons willing to use it (Price, 2015).

2. Caper Technologies Solution

Caper technologies also applied the iBeacon technology for libraries but in a different context of using the internet provider of the libraries and enabling integration of mobile applications with existing library systems. The provided application can be tailored to the individual needs of the library, providing other functionalities such as patrons being able to receive notifications on their library account, being notified of library events, and being able to search directories.

To conclude this section, Figure 17 presents the taxonomy of the areas of IoT application in the library. It categorizes the areas into two: the library and librarians' functions and the patrons' functions.

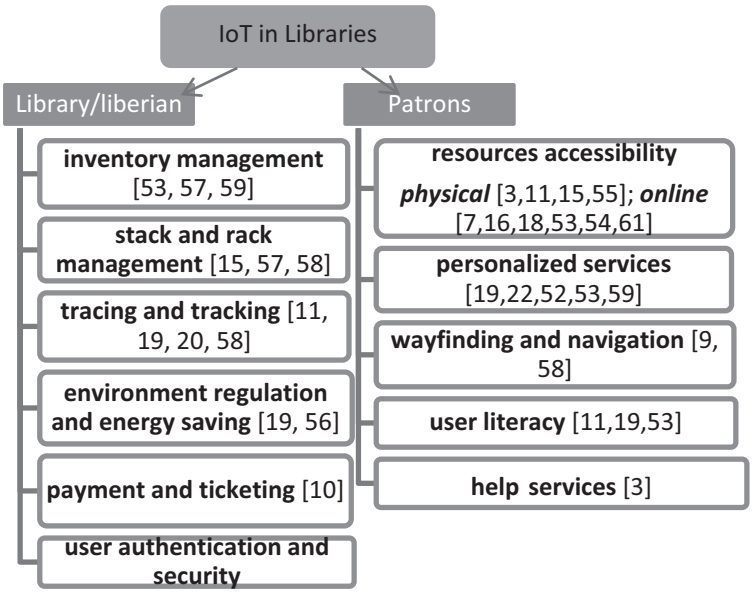


Figure 17: A taxonomy of the areas where the IoT is used in libraries.

Proposed IoRT-Library Model

Haven seen the application of IoT in library operations and management on one hand, and the integration of IoT and robotics technologies for a smarter and more efficient operation context on the other, the application of IoRT in the library is very much at hand. Robots, both humanoid and others, will be used in

both autonomous and assistive capacity to operate and manage the physical as well as the digital libraries. Robots in conjunction with smart library collections, smart shelves, and racks will form an IoRT environment for the efficient and effective operation of libraries.

In the context of IoRT, the functions that can be performed by robots in conjunction with other "things" include:

(i) Collection management: placement of books on shelves and racks can be handled by robots. This will prevent the misplacement of books. Robots can be made to scan through library rooms to detect books dropped on tables after use by patrons and then move the books back to the shelf at the appropriate position. Such re-shelving tasks can be done periodically or autonomously by the robots. The latter will ensure that the shelves are optimally kept balanced at all times, i.e. books and materials are always kept at designated positions on the shelve racks–this will ensure availability for the next users.

(ii) Resource accessibility and personalized services: through senses, scanning, or reading EPC on RFID, QR codes, or barcodes, robots can discern the interest of visiting patrons as they walk into library buildings and thus can direct them to the rooms or floor where they can access related resources and easily get help. It will be interesting to see a robot physically accompanying a patron to where the book s/he requires or to the room where more related resources are placed.

(iii) Environment regulation and energy saving: robots can scan through library rooms to detect the presence or absence of patrons and/or librarians and regulate the environmental conditions such as temperature and light by sending a signal to the air conditioner and light switches to turn on when users are present or turn off when the room is empty. This process can be further enhanced by the robots measuring the proximity of users to the air conditioners and lights to determine which of the conditioners or lights in the room should be turned on. This will cutdown on the energy consumption of the library.

(iv) User authentication and access control: robots and smart objects can authenticate users as they access library facilities through ID scanning and facial recognition; users' IDs are sensed and checked against library databases. Also, access to restricted areas can be monitored and invites to sessions in the library can be authenticated through role-based access control (RBAC).

Figure 18 presents a representation of the theoretical framework for the application of IoRT in the library. The robots are autonomous and are connected to other smart things in the library such as smart shelves, smartbooks, and other resour-

ces, both physical and online. The reading rooms/sections can be manned by robots to ensure shelve balancing (i.e. books are always in the designated positions when not in use by patrons and within the library building) and room conditioning by regulating the temperature and lighting. Furthermore, these robots can be used for safety purposes. The borrowing, returning, and re-shelving of books can also be manned by robots. Access to information, help, and the physical and digital resources can be handled by robots in the IoRT environment.

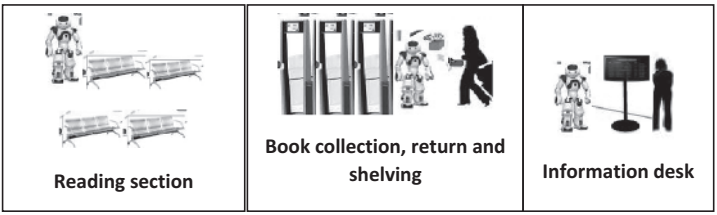


Figure 18: A theoretical framework for IoRT in Libraries.

Conclusion

The Internet of Things and robotics have been used in the automation of library operation and management just like in other domains such as smart environment, manufacturing, military, and security –although not as extensive in these other areas. However, the 4IR and also the integration of the IoT and robotics into IoRT have brought about a new paradigm for better and smarter automation. The library can leverage this integration to enhance its operation and management. Robots in conjunction with other things can autonomously manage library collections; facilitate easy access to resources and facilities based on patrons' interest; and regulate the library environment's temperature and lighting, thereby saving energy through its optimal use, as well as security and access control. Besides giving the taxonomy of the application of the IoT in the library, this chapter also proposed a theoretical framework for this application of IoRT in the library.

Further studies will involve the experimentation of IoRT in a library and collecting empirical data to evaluate the cost-benefit of the application of the technology.

References

214 Technologies Inc. (2020). Truface: The world's leading computer vision solution. https://trueface.ai/

Abo-Seada, A. A. (2019). The impact of the Internet of Things on libraries and users. *Computers Libraries*. http://www.infotoday.com/cilmag/jan19/Abo-Seada–The-Impact-of-the-Internet-of-Things-on-Libraries-and-Users.shtml

Abuarqoub, A., Abusaimeh, H., Hammoudeh, M., Uliyan, D., Abu-Hashem, M. A., Murad, S., Al-Jarrah, M., & Al-Fayez, F. (2017). A survey on Internet of Things enabled smart campus applications. In *International Conference on Future Networks and Distributed Systems (ICFNDS)* (pp. 1–7). Association for Computing Machinery (ACM). https://doi.org/10.1145/3102304.3109810

Adams, S., Peltria, E., & Kostyukov, D. (n.d.). Meet Zora, the robot caregiver. *The New York Times – Technology*. https://www.nytimes.com/interactive/2018/11/23/technology/robot-nurse-zora.html

Afanasyev, I., Mazzara, M., Chakraborty, S., Zhuchkov, N., Maksatbek, A., Yesildirek, A., Kassab, M., & Distefano, S. (2019). Towards the Internet of Robotic Things: Analysis, Architecture, Components and Challenges. *Proceedings – International Conference on Developments in ESystems Engineering, DeSE* October-20: 3–8. https://doi.org/10.1109/DeSE.2019.00011

Agra, A., Christiansen, M., Ivarsøy, K. S., Solhaug, I. E., & Tomasgard, A. (2017). Combined ship routing and inventory management in the salmon farming Industry. *Annals of Operations Research*, vol. 253, pp. 799–823, https://doi.org/10.1007/s10479-015-2088-x

Bader, F., & Rahimifard, S. (2020). A methodology for the selection of industrial robots in food handling. *Innovative Food Science & Emerging Technologies*, *64* (102379). https://doi.org/https://doi.org/10.1016/j.ifset.2020.102379

Bansal, A. (2018). Internet of Things: Beginning of new era for libraries. *Library Philosophy and Practice* (e-journal). 2081. http://digitalcommons.unl.edu/libphilprac/2081

Brian, A. L. A., Arockiam, L., & Malarchelvi, P. D. S. K. (2014). An IOT based secured smart library system with NFC based book tracking. *International Journal of Emerging Technology in Computer Science & Electronics (IJETCSE)*, *11*(5), pp. 18–21.

Brown, J., Morley, T., & Salter, L. (2006). Council of Australian state libraries (CASL) working group on stack management: Guidelines for planning collection storage of physical collections. *Library Collections, Acquisitions, and Technical Services*, *30* (1–2): 85–101. https://doi.org/https://doi.org/10.1016/j.lcats.2004.12.002

Cheng, H., Huang, L., Xu, H., Hu, Y., & Wang, X. A. (2016). Design and implementation of library books search and management system using RFID technology. In *Proceedings – 2016 International Conference on Intelligent Networking and Collaborative Systems, IEEE INCoS 2016* (pp. 392–397). https://doi.org/10.1109/INCoS.2016.35

Chickowski, E. (2014). Internet of Things contains average of 25 vulnerabilities per device. *Information Week*. www.darkreading.com/vulnerabilities–threats/internet-of-things-contains-average-of-25-vulnerabilities-per-device/d/d-id/1297623%0AMorgan

Cirani, S., Picone, M., Veltri, L. (2015). mjCoAP: An Open-Source Lightweight Java CoAP Library for Internet of Things Applications. In: Podnar Žarko, I., Pripužić, K., Serrano, M. (eds) Interoperability and Open-Source Solutions for the Internet of Things. Lecture Notes in Computer Science(), vol 9001. Springer, Cham. https://doi.org/10.1007/978-3-319-16546-2_10

Coxworth, B. (2011). BiKN uses iPhone to keep track of your stuff . . . or kids. *New Atlas*. https://newatlas.com/bikn-iphone-tracking-system/20497/

Du, L., & Liu, T. (2014). Study on the development of smart library under Internet of Things. *Applied Mechanics and Materials*, *529*, 716–720. https://www.scientific.net/AMM.529.716

Evans, H., & Sweeney, G. (2005). Defining stack management. *Library Collections, Acquisitions, and Technical Services*, *29*(1), 51–60. https://doi.org/https://doi.org/10.1016/j.lcats.2004.12.002

Fernandez, P. (2015). Through the looking glass: Thinking through the Internet of Things. *Library Hi Tech News*, *32*(5), 4–7.

Fortino, G., Rovella, A., Russo, W., Savaglio, C. (2016). Towards Cyberphysical Digital Libraries: Integrating IoT Smart Objects into Digital Libraries. In: Guerrieri, A., Loscri, V., Rovella, A., Fortino, G. (eds) Management of Cyber Physical Objects in the Future Internet of Things. Internet of Things. Springer, Cham. https://doi.org/10.1007/978-3-319-26869-9_7

Gawli, K., Karande, P., Belose, P., Bhadirke, T., Bhargava, A., & Atharva College. (2017). Internet ofThings (IOT) based robotic arm. *International Journal of Engineering Research & Technology*, *5*(1), 757–759.

Grieco, L. A., Rizzo, A., Colucci, S., Sicari, S., Piro, G., Di Paola, D., & Boggia G. (2014). IoT-Aided robotics applications: Technological implications, target domains and open issues. *Computer Communications*, *54*, 32–47. https://doi.org/10.1016/j.comcom.2014.07.013

GROUND Lab. (2020). Open Source Lion Tracking Collars. http://home.groundlab.cc/about.html.

Ha, Q. P., Yen, L., & Balaguer, C. (2019). Robotic autonomous systems for earthmoving in military applications. *Automation in Construction*, *107*. https://doi.org/https://doi.org/10.1016/j.autcon.2019.102934

Hahn, J. (2017). The Internet of Things: Mobile technology and location services in libraries. *Library Technology Reports*, *53*(1), 1–27. https://go.gale.com/ps/anonymous?id=GALE%7CA485670905&sid=googleScholar&v=2.1&it=r&linkaccess=abs&issn=00242586&p=AONE&sw=w

Hahn, J. (2018). The bibliotelemetry of information and environment: An evaluation of IoT-Powered recommender systems. *Proceedings of the Association for Information Science and Technology*, *55*(1), 151–160. https://doi.org/10.1002/pra2.2018.14505501017.

Hoy, M. B., Brigham, T. J., Column Editors, & Hoy, M. B. (2015). The "Internet of Things": What it is and what it means for libraries. *Medical Reference Services Quarterly*, *34*(3), 353–358. https://doi.org/10.1080/02763869.2015.1052699

Jabbar, S., Ullah, F., Khalid, S., Khan, M., & Han, K. (2017). Semantic interoperability in heterogeneous IoT infrastructure for healthcare. *Wireless Communications and Mobile Computing*. https://doi.org/10.1155/2017/9731806.

Kaladhar, A., & Somasekhara Rao, K. (2017). Internet of Things: A route to smart libraries. *Journal of Advanceents in Library Sciences*, *4*(1), 29–34.

Khan, R. H., Sohrforouzani, M. A., & Lundman, M. (2018). Developing a prototype for IoT enabled library management system by applying participatory design approach. DOI:10.13140/RG.2.2.24000.02567

Li, D. Y., Xie, S. D., Chen, R. J., & Tan, H. Z. (2016). Design of Internet of Things system for library materials management using UHF RFID. In *2016 IEEE International Conference on RFID Technology and Applications, RFID-TA 2016* (pp. 44–48). IEEE. https://doi.org/10.1109/RFID-TA.2016.7750755

Li, L. (2014). Designing and implementation of university library automatic management system based on the Internet of Things. In *Lecture notes in computer science (including subseries lecture notes in artificial intelligence and lecture notes in bioinformatics)*, 8351 LNCS (pp. 241–247). https://doi.org/10.1007/978-3-319-09265-2_25

Malhotra, N., Singh, A., Divyakrishna, J., Saini, K., & Gupta, N. (2014). Context-aware library management system using augmented reality. *International Journal of Electronic and Electrical Engineering*, *7*(9), 923–929. http://www.irphouse.com.

Markakis, I., Samaras, T., Polycarpou, A. C., & Sahalos, J. N. (2013). An RFID-enabled library management system using low-sar smart bookshelves. In *Proceedings of the 2013 International*

Conference on Electromagnetics in Advanced Applications, ICEAA 2013 (pp. 227–230). https://doi.org/10.1109/ICEAA.2013.6632228

Massis, B. (2016). The Internet of Things and its impact on the library. *New Library World*, *117*(3), 289–292. https://doi.org/10.1108/NLW-12-2015-0093

Miorandi, D., Sicari, S., De Pellegrini, F., & Chlamtac, I. (2012). Internet of Things: Vision, applications and research challenges. *Ad Hoc Networks*, *10*(7), 1497–1516. https://doi.org/10.1016/j.adhoc.2012.02.016

Mohideen, Z. A., Kiran, K., & Muhamad, S. (2017). IoT: QoS in the digital library RFID based LIS. In *Proceedings of the 5th international conference on information and education technology* (pp. 101–105). ACM. https://dl.acm.org/doi/abs/10.1145/3029387.3029398

Nag, A., & Nikam, K. (2016). Internet Of Things applications in academic libraries. *International Journal of Informational Technology and Library Science*, *5*(1), 1–7.

Nie, W. (2017). The application of internet of things in the university library. In *Proceedings of the 2016 7th International Conference on Education, Management, Computer and Medicine* (pp. 24–27).

Noh, Y. (2015). Imagining Library 4.0: Creating a model for future libraries. *The Journal of Academic Librarianship*, *41*(6), 786–797. https://doi.org/10.1016/j.acalib.2015.08.020

Patel, M. A. (2019). Occupancy driven smart energy saving system for institute library Using IoT. In C. Pandy & S. Boricha (Eds.), *Librarianship development through Internet of Things and customer service* (p. 375). Gujarat Power Engineering and Research Institute ISBN: 978-93-5346-325-0.

Pew Internet. (2013). Library services in the digital age. https://www.pewresearch.org/internet/2013/01/22/library-services/

Price, G. (2015). The Internet of Things Plan To Make Libraries and Museums Awesomer. Available online at: https://www.infodocket.com/2015/01/07/orlando-the-internet-of-things-plan-to-make-libraries-and-museums-awesomer/

Pujar, S., & Satyanarayana, K. V. (2015). Internet of Things and libraries. *Annals of Library & Information Studies*, *62*(3), 186–190.

Pujari, T. S., & Deosarkar, S. B. (2017). Design of intelligent and robotic library system. In *Recent Trends in Electronics, Information & Communication Technology (RTEICT), 2017 2nd IEEE International Conference* (pp. 1903–1908.

Qin, J. (2018). The research of the library services Based on Internet of Things. In *Advances in Social sciences, education and humanities research* (pp. 412–420). Dordrecht, The Netherlands: Atlantis Press. https://doi.org/10.2991/isss-18.2018.83

Ray, P. P. (2016). Internet of robotic things: Concept, technologies, and challenges. *IEEE Access*, *4*, 9489–9500. https://doi.org/10.1109/ACCESS.2017.2647747

Renold, A. P., & Rani, R. J. (2013). An internet based RFID Library management system. In *2013 IEEE Conference on Information and Communication Technologies, ICT 2013* (pp. 932–36). IEEE. https://doi.org/10.1109/CICT.2013.6558229

Rose, D. (2014). *Enchanted objects: Design, human desire, and the internet of things*. Simon and Schuster. New York, NY : Scribner, https://books.google.com/books?hl=en&lr=&id=PkH6AwAAQBAJ&oi=fnd&pg=PR11&dq=David+Rose,+author+of+Enchanted+Objects+and+researcher+at+the+MIT+Media+Lab&ots=0IClQpCq_6&sig=y_DgTw3sLMfInSGPIPjEGFI1qrg

Rowland, C., Goodman, E., Charlier, M., Light, A., & Lui, A. (2015). *Designing connected products: UX for the consumer Internet of Things*. Sebastopol, CA 95472: O'Reilly Media, Inc., ISBN:978-1-4493-7256-9.

Sethi, P., & Sarangi, S. R. (2017). Internet of Things: Architectures, protocols, and applications. *Journal of Electrical and Computer Engineering*, 1–25. https://doi.org/10.1155/2017/9324035

Shatte, A., Holdsworth, J., & Lee, I. (2014). Mobile augmented reality based context-aware library management system. *Expert Systems with Applications*, *41*(5):,2174–2185.

Sheeja, N. K., & Susan, M. K. (2019). Internet of Things (IoT) in academic libraries. In *12th International CALIBER-2019 KIIT, Bhubaneswar* (pp. 45–51).

Siciliano, B., et.al. (2010). Robotics: Modelling, planning and control. In *Springer Science & Business Media* (pp. 22–23), Springer, ISBN: 9781849966344.

Simoens, P., Dragone, M., & Saffiotti, A. (2018). The Internet of Robotic Things: A review of concept, added value and applications. *International Journal of Advanced Robotic Systems*, *15*(1), 1–11. https://doi.org/10.1177/1729881418759424

Stefanidis, K., & Tsakonas, G. (2015). Integration of library services with Internet of Things Technologies. *Code4Lib Journal*, *30*. https://journal.code4lib.org/articles/10897

Sun, M. (2014). The research on the development of smart library. *Applied Mechanics and Materials*, *571*: 1184–1188. https://www.scientific.net/AMM.571-572.1184

Tella, A., Bajeh, A. I., Titilola, O. O., & Ayodeji, A. Y. (2021). Librarians and Information technology professionals skills need for sustainability at the advance information technology era. In *2nd International Conference on ICT for National Development and Its Sustainability (ICT4NDS2021)* (pp. 23–34). https://ijipc.com.ng/index.php/ijipc/article/view/513/281

The Prism Group. (2020). Appbot-LINK smart home security robot. https://iot.do/devices/appbot-security-robot

Tzafestas, G. S. (2018). Synergy of IoT and AI in modern society: The robotics and automation case. *Robotics & Automation Engineering Journal*, *3*(5). https://doi.org/10.19080/raej.2018.03.555621

Vermesan, O., Bröring, A., Tragos, E., Serrano, M., Bacciu, D., Chessa, S., Gallicchio, C., Micheli, A., Dragone, M., Saffiotti, A., Simoens, P., Cavallo, F., Bahr, R. (2017). Internet of Robotic Things – Converging Sensing/Actuating, Hyperconnectivity, Artificial Intelligence and IoT Platforms. In Cognitive Hyperconnected Digital Transformation. eBook ISBN: 9781003337584. pp. 97–155. Rivers Publisher.

Walsh, A. (2011). Blurring the boundaries between our physical and electronic libraries. *The Electronic Library*, *29*(4), 429–437. https://doi.org/https://doi.org/10.1108/02640471111156713

Wójcik, M. (2016). Internet of Things–Potential for libraries. *Library Hi Tech*, *34*(2), 404–420.

Xu, Q., Xin, X., Guo, L. F., Ming, J. G., & Luan, W. (2019). Design of intelligent campus multimedia interactive system based on Internet of Things technology. In *Proceedings – 2019 International Conference on Virtual Reality and Intelligent Systems, ICVRIS 20191* (pp. 223–226). https://doi.org/10.1109/ICVRIS.2019.00062

Yushi, L., Fei, J., & Hui, Y. (2012). Study on application modes of military internet of things (Miot). In *IEEE International Conference on Computer Science and Automation Engineering (CSAE), Vol 3* (pp. 630–634). IEEE.