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RFID: Past, Present, Future

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Abstract: This article surveys recent technical research and achievements in the field of RFID (Radio Frequency IDentification). Article also helps entering and better understanding the world of RFID systems. RFID tags are small, wireless devices that help identify objects and people. Thanks to dropping cost, they are likely to proliferate into the billions in the next several years – and eventually into the trillions. RFID tags track objects in supply chains, and are working their way into the pockets, belongings and even the bodies of consumers. This survey examines current status and future approaches proposed by scientists for possible usage of RFID systems, and treats the social and technical context of their work. While geared toward the non-specialist, the survey may also serve as a reference for specialist readers.

Keywords: information technology, radio frequency identification, RFID tag

1 Introduction

RFID (Radio-Frequency IDentification) is a technology for automated identification of objects and people. Human beings are skilful at identifying objects under a variety of challenge circumstances. A bleary-eyed person can easily pick out a cup of coffee on a cluttered breakfast table in the morning, for example. Computer vision, though, performs such tasks poorly. RFID may be viewed as a means of explicitly labelling objects to facilitate their "perception" by computing devices. [1]

Most histories of RFID trace the technology back to the radio-based identification system used by Allied bombers during World War II. Because bombers could be shot down by German anti-aircraft artillery, they had a strong incentive to fly bombing missions at night because planes were harder for gunners on the ground to target and shoot down. Of course, the Germans also took advantage of the cover that darkness provided. Early Identification Friend or Foe (IFF) systems made it possible for Allied fighters and anti-aircraft systems to distinguish their own returning bombers from aircraft sent by the enemy. These systems, and their descendants today, send coded identification signals by radio: An aircraft that sends the correct signal is deemed to be a friend, and the rest are foe. Thus, radio frequency identification was born.

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Shortly after the war, an engineer named Harry Stockman realized that it is possible to power a mobile transmitter completely from the strength of a received radio signal. His paper "Communication by Means of Reflected Power" introduced the concept of passive RFID systems.

Work on RFID systems as we know them began in earnest in the 1970s. In 1972, Kriofsky and Kaplan filed a patent application for an "inductively coupled transmitter-responder arrangement. The system used separate coils for receiving power and transmitting the return signal. In 1979, Beigel filed a new application for an "identification device" that combined the two antennas; many consider his application to be the landmark RFID application because it emphasized the potentially small size of RFID devices.

2 Elements of an RFID system

RFID systems fundamentally consist of four elements: the RFID tags themselves, the RFID readers, the antennas and choice of radio characteristics, and the computer network (if any) that is used to connect the readers [9].

The RFID tag consists of an integrated circuit (IC) embedded in a thin film medium. Information stored in the memory of the RFID chip is transmitted by the antenna circuit embedded in the RFID inlay via radio frequencies, to an RFID reader. The performance characteristics of the RFID tag will then be determined by factors such as the type of IC used, the read/write capability, the radio frequency, power settings, environment, etc.

RFID tags are categorized as either **passive** or **active** depending on whether they have an on-board power source or not [13]. Figure 1 shows graphical representation of tag's differences based on this criteria.

- **Passive** tags do not have an integrated power source and are powered from the signal carried by the RFID reader. Generally, these tags are powered by the reader antenna through an antenna located on the tag. The reader's transmission is coupled to the specially designed antenna through induction or E-field capacitance which generates a small voltage potential. This power is then used by the IC to transmit a signal back to the reader or reflect back a modulated, encoded identification.

- **Semi-passive** tags have an on-board power source, such as a battery, which is used to run the microchip's circuitry. However these tags utilize a battery but still operate using backscatter techniques. Tags of this type have greater range than totally passive tags and have the ability to monitor sensor inputs even when they are not in the presence of an RF field.

- **Active** tags incorporate a battery to transmit a signal to a reader antenna. These tags either emit a signal at a predefined interval or transmit only when addressed by a reader. Either way, the battery provides the power for RF transmissions, not an inductive or capacitive coupling. As a result of the built-in battery, active tags can operate at a greater distance and at higher data rates, in return for limited life, driven by the longevity of the built in battery, and higher costs. For a lower cost of implementation, passive tags are a more attractive solution.

The information stored in an RFID chip is defined by its read/write characteristics.

- **Read-only**: For read-only tag**,** the information stored must be recorded during the manufacturing process and cannot be typically modified or erased. The data stored normally represents a unique serial number, which is used as a reference to lookup more details about a particular item in a host system database. Read-only tags are therefore useful for identifying an object, much like the "license plate" of a car.

- **Write-once**: These differ from read-only tags in that they allow the end-user to program the tag's memory. Therefore, as an item progresses down a conveyor, for example, an end-user can encode a write-once tag with the item's serial number or part number which cannot be erased.

- **Read-write**: for a read/write tag, data can be written and erased on demand at the point of application. Since a rewriteable tag can be updated numerous times, its reusability can help to reduce the number of tags that need to be purchased, and add greater flexibility and intelligence to the application. Additionally, data can be added as the item moves through the supply chain, providing better traceability and updated information. Advanced features also include locking, encryption and disabling the RFID tag.

RFID systems are designed to operate at a number of designated frequencies, depending on the application requirements and local radio-frequency regulations. Four main frequency ranges exists:

- Low Frequency (125 kHz)
- High Frequency (13.56MHz)
- Ultra High Frequency (860-960 MHz)
- Microwave (2.45 GHz)

The RFID reader sends a pulse of radio energy to the tag and listens for the tag's response. The tag detects this energy and sends back a response that contains the tag's serial number and possibly other information as well [11].

In simple RFID systems, the reader's pulse of energy functioned as an on-off switch; in more sophisticated systems, the reader's RF signal can contain commands to the tag, instructions to read or write memory that the tag contains, and even passwords.

Historically, RFID readers were designed to read only a particular kind of tag, but so-called multimode readers that can read many different kinds of tags are becoming increasingly popular.

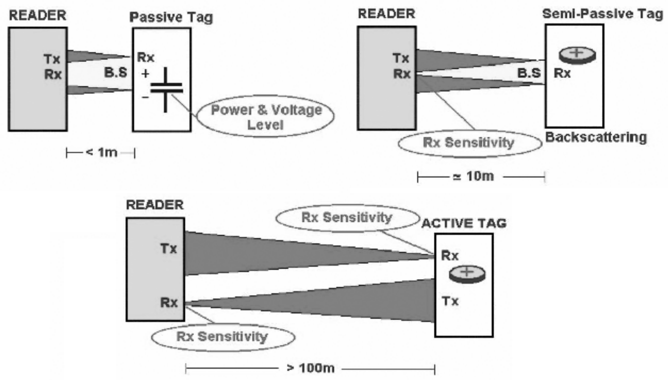

Fig. 1. Different reader tag couplings

RFID readers are usually on, continually transmitting radio energy and awaiting any tags that enter their field of operation. However, for some applications, this is unnecessary and could be undesirable in battery-powered devices that need to conserve energy. Thus, it is possible to configure an RFID reader so that it sends the radio pulse only in response to an external event. For example, most electronic toll collection systems have the reader constantly powered up so that every passing car will be recorded. On the other hand, RFID scanners used in veterinarian's offices are frequently equipped with triggers and power up the only when the trigger is pulled. Like the tags themselves, RFID readers come in many sizes. The largest readers might consist of a desktop personal computer with a special card and multiple antennas connected to the card through shielded cable. Such a reader would typically have a network connection as well so that it could report tags that it reads to other computers. The smallest readers are the size of a postage stamp and are designed to be embedded in mobile telephones.

A barcode scanner cannot read more than one barcode at a time. RFID readers, however, may be driven by specific software applications that can handle the reading of multiple RFID tags. This feature is called **anti-collision** as it permits a reader to avoid data collision from several tags that enter the reader's coverage [6].

In many existing applications, a single-read RFID tag is sufficient and even necessary: animal tagging and access control are examples. However, in a growing number of new applications, the simultaneous reading of several tags in the same RF field is absolutely critical: library books, airline baggage, garment, and retail applications are a few. In order to read multiple tags simultaneously, the tag and reader must be designed to detect the condition that more than one tag is active. Otherwise, the tags will all backscatter the carrier at the same time, and the amplitude-modulated waveforms would be garbled. This is referred to as a collision. No data would be transferred to the reader.

The tag/reader interface is similar to a serial bus, even though the "bus" travels through the air. In a wired serial bus application, arbitration is necessary to prevent bus contention. The RFID interface also requires arbitration so that only one tag transmits data over the "bus" at one time. A number of different methods are in use and in development today for preventing collisions; most are patented or patent pending, but all are related to making sure that only one tag "talks" (backscatters) at any one time.

The RFID physical layer consists of the actual radios and antennas used to couple the reader to the tag so that information can be transferred between the two. Radio energy is measured by two fundamental characteristics: the *frequencies* at which it oscillates and the strength or *power* of those oscillations [8].

Almost all RFID systems use the so-called *unlicensed spectrum,* which is a specific part of the spectrum set aside for use without a radio license.

As with most radio systems, the larger the antenna on the reader and the tag, the better an RFID system will work because large antennas are generally more efficient at transmitting and receiving radio power than are small antennas. Thus, a large antenna on the reader means that more power can be sent to the RFID tag and more of the tag's emitted energy can be collected and analyzed. A large antenna on the tag means that more of the power can be collected and used to power the chip. Likewise, a large antenna on the chip means that more power can be transmitted back to the reader.

As mentioned previously, active and passive RFID systems have very different reading ranges. With batteries and high-gain antennas, active RFID systems have ranges roughly equivalent to those of any other system operating under the rules for unlicensed radio systems. In most countries in the Europe, for example, an unlicensed system can transmit with up to 1 watt of power; under these conditions, a signal can be received over a mile if directional antennas are used and there are no obstructions.

As with all radio signals, the range of an RFID system is dramatically affected by the environment through which the radio signals travel [5]. Two of the most potent barriers for radio signals in the HF and UHF regions of the spectrum are water and metal, and they can profound impacts on RFID in typical operations. For example, cardboard is normally transparent to radio waves. But if a cardboard box picks up moisture, the water in the cardboard will attenuate the radio signal from an RFID reader, perhaps to the point that the RFID tag inside the box will not receive enough power to send back a response.

Metal blocks radio waves, so there's no hope of reading a tag inside a can. What about a tag that's on a can? The answer depends on where the reader is in relationship to the tag and the can, how far away the tag is from the can, and even what kind of antenna is built into the tag. In some cases, the can will block the radio waves, but in other cases, the can will focus the waves and make it easier to read the tag. This is especially a possibility if several cans are packed tightly together, as might be the case on a supermarket shelf.

If the intention is to shield an RFID tag against an RFID reader (privacy) , it is quite easy to do. A single layer of aluminium foil is sufficient to shield most low power RF devices. For RFID, aluminium needs to be only 27 microns thick, according to Matthew Reynolds at ThingMagic (www.thingmagic.com), to effectively shield a tag. And just 1mm of dilute salt water (also a conductor) provides similar protection.

3 RFID today

RFID is used extensively today, around the world and in a world of ways. In 2010 three key factors drove a significant increase in RFID usage: decreased cost of equipment and tags, increased performance to a reliability of 99.9% and a stable international standard around UHF passive systems. At RFID Journal Live 2010 in Orlando, Airbus detailed 16 active projects. The two other areas of significant use are financial services for IT asset tracking and healthcare with more than 60% of the top medical device companies using passive UHF RFID in 2010. RFID is becoming increasingly prevalent as the price of the technology decreases. In March, 2010 a Korean laboratory successfully created a printed chip using carbon nanotubes that would halve the price of a passive UHF RFID tag to about three cents by late 2011 [2].

RFID has been used for years as personal identification in the form of an employee badge (Fig. 2) used to provide access to secured buildings. The badges can take many form factors and provide a tamper-proof form of identification. They can also be used for automated time and attendance tracking, enabling companies to streamline payroll and maximize resource allocation.

Fig. 2. ID Badges

Wide spread usage of anti shoplifting systems (EAS – Electronic article surveillance) systems are just one example of RFID undetected integration into every days life. Shoplifting causes many problems, of which the actual theft is just one. Consumers who see shoplifting taking place feel uncomfortable and may not return to the store. Shoplifting also results in out-of-stock conditions that are not detected by the store's inventory management system because the items were never actually sold. Figure 3. shows typical outlook of gait antennas for EAS systems located at entry points.

Given that the primary focus of any health care institution is the patient, RFID technology is becoming a real life-saver, helping to provide solutions that address patient care validation, tracking, and extending services to families. In addition, Assisted-GPS technologies are providing wide-area tracking of assets and people in new and important ways for patient safety.

New methods of electronic monitoring of criminal offenders help tremendously in providing information critical to public safety. An example would be the case of a suspicious

Fig. 3. Typical EAS gates

Fig. 4. Electronic documents

pattern developing, such as a past offender entering into a zone near a playground or school. RFID technology can help track an individual with prior confrontations.

The most common applications currently being deployed in industry today are [3]:

- Asset Tracking – Movement of expensive or shared equipment
- Asset Inventory Collection – Physical inventories are greatly improved with the speed of RFID tag scanning versus bar-coding with the speed of RFID tag reading versus barcode scanning.
- Inventory Control Functions – Receiving, Put away, Picking, Ship confirmations are all being deployed with RFID as the main technology
- Authentication – Verifying authentic product by means of reading a covert RFID tag embedded within
- Asset Security – Tracking assets and their movement through exits and associating the assets with people
- Compliance Labelling – Meeting customer tagging requirements for supply chain from major retailers
- Work-In-Process (WIP) - Management of product movement through the manufacturing line
- Product Search – Finding lost or misplaced product or assets within a facility

- Yard (warehouse) Management – Inventory control of incoming and outgoing vehicles or products from a yard 5(open or closed warehouse).

Fig. 5. Multi tag identification at warehouse entrance.

Some of relatively new and interesting examples on RFID usage can be found each day [12].

A casino embeds computer chips in plastic gaming chips. The RFID-enabled gaming chips communicate with sensors and antennas throughout the casino, allowing operators to track gamblers' average bets and the location of high-denomination chips (Fig. 6).

Also, the U.S. Food and Drug Administration is requiring drug makers to use RFID labels by 2008. The proliferation of counterfeit drugs is seen as a growing problem worldwide.

Currently, wholesalers can buy smuggled drugs and send them to pharmacies with little difficulty. With RFID, pharmacists can determine a drug's origin. Though not foolproof, one Purdue Pharma official views RFID as the most significant drug-counterfeiting deterrent to emerge in two decades.

In Japan, RFID is the next wave in Kaiten-sushi restaurants. Kaiten-sushi meals are traditionally delivered to customers in conveyor-belt fashion—the meals are paraded in front of hungry patrons and claimed directly from the conveyor. At least one Kaiten-sushi restaurant now places RFID tags on its plates, allowing the wait staff to almost instantaneously calculate customers' tabs by simply scanning a party's accumulated plates.

A French company launches an RFID-based system to provide a way to reduce errors and improve productivity in the development of dental prosthetics such as crowns and bridges. Each prosthetic is embedded with a computer chip that records each step in the manufacturing process. The data can then be passed onto the patient, and/or retrieved for future dental work. The solution, which is aimed at the laboratories employed by dentists to produce dental prostheses, is designed to reduce the time it takes labs to accurately process each item.

While RFID is widely used today across many segments of the business world, because of the cost of tags and related technologies, mass adoption is still considered to be a few years away. Nonetheless, RFID's emergence is largely viewed in terms of when rather than if. Certainly, it's expected that the technology will ultimately become ubiquitous in the supply chain [1].

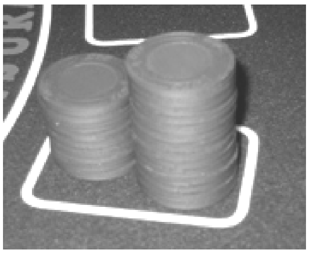

Fig. 6. RFID antenna integrated under each chips placing position

A cornerstone of RFID adoption that already appears to be in place is the formation of standards. International standards have been adopted for very specific applications, like animal tracking, and many other standards initiatives are underway through bodies like the International Organization for Standardization (ISO) and EPCglobal Inc.

4 New applications

4.1 Healthcare

Based on equipment produced by one of the leaders in intelligent RFID tag design KSW-Mikrotec author was leading the project to create a system that continuously monitors donated blood with the help of RFID chips. System was developed for German transfusion equipment producer company LMB (www.lmb.de).

The chip clearly identifies the blood bags from the blood donor to the patient. It also contains a temperature sensor. That's important because blood spoils quickly, and it's crucial to ensure an uninterrupted cooling chain. According to the German Red Cross, German hospitals alone require 15,000 blood donations per day. Nevertheless, depending on the kind of blood donation, between two and six percent of the donated blood is discarded, for reasons including interrupted cooling chains, unclear documentation, and expired "use by" dates.

In a study conducted by Austria's National Institute for Healthcare (ÖBIG) estimates that seamless documentation of blood donations can reduce this disposal rate by between 20 and 40 percent and thus save more than 1 million annually.

Today the precious bags of blood are for the most part manually monitored by means of routing slips. The new RFID chip is attached to the blood bag when the blood is drawn from the donor. From that point on it is a part of all steps in the process.

The biggest technical challenge is the need to protect the chip against the strong forces at work in centrifuges, where they are subjected to up to 5,000 times the force of gravity acceleration — about 1,500 kilograms. A specially developed elastic housing ensures that the RFID chip survives. A microcontroller stores up to 1000 measurement values of the sensor and a 256 Bytes of general blood information [4]. The data can be called up at any time.

A blood donation moves from the blood collection organization to the blood bag manufacturer to central blood banks and reaches its final destination at the patient. The pilot projects call for the RFID system to be integrated into the IT systems of all the partners in transfusion chain. Then each organization can document the data from the blood bag in its own system and transfer the bag data onto the chip. The blood is thus seamlessly documented from the vein of the donor to the transfusion point. The project was nicknamed „TempStamp“.

TempStamp is a credit card sized RFID label (Fig. 7) that works via wireless communication in the ISM-band at 13.56 MHz in accordance with ISO 15693-3. The integrated paper-thin battery enables the independent use of the temperature label outside of the range of a reader. Fast communication protocol allows the smooth access to the label, which is tamper-proof against unauthorized access to the label by a 3 level password hierarchy. TempStamp label enables the user to measure temperatures in a configurable measurement interval, to compare with the standard values and to store related information regarding the temperature characteristics. This temperature information will be collected by a RFID reader and can be processed afterwards according to the user's need. Depending from the application and measurement interval TempStamp label can be re-used.

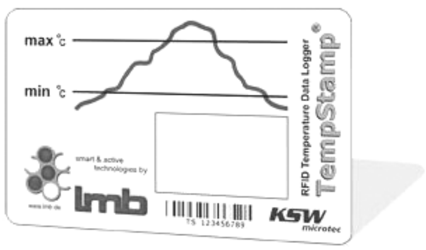

Fig. 7. Intelligent temperature monitoring RFID tag

4.2 Location systems

A real-time location system (RTLS) is one of a number of technologies that detects the current geo-location of a target, which may be anything from a vehicle to an item in a manufacturing plant to a person. Figure 8. shows comparison of different technology and methods for location tracking. RTLS-capable products are used in an ever-increasing number of sectors including supply chain management, health care, the military, retail, recreation, and postal and courier services [10].

Authors are currently engaged on a development of one such systems for medical usage.

The project involves upgrading existing RFID equipment with triangulation algorithm and radar possibilities [14].

Basically, RFID is the ability to detect the presence of a tag and to uniquely identify that tag. All RFID systems can perform these simple tasks: identification and presence detection. The range or distance from tag to reader, also known as access point or gateway, at which this task can be performed depends on the technology being used. Passive RFID's maximum range is about 20-30 feet (6-10 meters) while active RFID can achieve ranges of several thousand feet. Aside from presence detection and identification of tags, RFID is able to perform various types of locating. Both passive and active technologies are capable of performing basic chokepoint locating while the RTLS technology which is built upon active RFID technology, is capable of performing more sophisticated precision locating [15].

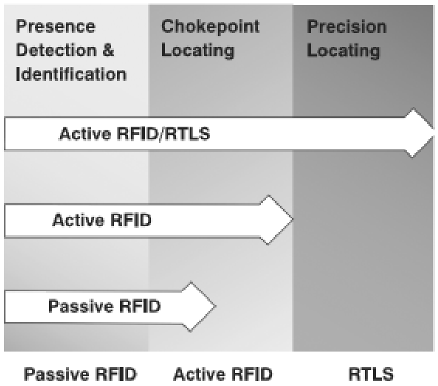

Fig. 8. Tracking level capability comparison chart.

The RFID-radar (standard reader with radar option) measures the path length for signals travelling from the transponder to the reader to determine range. By comparing signals arriving at two identical receivers with closely spaced antennas, the reader is able to determine the angle of arrival of the signals from the transponder and hence the direction of that transponder from the reader. In our project, as a test equipment, we are using Trolley Scan(Pty) Ltd RFID radar (Fig. 9).

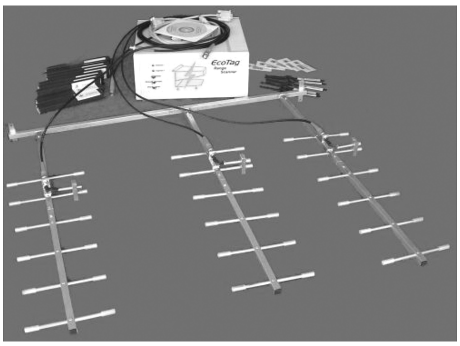

Fig. 9. RFID radar type reader with three directional antennas.

RFID-radar is a form of a relatively low cost RFID reader system. What was unique with this new technology was that it has the ability to measure the distance travelled by the radio signal very accurately. The system could also measure the location of multiple transponders simultaneously and used the same low cost passive transponders used in normal RFID readers.Based on RFID–radar measurements a triangulation algoritham should be used.

Triangulation applies the properties of a triangle to a set of known geometric information between anchor nodes and an unknown target node to compute the location of the target node. The discussion here is limited to two dimensional space because of available data amount.

There are two main approuch in triangulation: Lateration and angulation. Both methods have the same tolerances but different input data. In case of RFID-radar angulation method is used.

Angulation is similar to lateration, except that angles are used instead of distances in determining the position of a target node. In general, if two angle measurements and one distance measurement is known then the location of the target node can be determined (Fig. 10).

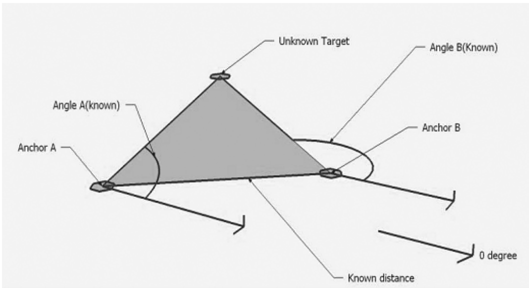

Fig. 10. Schematic explanation of angulation locating

5 The future

The progress of RFID adoption divides naturally into eras: the Proprietary era, the Compliance era, the RFID-Enabled Enterprise era, the RFID-Enabled Industries era, and the Internet of Things era (Fig. 11).

In the beginning, during the Proprietary era, businesses and governmental entities created systems designed to track one particular type of item, and this tracking information typically remained within the same business or governmental entity. In the Compliance era (the present era), businesses implement RFID to meet mandates for interoperability with important customers or regulatory agencies but often don't use the RFID data themselves. The future will bring the era of the RFID-Enabled Enterprise, where organizations will use RFID information to improve their own processes. The era of RFID-Enabled Industries will see RFID information shared among partners over robust and secure networks according to well-established standards. The final RFID era that is currently foreseeable is the era of the Internet of Things. By this time, the ubiquity of RFID technology and other enabling technologies, combined with high standards and customer demand for unique products based on this infrastructure, will lead to a revolutionary change in the way we perceive the relationship between information and physical objects and locations [7].

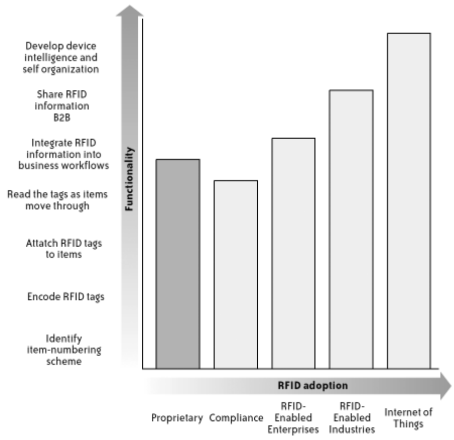

Fig. 11. Natural development of RFID chart.

Developments in RFID technology continue to yield larger memory capacities, wider reading ranges, and faster processing. It is highly unlikely that the technology will ultimately replace barcode — even with the inevitable reduction in raw materials coupled with economies of scale, the integrated circuit in an RF tag will never be as cost-effective as a barcode label. However, RFID will continue to grow in its established niches where barcode or other optical technologies are not effective [16]. If some standards commonality is achieved whereby RFID equipment from different manufacturers can be used interchangeably the market will very likely grow exponentially.

6 Conclusion

RFID is here to stay. That's apparent when some of the world's largest and best-known companies are investing in the technology. It's apparent given the potential RFID offers as a tool for businesses and consumers alike. It's also a given that costs will continue to be watched closely and that concerns like privacy will continue to be voiced.

References

[1] J. CURTIN, R. J. KAUFFMAN, AND F. J. RIGGINS. *Making the 'most' out of rfid technology: a research agenda for the study of the adoption, usage and impact of rfid*, Information Technology and Management, 8, 2 (2006), 87-110

[2] C. HALEY *Are You Ready for RFID?*, Wi-Fi Planet.com. <http://www.wi-fiplanet.com/columns/article.php/3109501> 11, 14 (2003).

[3] R. CLARKE. *Packaging RFID For The Real World,* Michigan State University School of Packaging. East Lansing, MI. 9, 8 (2005).

[4] H. METRAS. *RFID tags for ambient intelligence: present solutions and future challenges,* Article. Grenoble. 10 (2007).

[5] P. SORRELLS. *Optimizing read range in RFID systems,* Microchip Technology Inc. Article. 12, 7 (2000).

[6] [6] L. SANDIP. *RFID Sourcebook,* Prentice Hall PTR ISBN: 0131851373 8, 31 (2005).

[7] R. WANT. *The Magic of RFID,* Magazine article QUEUE. Volume 2 Issue 7, 10 (2004).

[8] K. FINKENZELLER. *RFID Handbook,* West Sussex: John Wiley & Sons Ltd, (2008).

[9] B. GLOVER, H. BHATT. *RFID Essentials,* O'REILLY, Second edition. (2007) 5-14

[10] M. O'CONNOR. *New markets for RTLS systems,* RFID Journal, Article. 2 (2010).

[11] S. GARFINKEL, H. HOLTZMAN. *Understanding RFID Technology,* JohnWiley & Sons Ltd, (2005).

[12] M. FARRAGHER. *Practical use of RFID,* Article. ¡ http://www.firstfocus.eu/Home.html¿ 11 (2009).

[13] *Passive, Battery-assisted Passive and Active Tags: A Technical Comparison,* Intelleflex Corporation. (2005)

[14] *RFID Radar user manual,* Trolley Scan(Pty) Ltd (2007).

[15] B. VENILAL. *Two Dimensional Localization of Passive UHF RFID Tags,* Thesis for the degree of Master of Science in Computer Engineering B.E., Mumbai University, India, (2003).

[16] *Engineering RFID Systems,* 2008 IEEE International Conference on RFID, <http://www.rfidjournalevents.com/live2008/ieee.html> 4, 16-17 (2008).