

Overview of RFID Technology and Its Applications in the Food Industry

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ABSTRACT: Radio frequency identification (RFID) is an alternative technology with a potential to replace traditional universal product code (UPC) barcodes. RFID enables identification of an object from a distance without requiring a line of sight. RFID tags can also incorporate additional data such as details of product and manufacturer and can transmit measured environmental factors such as temperature and relative humidity. This article presents key concepts and terminology related to RFID technology and its applications in the food industry. Components and working principles of an RFID system are described. Numerous applications of RFID technology in the food industry (supply chain management, temperature monitoring of foods, and ensuring food safety) are discussed. Challenges in implementation of RFID technology are also discussed in terms of read range, read accuracy, nonuniform standards, cost, recycling issues, privacy, and security concerns.

Keywords: applications in food industry, RFID, working principle

Introduction

Rapid identification technologies have led to a better handling of raw materials and finished products in the food industry. Traditionally, universal product code (UPC) barcodes have been used to automate and standardize the identification process. Even though the barcodes are less expensive, they require a clear line of sight between the reader and tag. Radio frequency identification (RFID) is an alternative technology that has been recently used to speed the handling of manufactured goods and materials. RFID is a generic term for technologies that use radio frequency waves to identify an object. RFID enables identification of an object from a distance without requiring a line of sight. RFID tags can incorporate additional data such as details of product and manufacturer and can transmit measured environmental factors such as temperature and relative humidity. Additionally, RFID readers can distinguish between many different tags located in the same area without any human assistance. However, RFID technology is more expensive than the traditional barcode technology (Want 2006).

There are 5 frequency ranges commonly used by RFID systems: low frequency (9 to 135 KHz), high frequency (13.553 to 15.567 MHz), amateur radio band (430 to 440 MHz), ultra high frequency (860 to 930 MHz), and microwave frequency (2.45 and 5.8 GHz) (Brown 2007). Typical applications of RFID technology include payment of highway tolls, labeling of products for rapid checkout, tracking of inventory, tagging of animals, securing of automobile keys, and so on. In the past few years, RFID technology has been increasingly applied in the food industry. Some of the applications of RFID technology in the food industry include those for supply chain management, temperature monitoring of foods, and ensuring food safety.

The purpose of this article is to inform the reader about key concepts and terminology related to RFID technology and to provide examples of how these RFID concepts/capabilities are being applied in the food industry.

Components of an RFID System

RFID tags

An RFID tag, also known as a transponder, is a small device that can be attached to an object so that the object could be identified and tracked. The tag is composed of a microchip, an antenna, and a substrate or encapsulation material. The microchip stores data whereas the antenna transmits and receives the data. The microchip and antenna attached to the substrate are referred to as the inlay. The inlay is encased in protective material such as paper, plastic, or a film. The size of a tag is usually determined by the size of its antenna because the microchip is usually very small in size (Brown 2007). Tags are available in many different shapes, sizes, and protective housings. The smallest tags commercially available measure $0.4 \times 0.4 \text{ mm}^2$ and are thinner than a sheet of paper (Roberts 2006).

Classification based on power source

Active tag. Active tags require a battery to power up its microchip. Active tags have longer range of operation, greater processing power, and higher operating frequency because they have their own power source. However, higher cost (\$20 to \$100), larger size to accommodate the battery, and shorter life of the batteries make active tags impractical for labeling applications (Brown 2007). Active tags operate at frequencies of 433 MHz, 2.45 GHz, or 5.8 GHz. Readers can communicate with active tags from a distance ranging from 20 to 100 m (Weinstein 2005).

Passive tag. Passive tags do not require any power source. They derive power from the signal received from the reader. Therefore, they require a strong signal from the reader and transmit a weak signal to the reader. They transmit only when they are in the field of the reader. These tags are less expensive (approximately 10 cents per tag for large quantities), have a very long operational life, and are small enough to fit onto an adhesive label. Passive tags are used

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in supply chain for tracking different items. Even at the price of 10 cents per tag, passive tags are more expensive than a barcode label, which costs less than 1 cent (Brown 2007). Passive tags typically operate at frequencies of 128 KHz, 13.6 MHz, 915 MHz, or 2.45 GHz. Readers can communicate with passive tags from a distance ranging from a few centimeters to 10 m (Weinstein 2005).

Semipassive tag. Semipassive tags, also known as semiactive tags, use a battery only to run the circuit of its microchip. They transmit the signal using the same method as that of passive tags. These tags can be read at a higher speed as compared to passive tags. These tags can also monitor and record external conditions using sensors, which are powered by a battery (Brown 2007).

Classification based on read-write capabilities. The initial entry of data into a tag is known as commissioning of the tag. Tags are classified as read-only, write-once read-many (WORM), electronically erasable programmable read-only memory (EEPROM), and read-write tags based on their read-write capabilities (Brown 2007).

Read-only tags. Read only tags have a unique identification number encoded into their microchip during their manufacturing. The identification number can provide specific information such as batch number of a product. However, these unique numbers cannot be changed once the tags are manufactured.

Write-once read-many (WORM) tags. Data to a write-once read-many tag is first written by the customer during application of the tag on the object to be tagged. WORM tags permanently establish any information onto the tag, which can be read by the reader anytime during the lifetime of the tag.

Electronically erasable programmable read-only memory (EEPROM) tags. Data of an EEPROM tag can be erased and rewritten many times with new information at different point of time.

Read-write tags. Data can be added to read/write tags by the reader at any point in their lifetime. These tags can monitor and record external conditions as a function of time.

Tag reader

The tag reader is a device that powers and communicates with a tag. The reader consists of a high frequency (HF) interface (consisting of a transmitter and a receiver), antenna, and a control unit. The HF interface generates power to activate and supply power to the tag, sends data to the tag, and receives data from the tag. The reader has one or more antennas that emit radio waves and receive signals transmitted from the tag. The control unit is based upon a microprocessor to control communication with the tag. The control unit also codes and decodes the signal received from the tag. The performance of a reader is usually measured in terms of the range and rate the reader can identify, read to, or write to a tag (Finkenzeller 2003; Brown 2007).

Antenna

The antenna is a conductive element that enables communication between the tag and an RFID reader. Both the reader and tag of an RFID system have antennas for transmitting and receiving data. The antenna of the reader converts the electricity produced by the reader to radio waves and transmits the waves to the tag. The antenna of the tag receives the radio waves and converts them to electricity for powering the microchip. The size of the antenna is important because it determines the operating range of a reader. For low (125 KHz) and high frequency (13.56 MHz) systems, antennas are coils of copper wire to support near-field waves, which are predominantly magnetic in nature. Antennas of amateur radio band, ultra high, and microwave frequency systems are designed similar to radio antennas to support electric nature of the ultra high

frequency (Sweeney II 2005). These straight antennas are tolerant of minor deviations and the radio waves emitted by them can travel longer distances (Brown 2007).

Working Principle of an RFID System

An RFID system is composed of a tag and a reader. The reader generates and transmits an interrogation signal to the tag. An active tag powers its microchip from a battery and transmits signal to the reader. A passive tag is powered by the reader either by magnetic induction (near-field coupling) or by electromagnetic wave capture (far-field coupling). Both of the methods can transfer enough power to a passive tag for sustaining its operation. RFID systems based on frequencies between 100 kHz and 30 MHz operate using magnetic induction. In contrast, RFID systems based on microwave frequencies (2.45 and 5.8 GHz) operate using electromagnetic wave capture (Finkenzeller 2003).

Magnetic induction

Faraday's principle of magnetic induction is the basis of near-field coupling between a reader and a tag (Figure 1). An alternating magnetic field is created by passing large alternating current through the antenna coil of the reader. If the tag, incorporating a smaller antenna coil, is placed in this magnetic field, an alternating voltage appears across the coil of the tag. This voltage, once rectified and coupled to a capacitor, results in accumulation of charge, which is used for powering the chip of a passive tag (Finkenzeller 2003).

Data is transferred from the tag to the reader using load modulation. The tag varies the energy released from the capacitor to the coil of its antenna. This variation is transmitted from the tag to the reader by transformer-type inductive coupling. The reader reads the signal by monitoring the change in the terminal voltage of the coil of its antenna. Thus, changing the load resistance attached across the coil terminals of tag's antenna has the effect of voltage amplitude modulation across the coil terminals of reader's antenna (Finkenzeller 2003; Weinstein 2005).

Near-field coupling is the preferred approach for implementing a passive RFID system. However, the range of operation for a near-field RFID system approximates to $c/2\pi f$, where c is the speed of light and f is the frequency of operation. This range is 3.5 and 0.05 m for frequencies of 13.56 and 915 MHz, respectively. As the frequency of operation increases, the range of operation decreases. Therefore, near-field RFID systems operate at a frequency of less than 100 MHz. The magnitude of magnetic field is inversely proportional to the cube of the distance (r) from the center of the reader coil to the tag. If the strength of the magnetic field is too weak at a given distance, the tag will not have sufficient energy to switch itself on. At 13.56 MHz, most near-field systems have a practical operating range between 0.01 and 0.30 m (Want 2004). These limitations associated with near-field RFID systems have led to far-field RFID systems (operating at a frequency of greater than 100 MHz) based on electromagnetic wave capture (Want 2006).

Electromagnetic wave capture

Far-field RFID system works on a principle similar to that of a radio set. Tags of far-field RFID systems capture electromagnetic waves propagating from the dipole antenna attached to the reader (Figure 2). A smaller dipole antenna in the tag receives this electromagnetic energy as an alternating potential difference. This potential difference is rectified and coupled to a capacitor for accumulation of charge and this is then used for powering the chip of a passive tag (Finkenzeller 2003).

The data of far-field RFID tags cannot be transferred to the reader using transformer-type inductive coupling because the tag operates beyond the near-field region. Instead, data is transferred from the tag to the reader using back scattering. Tags using backscatter reflect part of the electromagnetic wave sent from the reader, back to the reader. However, the tag can change the power of the reflected wave by varying the resistance of a load connected to its antenna. This variation in resistance of the load is controlled by the data to be transmitted. Thus, the power of the reflected wave received back at the reader is controlled by the tag's data and is the mechanism for transmitting the data from the tag to the reader in a far-field backscatter RFID system (Finkenzeller 2003; Weinstein 2005).

In far-field RFID systems, energy delivered to the tag and signal transferred to the reader follow an inverse law. This attenu-

ates the overall signal strength by $1/r^4$ where r is the distance between the center of the reader coil and the tag. The range of operation (approximately 3 m) for a far-field RFID system is limited by the amount of energy received by the tag and the sensitivity of the reader to the reflected signal. With advances in the semiconductor industry, the energy required to power a tag at a given frequency continues to decrease. Inexpensive readers with improved sensitivity have also been developed (Want 2006).

To achieve longer range and operate tags with greater power consumption, backscatter tags often have a backup battery to supply power to the tag's microchip. The tags generally have a power saving "power down" or "stand-by" mode to prevent the tag's backup battery from being used unnecessarily. If the tag moves out of the range of the reader, the tag automatically switches over to the "power down" mode. The tag is not reactivated until a sufficiently strong

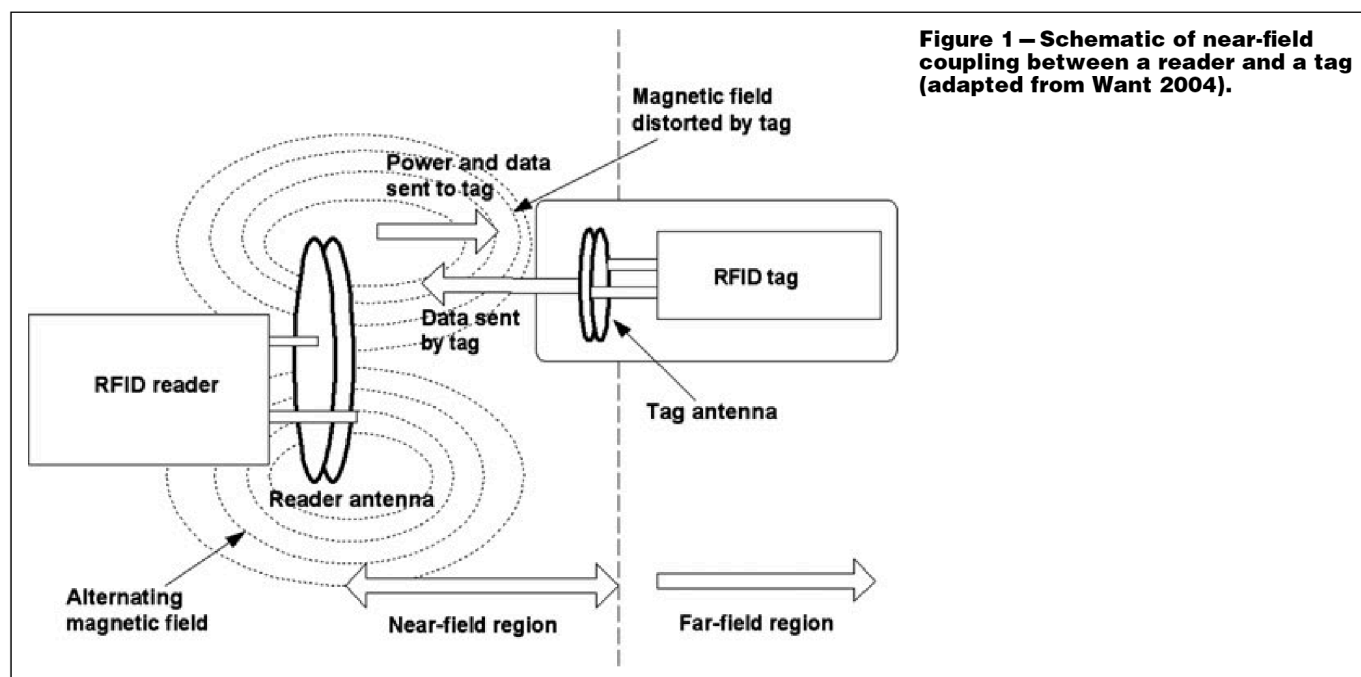


Figure 1 – Schematic of near-field coupling between a reader and a tag (adapted from Want 2004).

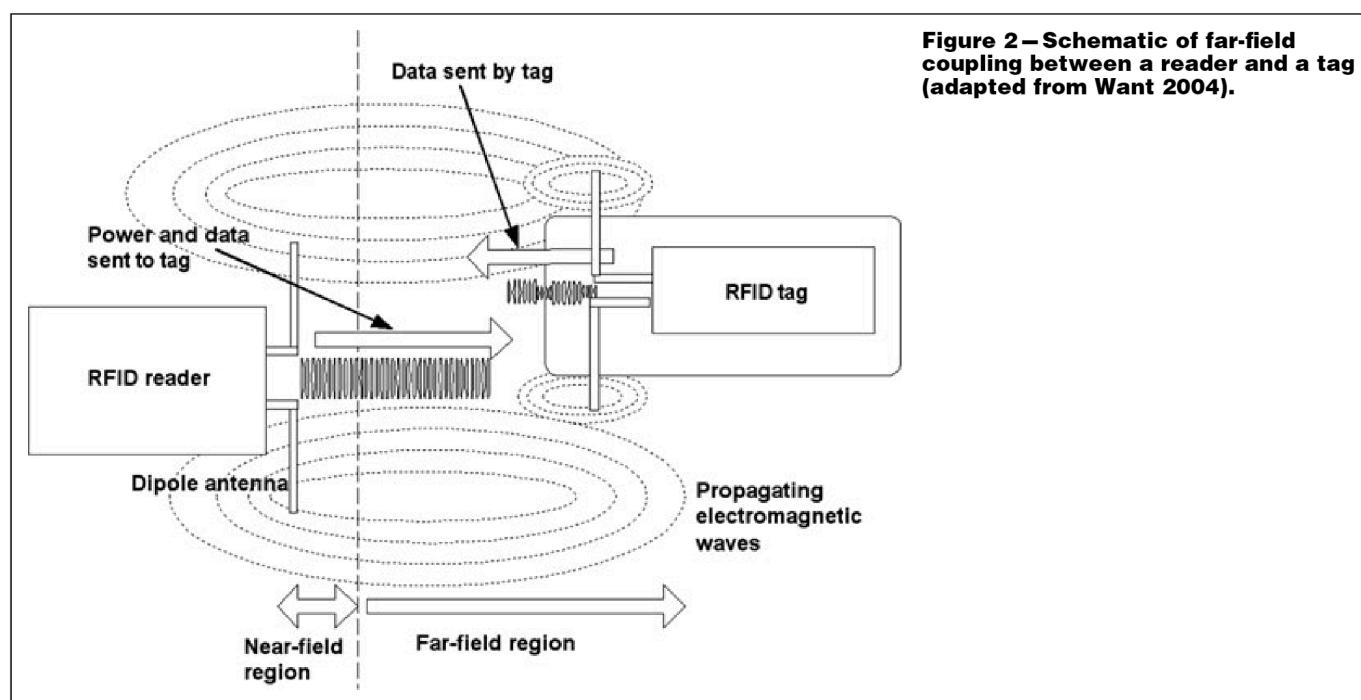


Figure 2 – Schematic of far-field coupling between a reader and a tag (adapted from Want 2004).

signal is received in the read range of the reader, whereupon it switches back to normal operation. This backup battery of the tag never provides power for transmission of data between the tag and reader, but serves exclusively for the supply of power for the tag's microchip. Data transmission between the tag and the reader relies exclusively upon the power of the electromagnetic field emitted by the reader (Finkenzeller 2003).

RFID Technology in the Food Industry

Numerous applications of RFID technology in the food industry include those for supply chain management, temperature monitoring of foods, and ensuring food safety.

Supply chain management

In supply chain management, RFID tags are used to track food products during distribution and storage. RFID technology serves as a replacement for barcode scanners for this particular application. RFID technology has the following advantages over barcodes: RFID systems do not require line of sight to read the tag, their range of operation is larger as compared to that of a barcode, readers can simultaneously communicate with multiple RFID tags, and tags can store more data as compared to a barcode. With its ability to scan multiple tags throughout 3-dimensional space, known as the interrogation zone, RFID technology also facilitates automated product shipments from a warehouse to a retail store. An RFID system implemented in a store can be used to maintain an accurate database of its inventory that automatically alerts a warehouse management system once the inventories are low. Wal-Mart has implemented such a just-in-time product shipment system (Weinstein 2005). Thus, RFID technology will provide benefits such as greater speed and efficiency in stock operations, better inventory tracking through out the supply chain, and enhanced forecasting (Jones and others 2005).

Wal-Mart stores Inc. was the 1st major company to push for RFID implementation in supply chain management. In June 2003, Wal-Mart announced that it would require its top 100 suppliers to put RFID tags on shipping cases and pallets by 1 January 2005. Each tag would store an Electronic Product Code (EPC) that would be used to track products as they enter Wal-Mart's distribution centers and then in turn are shipped to individual stores. Wal-Mart now requires its top 300 suppliers to place RFID tags on all it pallets and cases of products (Jones and others 2005).

British Telecommunications has launched a new online real-time food traceability system based on RFID technology. This system, known as BT foodnet, tracks products in real-time to speed-up and reduce the cost of recalling products. The online network provides retailers and their suppliers access to real-time synchronized data on the current and historical status of all stock items as they pass throughout the supply chain (from manufacturer to the point of sale). This system combines barcodes and RFID read/write tags with a secure data exchange platform on the Internet (Connolly 2007).

eProvenance (Bordeaux Cedex, France) has developed an RFID-based tracking system to preserve the quality of fine wines and trace their origin. This RFID system consists of 3 components. The 1st component is a 13.56 MHz semiactive RFID tag placed inside each case of wine. This semiactive tag enables wine producers and distributors to monitor and log ambient temperatures in each case of wine 3 times a day. The 2nd component is a 13.56 MHz passive RFID tag with a unique code attached to the base of each bottle for tracking and inventory management. The 3rd component is a proprietary and tamper-proof neck seal at the base of the capsule of each bottle. The seal has a unique identifying code printed with

invisible ink, which contains identification numbers of both the semiactive and passive tags. All 3 components are linked together with their unique identification numbers on an online database (Launois 2008).

Unilever (London, U.K.) uses RFID technology to move, handle, and track products in the warehouse. United biscuits (Hayes, U.K.) uses RFID technology to control the movement of raw materials and in weighing, mixing, and baking processes involved in the preparation of biscuits and cakes (Angeles 2005).

RFID technology has been used by cheese manufacturers to trace cheese along the supply chain with great precision. This tracking system could result in rapid product recall in case of a problem. Customers can find the entire history of the cheese after purchase by entering an alphanumeric code on a website (Regattieri and others 2007).

Temperature monitoring

FreshtimeTM semiactive RFID tags from Infratab Inc. (Oxnard, Calif., U.S.A.) monitor the shelf life of foods to which they are attached. The tag senses temperature and integrates it over time to determine the shelf life of a product, which can be communicated to a reader. The tags also have a battery and an optional visual display that provides green, yellow, and red indicators depending upon the status of the item (for example, green for fresh and red for unsafe). The range of operation for these tags is from -25 to 70°C .

An RFID-based temperature datalogger (i-Q32T) by Identec Solutions (Lustenau, Austria) is capable of storing up to 13000 temperature readings in its memory, which can be retrieved using a reader at distances of up to 100 m. The datalogger can be used to monitor and log the internal temperature of food products during processing and cool-down periods. The range of operation for this datalogger is from -40 to 85°C and it has a battery life of over 6 y. Temperature measurements are accurate to within 0.25°C and logging intervals can range from 1 min to 18 h (ElAmin 2005).

IDS-SL13A from IDS Microchip AG (Wollerau, Switzerland) is a passive/semipassive RFID datalogger optimized for single-cell battery-powered smart labels with sensor functionality. The datalogger can be powered from thin and flexible batteries (1.5 or 3 V) as well as from the radio waves transmitted by an RFID reader. The range of operation for this datalogger is from -40 to 110°C with a maximum accuracy of 0.5°C .

Food safety

RFID systems can be used to ensure that food products such as meat, fruit, and dairy products remain within a safe temperature range during transportation and storage. VarioSens[®] RFID tag from KSW Microtech AG (Dresden, Germany) can function as a temperature datalogger and as a supply-chain tracking tool. The range of operation for this datalogger is from -20 to 50°C . TurbotagTM from Sealed air (Elmwood Park, N.J., U.S.A.) is another temperature monitoring RFID tag, which captures and delivers the temperature history of any product to which it is tagged.

ThermAssureRFTM from evidencia (Memphis, Tenn., U.S.A.) is a new RFID-based datalogging system that combines tracking and tracing with temperature measurement. Combining RFID and temperature logging tags provides the processors with a means of, complying with Hazard Analysis and Critical Control Point (HACCP) requirements. ThermAssureRF can also track goods throughout the supply chain. This temperature logger is currently being used by a variety of companies that ship wine, produce, seafood, meat, poultry, pharmaceuticals, and cosmetics (ElAmin 2007).

Auburn Univ. Detection and Food Safety (AUDFS) project combines RFID technology with sensors for detection of pathogens in

food. The goal of this project was to coat microscopic structures with bacteriophages or viruses that bind with pathogens. When a pathogen binds with the coating, a signal will be transmitted to a handheld RFID reader (Nambi and others 2003).

Other applications

RFID technology has also been used in monitoring the ripening of climacteric fruits during transportation and vending. Vergara and others (2007) developed a prototype of an RFID system with metal oxide (MOX) sensors onboard the reader for monitoring the ripening of apples. They integrated a commercial off the shelf inductive coupling radio frequency transceiver operating at 13.56 MHz (ISO 15693 compliant), micro-hot plate gas sensors, driving, and readout electronics to assess the conservation stage of apples.

Appropriate RFID Technology for Different Applications

R FID technology should be used very carefully for different applications in the food industry. Food manufacturers should take into consideration the composition of food, packaging material, and the packaging environment. For example, foods with high moisture content such as fresh produce interfere with the working of an RFID system because water absorbs RFID signal. This interference by water is more pronounced for RFID systems operating at microwave frequency range. Therefore, RFID systems operating at low frequency (9 to 135 kHz) range should be used for such applications. Additionally, foods packaged in metal cans pose a unique challenge because metals can short out tags by reflecting signals. Therefore, the tag should be placed away from the metal piece of the can while still maintaining the integrity of packaging (Manias 2006). Recently, QinetiQ Ltd. (London, UK) has developed RFID tags (Omni-ID Prox™) in the UHF range that work in the presence of metals and liquids. This is a breakthrough for labeling foil-packaged products, canned products, and liquid food products (Connolly 2007).

Challenges in Implementation of RFID Technology

Technical challenges

One of the main technical challenges in implementing RFID technology is its unreliability in a retail environment. It is very difficult to read ultra high frequency tags near a human body because of the interference from the high water content of humans (Roberts 2006). Tags on the products with large amount of liquid or metals can not be read easily because liquids absorb signals while metals reflect them. Some of the other technical challenges in implementing RFID technology are discussed subsequently.

Read range. Most of the low frequency RFID systems have an operating range of about 1 m and ultra high frequency systems extend the operating range to 3 to 4 m. Reliable RFID readers with longer operating ranges will result in the widespread adoption of RFID technology (Want 2004).

Read accuracy. Although RFID readers do not require line of sight of the object for operation, the reader cannot communicate accurately with a tag, which is oriented perpendicular to the antenna of the reader. If a number of tagged objects are placed together randomly, some of them will be oriented in a direction that makes them invisible to the reader. This problem could be overcome either by changing the position of the reader or using antennas that are less sensitive to orientation. Most RFID readers do not operate properly in the presence of another reader. As RFID technology becomes widespread, the readers might interfere with each other (Want 2004). The Auto-ID Center at MIT has used the

Time Div. Multiple Access (TDMA) anticollision scheme to overcome this problem. Under TDMA, readers that are placed close to each other read tags at different times rather than simultaneously (Angeles 2005).

Nonuniform standards

There are differences in frequencies allocated for RFID applications because frequency allocation is generally managed by regulations of individual countries. For example, Europe uses 868 MHz for ultra high frequency whereas 915 MHz is used for ultra high frequency in the United States. Thus, a tag operating at a certain frequency in one country might not be readable in another country, which uses the same frequency for a different purpose. The lack of standardized frequency on a global basis is hampering the implementation of RFID technology for different applications. RFID standards for some applications such as supply chain (ISO 18000-3 and ISO 18000-6) have been developed (Roberts 2006).

The ISO 18000 standard defines the air interface standards (protocols by which readers and tags communicate) for various frequencies used around the world. This document is divided in 6 parts. Part 1 describes the generic parameters for all RFID frequencies. Part 2, 3, 4, 5, and 6 describes parameters for low frequency, high frequency, 2.45 GHz, 5.8 GHz, and ultra high frequency, respectively. EPCglobal specification, which incorporates and extends the ISO standard, is being incorporated into a forthcoming ISO standard (Brown 2007).

Cost

Cost is a major hurdle in the widespread use of RFID technology. Passive tags, which have some data storage capability, cost between 5 to 10 cents each when ordered in large quantities. However, they are still expensive as compared to a barcode label, which costs less than 1 cent. The cost of active tags, which are used for tagging high value items, can be up to \$100 per tag. The higher cost of the tags makes it uneconomical to incorporate tags into every retail item. Reduction in the price of the tags with improved manufacturing technologies and high volume usage might result in widespread adoption of RFID technology (Roberts 2006). The cost of implementing RFID technology can be reduced by printing a barcode, an RFID tag, and a human-readable text on one label (Ranky 2006).

Recycling issues

Adhesives, computer chips, pieces of metal from antennae, and conductive inks of an RFID tag can affect the process of recycling paper, glass, plastic, and metal. Copper used to make the antenna adversely changes the chemical and structural properties of steel during recycling of steel containers. Excess copper contamination during recycling of steel can result in soft steel making it unusable for its intended purpose (Foley 2006). During recycling of plastics, metal can contaminate polyethylene terephthalate (PET) and high-density polyethylene (HDPE). The impact on recycling can be minimized using alternative adhesives, using different metal for antenna, or by removing the tag before the package is recycled (Arnold 2005).

Privacy and security concerns

Consumer concern about privacy is a hindrance in public acceptance of RFID technology. Consumers are concerned about automatic tracking of their movement and buying habits. Use of kill switches to disable the tag at the point of sale can counter such privacy concerns regarding RFID technology. Security is another challenge in implementation of this technology. An unauthorized user

can scan tags to access private information such as details of shipments and inventory. Companies and government agencies should address these concerns to make consumers and the food industry more comfortable in implementing this technology (Weinstein 2005).

Future Trends

Industry and academic research and development on RFID technology in the near future will most likely focus on: (1) achieving 100% read rates at a speed of conventional barcode technology, (2) improving reliability of RFID tag readers, and (3) proper integration of RFID data collection with decision support tools for extracting useful information. Proper placement of tags on cases and pallets and proper configuration of pallets are needed to achieve 100% read rate. Currently, RFID tag readers are typically 80% to 95% reliable. However, these readers should become 100% reliable to extract correct information from each one of the tags (Ranky 2006). Research is also being conducted to develop low-cost (less than 1 cent) RFID tags which can be printed directly on the items to be tagged.

Conclusions

As with any new technology, there are plenty of challenges and opportunities associated with RFID technology. Some of the main challenges in implementation of this technology include unreliability in a retail environment, read range, read accuracy, nonuniform standards, cost, and recycling issues. Consumer concern about privacy and security is also a hindrance in public acceptance of this technology.

Despite all the challenges, RFID is a promising technology with the potential to be used for a variety of applications such as supply chain management, temperature monitoring, and ensuring food safety in the food industry. Use of RFID technology can improve the efficiency and productivity by providing better inventory management to reduce out-of-stock supplies and spoilage of food products. Integration of RFID tag with sensors can provide

food processors a means to monitor the temperature or quality of food products. Establishment of uniform standards and cost-effectiveness of implementing this technology could lead to widespread adoption of this technology in the food industry.

References

- Angeles R. 2005. RFID technologies: supply-chain applications and implementation issues. *Inf Syst Manag* 22(1):51–65.
- Arnold D. 2005. Impact of RFID tags on recycling. Available from: <http://www.tutorial-reports.com/wireless/rfid/environment/recycling.php>. Accessed 2009 April 10.
- Brown DE. 2007. RFID implementation. New York: McGraw-Hill. 466 p.
- Connolly C. 2007. Sensors trends in processing and packaging of foods and pharmaceuticals. *Sens Rev* 27(2):103–8.
- ElAmin A. 2005. RFID tag tracks temperature for food processor. Available from: <http://www.foodproductiondaily.com/news/ng.asp?id=63387>. Accessed 2009 April 10.
- ElAmin A. 2007. RFID tag a cold chain management tool. Available from: <http://www.foodproductiondaily.com/Quality-Safety/RFID-tag-a-cold-chain-management-tool>. Accessed 2009 April 10.
- Finkenzeller K. 2003. RFID Handbook. West Sussex, England: John Wiley & Sons. 427 p.
- Foley C. 2006. Radio frequency identification (RFID) tags copper content detrimental to recycling. Available from: <http://www.recyclingtech.org/AISL.SRI.RFID.2006.pdf>. Accessed 2009 April 10.
- Jones P, Clarke-Hill C, Comfort D, Hillier D, Shears P. 2005. Radio frequency identification and food retailing in the UK. *Br Food J* 107(6):356–60.
- Launois A. 2008. RFID tracking system stores wine bottle data. Available from: <http://www.foodproductiondaily.com/news/ng.asp?id=84511>. Accessed 2009 April 10.
- Manias G. 2006. Factors to consider when choosing a RFID system. Available from: <http://www.foodmanufacturing.com/scripts/ShowPR~RID~7222.asp>. Accessed 2009 April 10.
- Nambi S, Nyalamadugu S, Wentworth SM, Chin BA. 2003. Radio frequency identification sensors. 7th World Multiconference on Systemics, Cybernetics, and Informatics. Orlando, Fla. p 386–90.
- Ranky PG. 2006. An introduction to radio frequency identification (RFID) methods and solutions. *Assem Autom* 26(1):28–33.
- Regattieri A, Gamberi M, Manzini R. 2007. Traceability of food products: general framework and experimental evidence. *J Food Eng* 81(2):347–56.
- Roberts CM. 2006. Radio frequency identification (RFID). *Comput Secur* 25:18–26.
- Sweeney PJ II. 2005. RFID for dummies. Hoboken, N.J.: Wiley Publishing Inc. 388 p.
- Vergara A, Llobet E, Ramirej JL, Ivanov P, Fonseca L, Zampolli S, Scorzoni A, Becker T, Marco S, Wollenstein J. 2007. An RFID reader with onboard sensing capability for monitoring fruit quality. *Sens Actuators* 127:143–9.
- Want R. 2004. The magic of RFID. *ACM Queue* 2(7):41–8.
- Want R. 2006. An introduction to RFID technology. *IEEE Pervasive Comput* 5(1):25–33.
- Weinstein R. 2005. RFID: a technical overview and its application to the enterprise. *IEEE IT Prof* 7(3):27–33.