RFID-Based Indoor Positioning Technologies – Where Are We?

Yuntian Brian Bai
SMGS, RMIT University, Australia
yuntianbrian.bai@rmit.edu.au

Bin Hu
SMGS, RMIT University Australia
s3269490@student.rmit.edu.au

***Abstract*—Radio frequency identification (RFID) is an emerging technology that forms an essential part of ubiquitous positioning. For many years, it has been predominantly employed for tracking goods in supply chains. Recently, its usages have rapidly extended into manufacturing, defence, retail and many other application fields, for the purposes of people identification, suppliers monitoring and payment processing etc. RFID has been regarded as a core technology for indoor positioning due to its capability of wireless communication. However, the development and implementation of RFID technology has been so fast nowadays that the assessment of the techniques could hardly keep up with the pace of technical evolution. This paper presents an overview of various state-of-the-art RFID techniques and applications, with specific relevance to the field of indoor positioning. The latest performance parameters and advanced characteristics of the technology such as the ranging capability, system miniaturisation and robust multi-sensor integration are investigated, and selected novel applications and the future trends of RFID-based indoor positioning techniques are also discussed The results will be beneficial for researchers, industrial and other end users to better understand and innovatively use the technology.**

Keywords—RFID; indoor positioning; LBS; RFID solution; technology review

I. INTRODUCTION

Radio Frequency Identification (RFID) is an emerging technology that uses radio waves to transmit the identity of an object wirelessly in the form of a unique serial number [1]. RFID is similar to barcode identification systems, however, RFID does not rely on the line-of-sight reading that barcode scanning requires. Instead, RFID enables wireless data collection by readers from electronic tags attached or embedded in objects, which allows RFID to be used in harsh or dirty environments that may limit barcodes and 2D symbols for identification and/or other purposes [2, 3]. RFID technology was commercially available in 1980s and its wider spread usage was only in recent years, and it is often referred to as the Internet of things (IoT) for ubiquitous connectivity. The research and developments of RFID are broad and fast, however, the impact still exists, especially in standards development, security compliance and privacy concern [4]. The implementation of RFID requires diligent assessment of the need for RFID solutions in particular organisations. Therefore, it is important that these technologies are explored and reviewed in order to maximise the potential benefits of RFID and reduce the risk of its implementation.

II. OVERVIEW OF RFID TECHNOLOGY

2.1 History of RFID Development

RFID technology was first used by Britain to identify aircraft in the Second World War as part of the refinement of radar. It was during the 1960s that RFID was first considered as a solution for the commercial world. The first commercial applications involving RFID were in 1970s and 1980s and these applications were concerned with identifying some asset inside a single location. In 1998, researchers at the Massachusetts Institute of Technology (MIT) Auto-ID Center began to investigate new ways to track and identify objects while they were moving between physical locations, when is it considered as the third era of RFID [5]. Since the year of 2000, RFID has experienced a rapid evolution and broad implementation throughout the economy. It has been becoming a worldwide and fast-moving technology, and being proposed and combined with other ongoing technologies worldwide. Nowadays, there are a variety of technical solutions ranging from simple, inexpensive, and common to those with more functionality, better performance and more cost. As intelligent RFID technologies continue to develop, in conjunction with intelligent sensor technologies, RFID is becoming one of the core technologies for the IoT [5].

2.2 Principles of RFID technology

RFID technology is an emerging technology for mobility tracking of objects or people. There are mainly three types of

RFID systems: passive, semi-passive and active systems [6]. A typical RFID system contains tags (also referred to as transponders, smart tags, smart labels, or radio barcodes), readers/writers (with antennas), and a host computer and software/infrastructure. The readers and the host computer communicate through either a wire or wireless link.

Fig. 1 shows the principles of the work of a typical passive RFID system [1, 7-9]. Passive tags rely entirely on the reader as their power source. Radio signals are sent from a reader, a tag will be powered on by the signals when it enters the signal field of the reader, the reader captures an ID plus data transmitted from the tag and sends the data to the host computer. The computer, with RFID middleware installed on, processes the data and sends them back to the reader, the reader then transmits the processed data to the tag. Passive tags have no battery embedded and are normally used for applications in a shorter reading range.

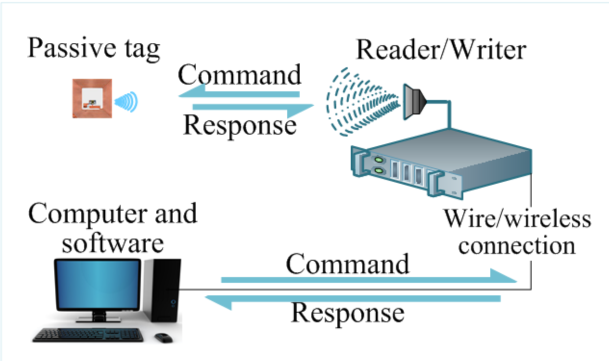

Figure 1. A typical passive RFID system

The principles of an active RFID system are slightly different from a passive system as shown in Fig. 2. An active RFID system usually uses active RFID tags and each tag periodically transmits its data which may contain information of identification, location, price, colour, and date of purchase. The RFID reader will cross-reference the tag's data within its self-contained database. After the reader receives new data, it will send the data to the host computer. An active RFID system can read several tags in the field simultaneously and the reading range is longer and less power is required for the reader. The distance between the reader and the host computer is normally less than 500 metres if it is connected wirelessly [5, 6, 10].

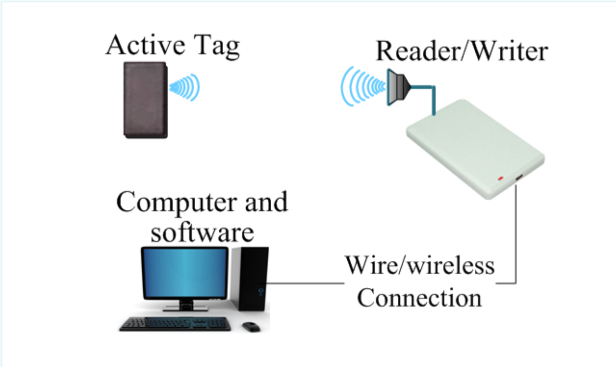

Figure 2. A typical active RFID system

2.3 RFID Tags

Generally, RFID tags can be classified into three types: passive, active and semi-passive (also known as battery-assisted passive, or BAP), which are differentiated by the way they communicate and how the communication is initiated. A typical RFID tag consists of a microchip attached to a radio antenna mounted on a substrate. The microchip can store data from 26 bits to 128 kilobytes [7, 11, 12].

Although both active tags and passive tags use radio frequency (RF) energy to communicate between a tag and a reader, they are fundamentally different in the method of powering the tags. An active tag uses an internal power source (e.g. batteries) within the tag to continuously power the tag and its RF communication circuits, whereas a passive tag has no internal power supply and relies on RF energy transferred from the reader to power the tag. This distinction may have significant impact on the functionality of the system [5, 12, 13].

Semi-passive (battery-assisted) RFID tags are similar to passive tags except for the addition of a small battery. This type of tags are normally reserved for more costly items that require being read over longer distances (e.g. 30 m) and faster in response. Semi-passive tags can produce a stronger signal when compared with passive tags as additional power may be used to boost these tags' reading ranges when necessary. They do not transmit a beacon and only transmit their data once activated by the reader. Due to the on board power source, semi-passive tags much like active tags can contain an on-board processor for customised applications and sensor integration. Thus, semi-passive tags are ideal for rapid development of customised RFID tags, since they do not require Federal Communications Commission (FCC) certification [11, 14, 15].

There are two basic types of chips available for RFID tags: read-only and read-write. Read-only tags cost less than read/write tags and the infrastructure required to support is also less expensive. The read-only tags still deliver on one of the main promises of RFID, that is, reduced operator involvement.

The size of RFID tags varies largely with different purposes, some tags (e.g. the active tags used in ports for trucks tracing) are as big as a brick [13, 16] while some others are as small as a fine powdery particle, e.g. Hitachi produced a tiny powder-type or called dust-type RFID chip measuring 0.05mm × 0.05mm × 0.005mm.

2.4 RFID Readers

An RFID reader/decoder/interrogator is a transmitter/receiver that reads the contents of RFID tags. It acts as a conduit or bridge between the RFID tag and the controller or middleware. The most important feature for a reader is the reading range, which can be affected by a number of factors such as the frequency used for identification, the antenna gain, the orientation and polarisation of the reader antenna and the transponder antenna as well as the placement of the tag on the object. Passive RFID requires stronger signals from the reader, and the signal strength returned from the tag is constrained to a very low level. In contrast, active RFID allows very low-level signals to be received by the tag, and the tag can generate high-level signals back to the reader.

Antennae are important components of RFID systems and their cost varies greatly, depending on functionality and base operating frequency. Antennae can be a shelf, mat, portal, wand or directional antenna and are required for different applications. In the case that many antennae are required by one reader, one or many multiplexers may be necessary depending on how many antennae being employed. Many readers contain built in multiplexers and external varieties are also available [13, 17].

2.5 Host Computers, Middleware and Other Considerations

The host computer generally is either a desktop or a laptop, positioned close to the readers. It receives data from the readers and performs data processing such as filtering and collation. It also serves as a device monitor for ensuring that the reader is functioning properly, securely and with up to date instructions. Host computers are connected to readers through networking technologies such as Transmission Control Protocol/Internet Protocol (TCP/IP) or sometimes through serial connectivity. It is possible for one computer to manage several readers, with the ratio being dependent on the data volume from those readers. Host computers and readers may communicate with each other via the EPCglobal Reader Protocol standard [14].

RFID middleware is software that facilitates communication between RFID readers and enterprise systems. It collects, filters, aggregates and applies business rules on data received from readers. Middleware is also responsible for providing management and monitoring functionality, ensuring that the readers are connected, functioning properly, and are configured in the correct way. Middleware may also contain a localised data store for archival of read events. Each middleware vendor normally provides firmware for all supported readers. Deployed either centrally or locally, middleware can be managed through user-friendly interfaces, similar to a standard software application. Also, middleware differs in its implementation style and may be implemented on a host computer, a centralised server or on intelligent readers [18, 19].

2.6 Reading Range and Frequency of RFID Technology

Nowadays, short-range communications have undeniably evolved along with technological advances. As one of the use of short-range communication technologies, RFID systems have operated at ranges from low and high frequencies to microwaves and have provided much longer reading ranges and services in Real Time Location Systems (RTLS). Compared with other short range technologies, RFID has a wider reading range and substantially increases productivity and efficiency of the integrated business [14].

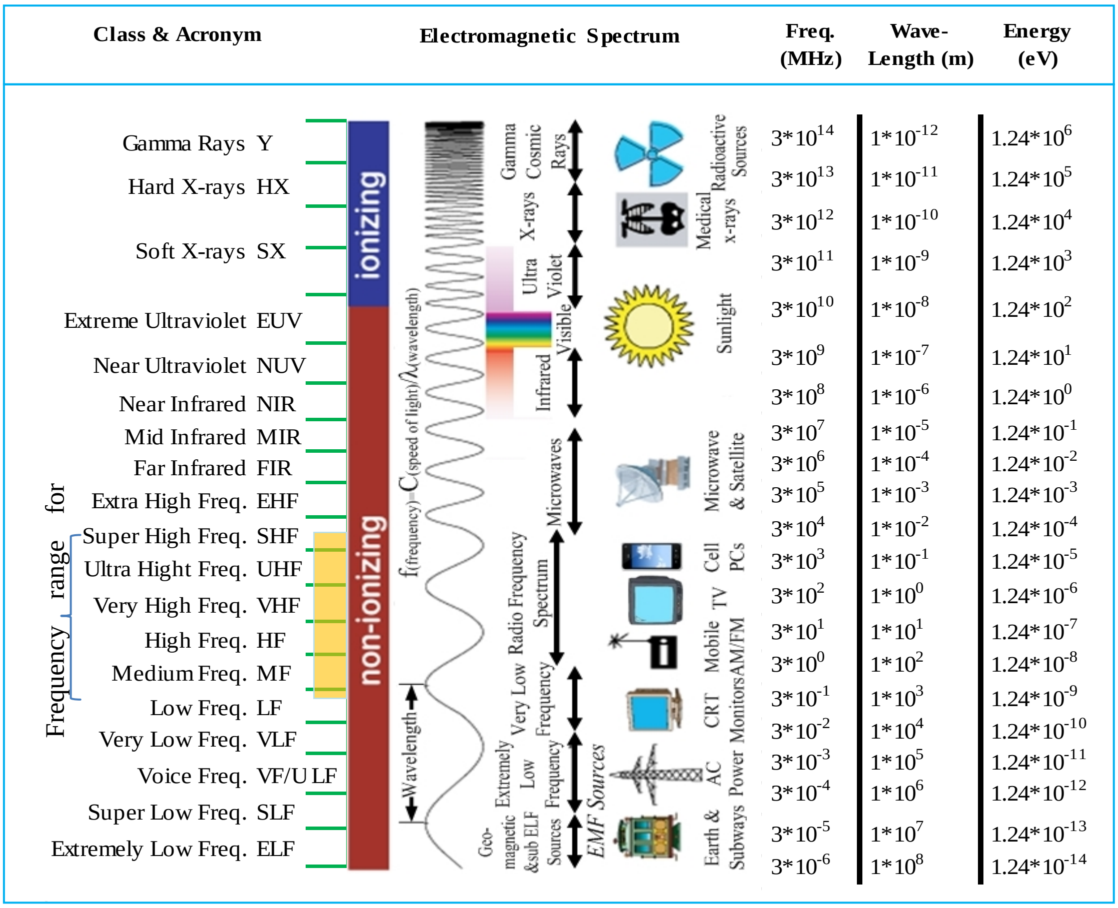

Figure 3. Electromagnetic spectrum, frequency, wave-length and energy for RFID

RFID systems can incorporate the use of electromagnetic or electrostatic feature in the Radio Frequency (RF) portion of the electromagnetic spectrum to uniquely identify, track, sort or detect a wide variety of tagged objects or assets. The specific electromagnetic spectrum, its frequency, wave-length and energy required are shown in Fig. 3 [5, 12].

RFID systems also operate in several regions of the RF spectrum and differing regions tend to be used for different applications. No one frequency is good for all applications, all geographies, or all types of operating environments. The International Telecommunication Union (ITU) defined three Regions globally:

- Region 1 - Europe, North Africa, Middle East (west of the Persian Gulf), former Soviet Union.
- Region 2 - North and South America.
- Region 3 - Asia, Middle East (east of the Persian Gulf), Australia and Oceania.

Generally, there are four primary frequency bands allocated for RFID uses: Low Frequency (LF), High Frequency (HF), Ultra High Frequency (UHF) and Super High Frequency (SHF)/microwave. Research shows that all the frequency bands can be used for both passive and active tags. The characteristics and performance of standard radio frequency ranges used for RFID are summarised in Table I [12, 20]. Typical applications for LF systems are pet recovery, cattle tagging, access cards and car immobilisation systems. HF systems are frequently used for smart shelf applications, access control and smart-cards. Related technologies such as near-field communications (NFC) also use the HF band. HF has the advantage of a tunable field shape so that its reading pattern can be precisely controlled.

TABLE I. CHARACTERISTICS OF DIFFERENT FREQUENCIES FOR RFID SYSTEMS

	LF	HF	UHF	SHF
Freq.R. (MHz)	< 0.135	3~28	433-435, 860-930	2400~2454 5725~5875
R.R.(P)	≤ 0.5 m	≤ 3 m	≤10 m	≤ 6 m
R.R.(A)	≤ 40 m	300 m	≤ 1 km	≤ 300 m

Freq.R.: Frequency Range
R.R.(P): Typical Reading Range for Passive Tags
R.R.(A): Typical Reading Range for Active Tags

Another advantage for HF is its better ability to read near metal or water. The disadvantage of HF is its relative short reading ranges (less than 1 m for passive RFID systems). UHF has a higher reading range and a faster data transfer rate than HF. It is more useful for tracking people or mobile objects. SHF (the main frequency is 2.45 GHz) tags have the advantage of being smaller than UHF tags, but generally have shorter reading ranges. The frequency of 2.45 GHz is in the same band as Wi-Fi and Bluetooth.

2.7 RFID Standardisations

RFID is an information technology defined in many standards across the whole world. These standards are contributed from different organisations as well as industries. Several areas of standards need to be reviewed for a complete understanding of RFID technology. The set of standards adopted by ISO and EPCglobal are generally considered to be RFID's main reference as summarised in Table II [14]. Several other standards are applied to RFID and the list of which evolves continuously. These standards need to be taken into account prior to purchasing an RFID system.

TABLE II. RFID STANDARDS FROM ISO AND EPCGLOBAL

Frequency Spectrum	ISO	EPCglobal
LF	ISO 11784 ISO/IEC 18000-2A ISO/IEC 18000-2B	
HF	ISO/IEC 14443 ISO/IEC 15693 ISO 18000-3	
UHF	ISO 18000-7	
UHF	ISO 18000-6A ISO 18000-6B ISO 18000-6C	Class 0 Class 1 Class 1 Gen 2
SHF	ISO 18000-4 ISO/IEC 24730-2	

III. RFID APPLICATIONS

RFID technology has been applied for many years in transport, access control cards, event ticketing and logistics for goods distribution. More recently, it was also applied in government identity cards and passports, and extensively applied in manufacturing, tracking of people and mobile objects and positioning. RFID applications are expanding wider and wider areas such as emergency, health, safety, security, and convenience, entertainment, travelling, shopping, asset tracking. The governments, enterprises, research institutes and consumers are all involved in the diverse RFID applications and playing different roles according to their specific purposes.

3.1 Typical RFID Applications

RFID systems are application-specific, some use passive, low cost tags with short reading ranges, most data on the network, and only small amounts of information on tags. Others use sophisticated, high performance tags with high data capacity or reading ranges that can have considerable data on tags without network connection. A number of typical RFID applications are categorised and summarized in Table III, and some of their typical examples are also shown in this table. In fact, there are a large number of different RFID applications available currently.

3.2 Application Combinations

Choosing the most appropriate RFID system for a particular application can be a daunting task as many types of RFID readers, tags and various environments need to be considered. One emerging solution is to use a hybrid system. For example, Retscher et al. implemented an indoor pedestrian navigation system using the combination of RFID, GPS, DR, digital compass, Wi-Fi and barometer. In this system, one sensor or sub-system played a unique role in situations where the rest sensors became less reliable: the low-cost GPS was for outdoor horizontal positioning; the biometric pressure sensor for vertical measurements; the digital compass for measuring orientations and the Wi-Fi for indoor positioning [21, 22]. In recent years, more and more hybrid tags such as those combining RFID with GPS, Wi-Fi, ultrasonic or infrared have been available. A range of other systems were occasionally presented as alternatives or compensations to RFID, including Near Field Communication (NFC), ZigBee, Wi-Fi and UWB. Most of the related research showed that hybrid RFID systems are the optimum solutions for RFID-based indoor positioning [22-27].

TABLE III. SELECTED RFID APPLICATIONS [23, 28-39]

	Application Areas	Typical Application Examples
01	Agriculture & forestry	Plant guiding; seed quality tracking; inventory audit in forestry
02	Airports & aviation	Baggage handling; dolly management; aircraft maintenance
03	Automotive & parts	Smart operation control; automation of mixed-flow assembly
04	Business services	Replacement of the manual methods in business process for efficiency; real-time visibility of spare-parts inventory for great improvement of business services
05	Chemicals industry	Vapours identification by using an RFID tag coated with a chemically sensitive film
06	Constructions	Inventory location reporting in lay down yards; tracking of returnable assets
07	Consumer goods	Electronic proofing of delivery; the War-Mart RFID mandates system
08	Defence	Tracking and positioning of wounded/soldiers; RFID-based tool tracking for combat ship
09	Education	Automatically collecting students daily records and sending to their parents; RFID-based book management system for college libraries
10	Energy & utilities	Electricity and gas meter data collection and reporting automatically; smart home applications
11	Entertainment	RFID wristbands for customer safety, identification, positioning and checkout
12	Environmental protection	Automatic identification of recyclable solid waste components; tracking of radioactive waste
13	Finance & banking	Visa RFID Credit Cards and customer passbooks with RFID embedded in
14	Food & drinking	Linking between a customer and particular flavours of food/drink by using “RFID flavour tags”
15	Governance	Government identity cards; E-passports
16	Healthcare & medication	Patients tracking through RFID-based wristband; medication management
17	Information technology	Automation of data collection for ERP (Enterprise Resource Planning); RFID-based sensor network for indoor positioning purpose
18	Logistics	Goods tracking and positioning from manufacture to retail; parcels tracking from shipment to end customer; providing visibility in the supply chain services/process
19	Manufacturing	Moulds/cutting tools management; control of flexible manufacturing process by recognising items being built on a production line
20	Media	The object-based media playing
21	Packaging	Medication monitoring and communicating hard-to-read information on labels in smart packaging
22	Public Services	Tracking waste to protect the environment; Allocating costs according to the amount of waste
23	Publishing & printing	Linking between printed newspapers/magazines and cyber resources
24	Real estate	Intelligent building management and document tracking
25	Retail & wholesale	The change room service for clothing buyers; product availability handling
26	Security	Door access cards and the anti-thievery application; Product authentication (e.g. jewellery products)
27	Stock raising	Animal identification and raw material (e.g. bales of hay) tracking
28	Telecommunications	Parts dispatching and management
29	Textiles & clothing	Reels processing; warehouse management; clothes fitting on (the RFID mirrors) for consumers
30	Transportation	Toll collection; bus prediction system (e.g. prediction of the bus arrival/departure time); the contactless transaction cards
31	Travel & leisure	Anti-theft travel wallets/handbags; RFID-based Travel service cards; tickets authentication and hotel room keys

IV. RFID-BASED INDOOR POSITIONING TECHNIQUES

4.1 Advantages and Disadvantages of RFID-based Indoor Positioning Techniques

RFID-based positioning techniques can be split into two main categories: tag-oriented and reader-oriented. The former aims at locating RFID tags, while the latter tries to find the position of portable RFID readers. Both approaches are likely to be employed as a basis to implement location-based services. In many RFID-based positioning applications, cables need to be removed from measurement setups and replaced with wireless devices that are connected to sensors and send data wirelessly to the host computers via network. RFID-based techniques provide a relatively large coverage area using a small number of devices, but they have serious multipath effects. The advantages and disadvantages of RFID technique for indoor positioning are summarised below.

The advantages of using RFID in indoor positioning include:

a) Simplicity of the system;
b) Low-cost of the device;
c) High portability;
d) Ease of maintenance;
e) Capability of providing both identification and location;
f) A long effective range (up to 1000 m for a single

transmitter in free space);

g) High penetration capabilities; and

h) Flexible in tag size.

The disadvantages of using RFID in indoor positioning include:

a) One-way communication links;

b) Multipath effects; and

c) Unstable Received Signal Strength (RSS).

Although RFID is spread across the world as a superior technique for tracking objects/people, it has not yet matured enough to use RFID technique alone for indoor positioning at present.

4.2 Hybrid Techniques for RFID-based Indoor Positioning

Other existing techniques used for indoor positioning such as Assisted GPS (AGPS), ZigBee, Wi-Fi, Bluetooth, Ultra Wide Band (UWB), Ultrasonic and Infrared are also have their own strengths and weaknesses according to the intensive review and comparisons from many researchers. One emerging solution for developing a low-cost reliable indoor positioning system is to use a hybrid system–integrating multiple sensors to compensate for the limitations in each single technique. Generally, in such hybrid systems, GPS is used for tracking and positioning in outdoor environments, and RFID and other techniques are used in indoor environments. The integrated techniques are capable of providing reliable and more accurate positions with the use of portable devices [40-42].

Wi-Fi technology is the WLAN (Wireless Local Area Network) technology that has gained the greatest success due to its low cost, widespread diffusion and robust communication capabilities, even in non-Line-of-Sight (NLOS) conditions. Wi-Fi based positioning technique originates a so-called radio map (or fingerprint database), in which any single dataset is called fingerprint. During the subsequent online location determination phase, the Received Signal Strength Indicator (RSSI) receives signals from a subset of Access Points (Aps) first and then searches for similar patterns in the radio map. The best match is chosen, and its physical coordinates are returned as the position estimates. [40, 43].

ZigBee is another wireless technology best suited to work with RFID for indoor positioning. ZigBee protocols are intended for use in embedded applications requiring low data rates and low power consumption, enabling devices to form a mesh network of up to 65 000 nodes, covering a very large area. One of the major differences between ZigBee and Wi-Fi is that ZigBee nodes use the ZigBee protocols rather than any native Internet protocol like TCP/IP or UDP. Therefore, ZigBee nodes need a dedicated Access Point that translates ZigBee into TCP/IP in order for the data to be sent over the network [44, 45].

It is also feasible to combine RFID with bluetooth and NFC for short-range communications in sub-areas. However, either Bluetooth or NFC is rarely used independently for the purposes of tracking and positioning due to their short reading ranges. Infrared, ultrasonic and UWB technologies [46] are also capable of functioning with RFID for indoor positioning. Both infrared and ultrasonic technologies cannot penetrate solid walls so they can only provide room-level location-sensing capabilities. Usually, infrared is less reliable and less accurate than ultrasonic because infrared is more dependent on line-of-sight and is often disturbed by e.g. direct sunlight. Infrared and ultrosonic technologies have been used in several common devices, such as television remote controls (infrared) and hospital environment (ultrasonic) for decades. They have also been often used for detecting objects, for example, O'Connor demonstrated a system called *RFID-enabled Robotic Guide Dog* with ultrasonic sensors mounted on a smart cane (near the handle) for detecting obstacles [47, 48].

UWB technology transmits information over a large bandwidth but at low power levels. It can send data at a high speed and can also penetrate walls. Thus its location estimates are more accurate than that of Wi-Fi. The major imitation of UWB is the short reading ranges. When combined with RFID, UWB is often used for determining precise location and RFID for measurement control and telemetry.

V. FUTURE TRENDS OF RFID-BASED INDOOR POSITIONING TECHNIQUES

RFID-based indoor positioning techniques have been and will be constantly changing and evolving, with new ideas and advanced technologies being tested and implemented. It is difficult to predict the future trends of RFID-based indoor positioning techniques precisely. However, several trends are evident in the development of RFID [18, 21, 35, 40, 49-51]:

- Generally, RFID-based indoor positioning techniques will improve the positioning accuracy and other capabilities of RFID technology, and remove the challenges associated with it.
- Either RFID-based hybrid positioning algorithms or hybrid tags will overcome the limitations of current indoor positioning.
- Wireless Sensor Network (WSN) will become more and more dominant and eventually replace RTLS due to its more intelligent and versatile functions and ease of implementation.
- It will be prosperous in integrating the fragmented location systems belonging to different communities, such as indoor and outdoor positioning systems.

VI. CONCLUSION

This paper provides an overview of RFID technology, its history, key areas of latest applications and RFID-based indoor positioning techniques in particular. This includes state-of-the-art developments of RFID technologies such as system miniaturisation, capacity and capability. As the primary interest of this research, current RFID-based indoor positioning techniques and their performance were discussed and the future trends of RFID-based indoor positioning technologies were also predicted. Both research and commercial market have indicated that RFID-based indoor positioning technology will open a new era in the future and will greatly change the daily lives of people.

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