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Overview of RFID-Based Indoor Positioning Technology

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Abstract: Radio frequency identification (RFID) technology was originally invented for military uses. From 1980s, commercial RFID products started to be available and they were mainly applied in areas of supply chains, transport, manufacturing, personnel access, animal tagging, toll collection etc. Nowadays, RFID has been recognised as an emerging technology for ubiquitous positioning (UP), especially in an indoor environment. The development and implementation of RFID-based positioning technology are very fast, whilst according to the literature, little comprehensive review and convinced assessment for the latest RFID technology have been conducted, and some of the main features of the latest RFID technology have rarely or unclearly been presented in the literature, for example, the longest reading range of RFID systems, the smallest tag size and overall commercial application fields. This paper provides an overview of state-of-the-art RFID technology, particularly for the purpose of indoor positioning. It includes a review of historical and current development of RFID technology and its applications, an evaluation of up-to-date RFID-based positioning techniques and their performance as well as a prediction of future trends of RFID-based indoor positioning techniques. This paper can be a valuable guidance and solution for researchers and other end users to better understand RFID and critical factors considered on system requirements, hardware selection and positioning performance for various applications.

Keywords: RFID; indoor positioning; LBS; RFID solution.

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1. Introduction

Radio Frequency Identification (RFID), which uses radio waves to wirelessly transmit the identity (e.g. a unique serial number) and other information of an object, is an emerging technology for indoor positioning (Ahuja & Potti 2010). RFID was invented during the Second World War II and was first used by Britain to identify aircraft as part of the refinement of the radar. It was during the 1960s that RFID was first considered for the commercial world, RFID products started to be available in 1980s and its wider spread usage was only in recent years. Earlier RFID applications were mainly applied to identifying assets in 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 different locations, when is considered as the third era of RFID (Holloway 2006b). Since 2000, RFID has experienced a rapid evolution and broad implementation throughout the economy. It has become a worldwide and rapid-evolving technology, which has been combined with other emerging technologies worldwide. Today, there are a variety of technical solutions, some being simple and common, while others are complex and expensive but offer better functionality and performance. RFID has substantially increased productivity and efficiency of its associated business (Ramli 2010). As intelligent RFID technology continues to develop, in conjunction with intelligent sensor technologies, RFID has been becoming the core technology of the Internet of things (IoT) (Holloway 2006b). Research and developments of RFID has been rapid, however, challenges remain, particularly in standards development, security compliance and privacy concerns (Choi et al. 2011). The implementation of RFID requires diligent assessment of the need for RFID solutions in particular organisations. Therefore, it is important to explore and review this technology in order to maximise its potential benefits and reduce the risk of its implementation.

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2. Overview of RFID technology

2.1 Principles of RFID technology

RFID technology is an emerging technology that allows for mobility tracking of objects or people. There are mainly three types of RFID systems: passive, semi-passive and active systems (Berthiaume, Donahue & Romme 2011). A typical RFID system contains tags (also referred to as transponders, smart tags, smart labels, or radio barcodes), a reader (also called writer, decoder, interrogator, transmitter, receiver, or transceiver), and a host computer and software/infrastructure. The reader and the host computer communicate through either a wire or wireless link.

Figure 1 shows the work principles of a typical passive RFID system (Ahuja & Potti 2010; Kefalakis et al. 2011; Kuester et al. 2011; Weinstein 2005). The power source of a passive tag is provided by the reader. When a radio signal is sent from a reader, when the tag enters the signal field of the reader, it will be powered on by the signal, the reader then captures the ID and data from the tag and sends this information to the host computer. The computer, with RFID middleware installed on, processes the data and sends it back to the reader; the reader then transmits the processed data to the tag. Passive RFID systems are normally used for applications in shorter reading ranges.

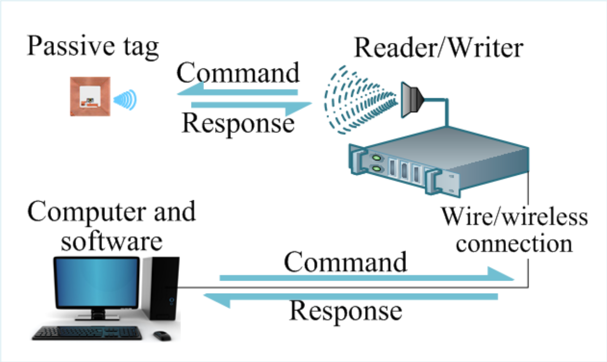

Figure 1. A typical passive RFID system

The principles of an active RFID system are slightly different from a passive system as shown in Figure 2. An active RFID system usually uses active RFID tags (with a battery built in) and each tag periodically transmits its data which may contain identification and other application-specific information such as location, price, colour, and date of purchase. The RFID reader will cross-reference the tag's data within its self-contained database. Compared to a passive system, an active RFID system can simultaneously read several tags in the field, its reading range is longer and its power required is less. The distance between the reader and the host computer is normally under 500 m if they are connected wirelessly (*Long range RFID readers and tags* 2012; Berthiaume, Donahue & Romme 2011; Holloway 2006b).

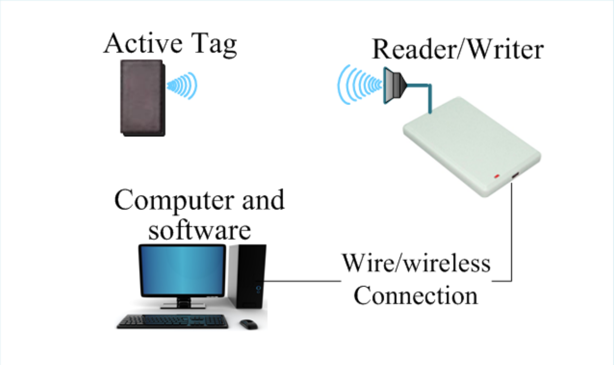

Figure 2. A typical active RFID system

The principles of a semi-passive RFID system are similar to that of the passive system, except that there is a battery embeded in the semi-passive tag. The battery provides an on-board power source for the telemetry and sensor asset monitoring circuits of the tag so that the tag have more power to communicate. However, the on-board power is not directly used to generate radio frequency (RF) electromagnetic energy.

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2.2 RFID Tags

RFID tags can be also classified into three types: passive, active and semi-passive (also known as battery-assisted passive, or BAP). 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 (Intermec 2012; OECD 2008; Weinstein 2005).

Although both active and passive tags use RF energy to communicate with a reader, they are fundamentally different in the method of powering the tags. An active tag uses an internal power source, usually batteries, within the tag to continuously power the tag and its RF communication circuits, whereas a passive tag completely relies on RF energy transferred from the reader. This distinction may have significant impact on the functionality of the system (Ahsan, Shah & Kingston 2010; Holloway 2006b; OECD 2008). Semi-passive tags overcome two key disadvantages of pure passive RFID tags, one is the lack of a continuous source of power for the circuits and the other is the short reading range. **S**emi-passive tags are ideal for rapid development of customised RFID tags since they are not required for Federal Communications Commission (FCC) certification (Folea & Ghercioiu 2010; Intermec 2012; Ramli 2010).

There are two basic types of chips available for RFID tags: read-only and read-write. Read-only tags are cheaper and their required infrastructure is also less expensive, they still deliver on one of the main promises of RFID, which is the reduction of operator involvement.

The size of RFID tags varies largely with the purpose of applications. For example, RFID tags used for truck location in shipping ports, can be as big as a building brick (Ahsan, Shah & Kingston 2010; Ruhanen et al. 2008), Others, like the tiny powder-type or called dust-type RFID tags produced by Hitachi, can be as small as a fine powdery particle. These may be some sixty times smaller than the “mu-chip” as shown in Figure 3 (*Hitachi develops RFID powder* 2007).

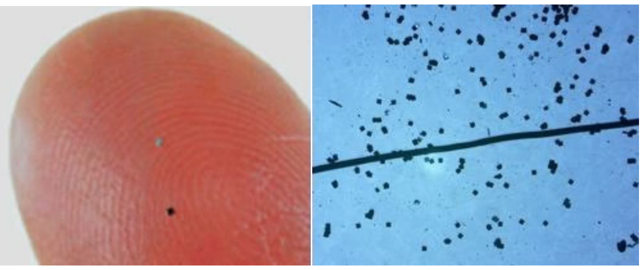

Figure 3. Powder-type tiny RFID tags: the left – Hitachi mu-chip tiny RFID tags with a size of 0.4mm × 0.4mm; the right – Hitachi powder-type tiny RFID tags (in contrast with a human hair) with a 128-bit of read-only memory and a size of 0.05mm × 0.05mm × 0.005mm.

2.3 RFID Readers

An RFID reader reads data from RFID tags and it acts as a conduit or bridge between RFID tags and the controller or middleware. The most important feature of a reader is its reading range, which can be affected by a number of factors such as the frequency, the antenna gain, the orientation and polarisation of the reader antenna, the transponder antenna and the placement.

2.4 Host Computer, Middleware and Other Considerations

The host computer can be 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. The host computer and the readers communicate with each other often via the EPCglobal Reader Protocol standard (Ramli 2010).

RFID middleware is software that facilitates communication between RFID readers and enterprise systems. It also collects, filters, aggregates and applies business rules on data received from the readers. Middleware is also responsible for providing management and monitoring functionality, ensuring that the readers are connected, functioning properly, and being configured correctly. Middleware may be implemented on a host computer, a centralised server or on intelligent readers (Grosso et al. 2011; Sheng, Li & Zeadally 2008).

2.5 Reading Range and Frequency

Nowadays, short-range communications have undeniably evolved with technological advances. As one of the short-range communication technologies, RFID has operated at ranges from low- and high-frequencies to microwaves, and has provided longer reading ranges than other short-range communication technologies and services. The specific electromagnetic spectrum, frequency, wave-length and energy used for RFID are shown in Table 1 (Holloway 2006b; OECD 2008).

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Table 1. Ranges of RFID frequency and wave-length

Band	LF	HF	UHF	SHF
Frequency	30–300 kHz	3−30 MHz	300 MHz−3GHz	3−30 GHz
Wavelength	10−1 km	100−10 m	1− 0.1 m	10−1cm

RFID systems also operate in several regions of the RF spectrum. Different regions tend to be used for different applications and no one frequency is good for all applications, all geographies, or all types of operating environments. 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 has shown 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 2 (OECD 2008; Weiku 2012). Typical applications of LF systems are pet recovery, cattle tagging, access cards and car immobilisation systems. The 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. Due to the advantage of the Ftunable field shape of HF, its reading pattern can be precisely controlled.

Table 2. Characteristics of different frequencies for RFID systems

	LF	**HF**	**UHF**	**SHF**
FR (MHz)	< 0.135	3~28	433-435, 860-930	2400~2454 5725~5875
RR(P)	≤ 0.5 m	≤ 3 m	≤ 10 m	≤ 6 m
RR(A)	≤ 40 m	300 m	≤ 1 km	≤ 300 m
TRR	Slower ⟷ Faster			
ARMW	Better ⟷ Worse			

FR: Frequency Range
RRP: Typical Reading Range of Passive Tags
RRA: Typical Reading Range of Active Tags
TRR: Tag Reading Rate
ARMW: Ability to Read near Metal or Water

Another advantage of HF is its greater ability to operate near metal or water. The disadvantage of HF is its relative short reading ranges (< 1 m for passive RFID systems). UHF has a longer 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 smaller size than UHF tags, but generally have shorter reading ranges. The 2.45 GHz is in the same band as Wi-Fi and Bluetooth.

3. 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 today are expanding to include wider and wider areas such as emergency, health, safety, security, and convenience, entertainment, travelling, shopping and asset tracking. 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 storage capacity and reading ranges that can have considerable data on tags without network connection. Some of the typical RFID applications are categorised and summarized in Table 3, along with some of their typical examples (Faggion & Azzalin 2011; Goller & Brandner 2011; Holloway 2006a; Jimenez et al. 2011; Meadati, Irizarry & Akhnoukh 2010; Rantakokko et al. 2010; Retscher, Zhang & Zhu 2012; Ruiz-de-Garibay et al. 2011; Ruiz et al. 2010; Sarac, Absi & Dauzere-Peres 2010; Sheridan, Tsegaye & Walter-Echols 2005; Shkel 2010; Zhu 2010)

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Table 3. Selected typical RFID applications and examples

	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	Real-time visibility of spare-parts inventory for 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
09	Education	Collecting students records and sending to their parents; book management
10	Energy & utilities	Electricity and gas meter data collection and reporting a; 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 customer and particular flavours of food by using “RFID flavour tags”
15	Governance	Government identity cards; E-passports
16	Healthcare	Patients tracking through RFID-based wristband; medication management
17	Information technology	Automation of data collection for ERP (Enterprise Resource Planning)
18	Logistics	Goods tracking and positioning from manufacture to retail; supply chain services
19	Manufacturing	Moulds/cutting tools management; control of flexible manufacturing process
20	Media	The object-based media playing
21	Packaging	Communicating hard-to-read information on labels in smart packaging
22	Public Services	Tracking waste to protect the environment
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
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; clothes fitting on (the RFID mirrors) for consumers
30	Transportation	Toll collection; bus prediction system ; the contactless transaction cards
31	Travel & leisure	Anti-theft travel wallets; RFID-based tickets authentication; and hotel room keys

3.2 Challenges of RFID Implementations

RFID solutions involve more than just the use of tags and readers in business applications. These applications typically involve ongoing support, collaboration with supply chain partners and security/privacy support, for example, for integration with Enterprise Resource Planning (ERP) solutions that run the company's businesses. It is better to focus on a few clear objectives when dealing with an RFID implementation since the deployment for multiple goals may lead to a complex project. This is likely to slow down the business and become costly (OECD 2008; Sarac, Absi & Dauzere-Peres 2010; Weinstein 2005). Challenges such as privacy concerns, evolving standards, security concerns, impact of surrounding environments, lack of integration and skilled personnel, data interference, and multiplicity of vendors need to be taken into account during the RFID implementation. −

4. 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 is to find the position of portable RFID readers. 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 a network.

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RFID-based techniques provide a relatively large coverage area by a small number of devices, but they may have significant multipath effects. The advantages of RFID techniques for indoor positioning can be summarised as:

- Simplicity of the system;
- Low-cost of the device;
- High portability;
- Ease of maintenance;
- Capability of providing both identification and location;
- A long effective range (up to 1000 m for a single transmitter in free space);
- High penetration capabilities; and
- Flexible in tag size.

The disadvantages of using RFID in indoor positioning include:

- One-way communication links;
- Multipath effects; and
- Unstable Received Signal Strength (RSS).

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

4.2 Hybrid Techniques for RFID-based Indoor Positioning

Research (Holm, S. & Nilsen 2010; Spinella, Iera & Molinaro 2010) has shown that various indoor positioning techniques (e.g. Assisted GPS (AGPS), ZigBee, Wi-Fi, bluetooth, ultra wide band (UWB), ultrasonic and Infrared) all have both strengths and weaknesses. One emerging solution for developing a low-cost reliable indoor positioning system is to use a hybrid system. These integrate RFID with either multiple sensors or multiple techniques to compensate for the limitations in each single technique. The integrated techniques are capable of providing more reliable and more accurate positions with the use of portable devices.

Sardroud et al. (2012) presented a hybrid approach to identifying and automatically tracking the location of materials. RFID and GPS are used for tracking and positioning in indoor and outdoor environments respectively. Their approach leveraged the automatic reading of RFID tagged materials by field supervisors or materials handling equipment and a GPS receiver. Their test results indicated that the RFID technology had reached the point where it could function effectively on construction sites that involved large metal objects and required a considerably long reading range. Zhu et al. (2010) proposed another approach that integrated low-cost GPS, RFID and INS techniques, which could provide a metre-level accuracy positioning. In this approach, GPS was for outdoor positioning, while RFID and INS mainly for indoor positioning or for the areas where GPS signals were blocked. This combination of RFID and GPS provides a seamless indoor and outdoor positioning solution (Mathiassen, Hanssen & Hallingstad 2010; Sardroud 2012; Zhu 2010).

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 techniques originate a so-called radio map (or fingerprint database), in which a single dataset is called a 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's physical coordinates are returned as the optimal position estimates. The strong identification capability of RFID technology is very useful to improve the positioning accuracy of this approach (Schulcz & Varga 2010; Spinella, Iera & Molinaro 2010).

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. This enables devices to form a mesh network of up to 65, 000 nodes. 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 via the network. ZigBee networks can support a larger number of devices, its allowed reading ranges are usually longer than Bluetooth but shorter than RFID (Abinaya & Bharathi 2012; Eslambolchi 2012).

In sub-areas of indoor positioning, it is feasible to combine RFID with bluetooth or other Near Field Communication (NFC) techniques for short-range communications. However, NFC techniques are rarely used independently for the purposes of tracking and positioning due to their short reading ranges. Infrared, ultrasonic and UWB technologies (Álvarez & Cintas 2010) can be combined 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 it can even be disturbed by direct sunlight. For example, infrared and ultrasonic technologies have been used in several common devices, such as television remote controls (infrared)

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and hospital environment (ultrasonic) for decades. They have also been often used for detecting objects, e.g. O'Connor (2009) demonstrated a system called *RFID-enabled Robotic Guide Dog* with ultrasonic sensors mounted on a smart cane (near the handle) for detecting obstacles (Dai & Su 2008; Holm, Sverre 2009).

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 limitation of UWB is its short reading range. When combined with RFID, UWB is often used for determining precise position and RFID for measurement control and telemetry.

5. Overview of RFID-Based Positioning Algorithms

5.1 Typical Measurement Models for RFID-based Positioning

Time of arrival (TOA), Time difference of arrival (TDOA), RSS and Angle of Arrival (AOA) are the most commonly used measurements models commonly for the observation of source positioning. Basically, TOAs, TDOAs and RSSs are used to calculate distances between the source and receivers, while AOAs is for the bearings of the source relative to the receiver (Zekavat, Kansal & Levesque 2012).

The TOA model uses the one-way propagation time of the signal traveling from a source to a receiver to determine the range. It should be noted that the source and all the receivers should be synchronised precisely for obtaining accurate TOA information, although such a synchronisation is not needed if a round-trip TOA is measured. Geometrically, at least three receivers are needed for 2D positioning.

The TDOA model uses the difference of the arrival times of the emitted signal received at a pair of receivers. In this model, the receivers need to be synchronised. Nevertheless, the positioning algorithm using TDOA is simpler than that using TOA because the latter needs to be synchronized with the source as well. This leads to higher hardware costs. Similar to TOA, the range difference between the source and the pair of receivers can be obtained by multiplying TDOA by the known propagation speed. The RSS model uses the average power received at the sensor from the emitted source. It is commonly assumed that the received power follows an exponential decay model, which is a function of the transmitted power, the path loss constant and the distance between the source and the receiver. The positioning algorithm using RSS is simpler than those using TOA or TDOA measurements in that it does not need synchronisation.

The AOA model uses the arrival angle of the emitted source signal observed at the reader. The line of bearing (LOB) from the source to the receiver can be drawn and the intersection of at least two LOBs can be used to obtain the location of the source. Although this model does not need clock synchronisation like TOA-based positioning, it does require the installation of an antenna array on each receiver.

A comparison of the above four measurements models is shown in Table 4.

Table 4. Comparison of four measurement models

Model	Advantage	Disadvantage
TOA	High accuracy	Time synchronisation across source and all receivers needed; LOS is assumed
TDOA	High accuracy; time synchronisation at source needed	LOS is assumed
RSS	Simple; no time synchronisationneeded	Low-medium accuracy
AOA	Only two receivers needed; time synchronisation is not needed	Antenna arrays needed; complexity and LOS is assumed

5.2 Algorithms for RFID-based Indoor Positioning

Unlike an outdoor free space environment, obtaining an indoor source position can be problematic using TOA, TDOA and AOA. This is due to the non-line-of-sight (NLOS) environment caused by obstructions between the source and the receivers and its observations contain large biases. For this reason for that TOA, TDOA and AOA are rarely used for indoor positioning (Nilsson, Skog & Handel 2010; Walder & Bernoulli 2010; Zhu 2010). In contrast, RSS can provide a better solution and also

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compatible with many of the current radio technologies such as RFID, ZigBee and Bluetooth. Moreover, RSS is also compatible with most existing wireless infrastructures (e.g. Wi-Fi network). This means tremendous cost savings for positioning-specific hardware. Therefore, we focus on RSS-related algorithm in the remaining sections of this paper.

RSS varies with the distances between a transmitter and a receiver. The longer the distance, the weaker the RSS. When dealing with RSS-based positioning algorithms, such as the lateration, Cell of Origin (CoO) and location fingerprint, the position of the mobile users/objects can be estimated by the known coordinates of the transmitters and the distance measurements between the transmitters and the receiver.

Lateration is the most common algorithm for indoor positioning. The location of a mobile object can be optimally estimated using the observed distance from the object to multiple anchors.

CoO is simple and less prone to environment effects. However, the accuracy of its time measurements is low, and it is also difficult to obtain stable and long-range signal strengths. The probabilistic CoO algorithm, developed by Zhu (2010), is better than the deterministic CoO algorithm as it solved the contradiction between the cell size and accuracy, which exists in the conventional CoO algorithm.

Location fingerprinting is an effective algorithm for indoor positioning. To use this approach, a fingerprint database/map needs to be established before implementing positioning tasks. The signal strength observations at known locations are required in an offline phase and the obtained values are stored in the database. The database data will be used later in the online phase for determination of the user's position. Thus, an accurate and up-to-date fingerprinting map is essential for accurate positioning in this algorithm.

The least squares (LS) and Kalman Filtering (KF) are usually used to during the process of positioning estimation. The LS is usually for estimating the position of static objects while KF is suitable for positioning of dynamic objects.

5.3 Comparison of Algorithms

A variety of features can be used for evaluating the performance of RFID-based indoor positioning systems, for example, the positioning accuracy, precision, robustness, complexity and stability. Positioning accuracy is considered as the most important factor among these features.

The CoO algorithm results in accurate and discrete positions on correct spots and its positioning accuracy is dependent upon the cell size. The lateration algorithm can provide continuous positioning estimates but the accuracy can be largely affected by the surrounding reflections and obstructions of the signals. The location fingerprinting algorithm can also provide continuous positioning estimates and with more accuracy, the detrimental effects of surrounding environments are considered and eliminated during the training phase.

As all RFID-based indoor positioning algorithms are application-oriented and one specific positioning system may employ one or multiple algorithms for positioning, it is common to compare the performance of various positioning systems rather than the algorithms. A comparison for the general characteristics of these positioning algorithms are summarised in Table 5 (Álvarez & Cintas 2010; Koyuncu & Yang 2010; Schmitz-Peiffer et al. 2010; Zekavat, Kansal & Levesque 2012).

Table 5. Comparison of RFID-based positioning algorithms

Algorithm	Accuracy	Advantage	Disadvantage
CoO	Medium	Simple algorithms	Discrete positioning; positioning accuracy dependent upon the size of cells; a large number of sensors may be needed
Lateration	Medium	Continuous positioning; no training phase needed	At least three receivers needed; distance estimates based on RSS contain large errors, caused by environmental effects
Fingerprinting	High	Continuous positioning; environmental effects considered in the training phase	Inaccurate in a dynamic environment due to the RSS variations; affected by the RSS directional patterns and the errors? in the training phase

6. Future Trends of RFID-Based Indoor Positioning Techniques

RFID-based indoor positioning techniques have been and will be constantly changing and evolving with the implementation of new ideas and advanced technologies. An accurate a prediction of the future of RFID is difficult to make. From the current research (Chattopadhyay, Prabhu & Gadh 2011; Merico, Bisiani & Mileo 2010; Ruiz-de-Garibay et al. 2011; Schmid et al.

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2010; Sheng, Li & Zeadally 2008; Spinella, Iera & Molinaro 2010; Vegni, Carli & Neri 2010), the following trends can be highlighted:

- Generally, the positioning accuracy of RFID-based indoor positioning techniques and other capabilities of RFID technology will be improved, and the challenges associated with RFID will be reduced or removed. There will be new roles played by RFID for indoor positioning. For example, with the reduction of cost and the protection of privacy, RFID-tagged loyalty cards and credit cards will become more and more popular since they can be used for recording the purchase behaviour of the card holders ,based on which customer services can be adjusted for improvements.
- Although hybrid positioning systems and hybrid sensors/tags still have some limitations at present, they have been used in industries for years and have demonstrated a promising future. The limitations will be eliminated and the advantages of the integration of different types of hardware and/or software will be maximised. Many examples have shown great improvements in positioning accuracy and cost reduction, for example, the multi-frequency active tags used to increase the lifespan of the tag batteries, RFID tags with the function/ability of Wi-Fi/ZigBee/bluetooth/ultrasonic/infrared/UWB.
- Along with the development of sensor technology, Wireless Sensor Network (WSN) will become more and more dominant and eventually replace the current most popular Real Time Location Systems (RTLS) due to its more intelligent and versatile functions and ease of implementation.
- Systems without requiring any attached tag/reader to the target objects/people will be another prospective trend; such systems will be more convenient and more acceptable to the end users.
- Chipless RFID tags will be commonly and widely used in many aspects of our lives in future. These tags can be printed directly on products or product packaging at a very low cost, and they will be definitely more convenient and easy for implementation.

7. Summary and Concluding Remarks

In this paper, RFID technology and applications, and RFID-based indoor positioning techniques and algorithms were reviewed. A number of up-to-date developments in RFID and the latest RFID applications were investigated. RFID-based indoor positioning techniques, algorithms and their characteristics were compared. Furthermore, a prediction for future trends of RFID-based indoor positioning technologies was offered. Both research and commercial market have indicated that RFID-based indoor positioning technology will open a new era and will greatly change the daily lives of people in future.

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