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Invited Paper

RECENT EVOLUTION IN THE TECHNOLOGY AND APPLICATIONS OF RADIO FREQUENCY IDENTIFICATION SYSTEMS

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Abstract: The evolution of RFID systems, in recent years, is shown both from a technological as from an application viewpoint. Next to technological development, attention is paid to the business approach of organisations implementing RFID. From the applications' side a wide range of new applications is presented and special attention is paid to RFID in supply chains.
Key words: RFID, business development, supply chains

1. INTRODUCTION

Radio Frequency Identification (RFID) is a wireless communication technology that let computers read the identity of electronic tags from a distance, without requiring a battery in the tags. RFID is based on storing and remotely retrieving information or data as it consists of an RFID tag, an RFID reader and a backend database. RFID tags store unique identification information of objects and communicate the tags in order to allow remote retrieval of their ID. RFID technology depends on the communication between the RFID tags and RFID readers. Readers depend on their operational frequency and have their own software running and communicate with other software to manipulate the identified tags. Basically, the application which manipulates tag deduction information for the end user, communicates with the RFID reader to get the tag information through antennas [1].

RFID systems are continuously in evolution. Modern RFID tags, like other pervasive technologies represent a culmination of the evolution toward wireless infrastructure and low-cost embedded computers. RFID tags are now the size of a grain of rice and have built-in logic (microchip), a coupling element (analogue front-end with antenna), and memory. Passive and semi-active tags use RFID readers' power to communicate, while active tags use battery power for greater range. One can read low-frequency tags up to 30 cm away, high-frequency tags up to 1 m away, ultra-high-frequency tags up to 7 m away, and active tags 100 m away or more.

RFID has become popular because it increases efficiency and provides better service to various stakeholders. But, in the past, the lack of widely accepted industry standards and resulting market fragmentation limited RFID use to a few applications. However, the situation is now changing, opening a debate about RFID's merits and implications. As RFID technology matures, it will likely unleash a new wave of applications that will exploit inexpensive and highly available automatic identification. But as the industry converges on standards that enable tags and readers to be reused and as the cost of tags approaches a few pennies per tag, new applications in new areas will develop.

2. RFID TECHNOLOGY

2.1. How an RFID system works

Most RFID systems consist of tags that are attached to the objects to be identified. Each tag has its own "read-only" or "rewrite" internal memory depending on the type and application. A typical configuration of this memory is to store product information. The RFID reader generates magnetic fields that enable the RFID system to locate objects (via the tags) that are within its range [1]. The high-frequency electromagnetic energy and query signal generated by the reader triggers the tags to reply to the query; the query frequency could be up to 50 times per second [2]. As a result communication between the main components of the system i.e. tags and reader is established. In this way, large quantities of data are generated. Supply chain industries control this problem by using filters that are routed to the backend information systems. This software acts as a buffer between the Information Technology and RFID reader.

Several protocols manage the communication process between the reader and tag. The protocols (ISO 15693 and ISO 18000-3 for HF or the ISO 18000-6, and EPC for UHF) begin the identification process when the reader is switched on. These protocol works on selected frequency bands (e.g. 860 – 915 MHz for UHF or 13.56 MHz for HF). If the reader is on and the tag arrives in the reader fields, then it automatically wakes-up and decodes the signal and replies to the reader by modulating the reader's field. The reader is also able to detect signal collision. Signal collision is resolved by applying anti-collision algorithm which enables the reader to sort tags and select/handle each tag based on the frequency range and the protocol used [1].

2.2. A comparison between RFID and bar codes

Both are support tools to automate processes and to improve operations management. They share the advantages of reducing labour, nearly eliminating human errors, and obtaining a wealth of data for further analysis. But there are differences too, as RFID tags can be hidden with no need for line-of-sight. They can be read through various materials (like wood, plastic, cardboard) except metal. Tags can re-programmed on-the-fly and they are applicable outdoors, with moisture and in high temperatures.

The high popularity of barcodes in many application domains has clarified their limitations. Conventional barcodes can only hold a small amount of information, and cannot be reprogrammed. They are susceptible to damage while the packages are being transported, and they always require line-of-sight to be read successfully. These limitations do not exist with RFID tags [3].

RFID tags can store substantial amount of data and some tags can be reprogrammed with new information throughout the items' life cycle. Also, since tags do not require human intervention, human-induced errors are reduced. Each tag can carry a distinctive 96-bit identifier, which allows billions of items to be uniquely identified.

2.3. Components of an RFID system

An RFID system consists of various components which are integrated. This allows the RFID system to deduct the objects (tag) and perform various operations on it. The integration of RFID components enables the implementation of an RFID solution. The RFID system consists of following five components: (1) a tag (attached with an object, unique identification); (2) an antenna (tag detector, creates magnetic field); (3) a reader (receiver of tag information, manipulator); (4) a communication infrastructure (enables reader/RFID to work through IT infrastructure); and (5) application software (user database/application/ interface) [4].

Tags contain microchips that store the unique identification (ID) of each object. The ID is a serial number stored in the RFID memory. The chip is made up of integrated circuit and embedded in a silicon chip. RFID memory chip can be permanent or changeable depending on the read/write characteristics. A read-only tag contains fixed data and cannot be changed without re-program electronically. A re-write tag can be programmed through the reader at any time without any limits [2]. RFID tags can be different sizes and shapes depending on the application and the environment at which it will be used. A variety of materials are integrated on these tags. Labels are embedded in a variety of objects such as documents, cloths, manufacturing materials [5].

The range of the RFID tags depends on their frequency. This frequency determines the resistance to interference and other performance attributes. The use/selection of RFID tag depends on the application. Different frequencies are used on different RFID tags. EPCglobal and International Standards Organization (ISO) are the major organizations working to develop international standards for RFID technologies in the UHF band. Both organisations are still evolving and are not fully compatible with each other. In order to avoid the use of different radio frequencies standards, most of the international communities are obliged to comply with the International Telecommunication Union (ITU) standards.

RFID *antennas* collect data and are used as a medium for tag reading. It consists of the following: (1) Patch antennas, (2) Gate antennas, (3) Linear polarized, (4) Circular polarized, (5) Di-pole or multipole antennas, (6) Stick antennas, (7) Beam-forming or phased-array element antennas, (8) Adaptive antennas, and (9) Omni directional antennas.

An RFID *reader* works as a central place for the RFID system. It reads tags data through the RFID antennas at a certain frequency [4]. Basically, the reader is an electronic apparatus which produce and accept a radio signals. The antennas contains an attached reader, the reader translates the tags radio signals through antenna, depending on the tags capacity. The readers consist of built-in anti-collision schemes and a single reader can operate on multiple frequencies. Network readers can use Wifi as wireless option. Readers can be used as standalone or be integrated with other devices and the following components/hardware into it [1].

3. ECONOMIC IMPACT AND BUSINESS ASPECTS

RFID leads to improvements of the operational and financial performance of companies by enabling organizational capabilities and coordination with supply chain partners. Additionally, RFID significantly reduces the costs of sharing information, enhance real-time information sharing, coordination, and decision making among business partners.

Analyses [6] show that the biggest economic impacts of the RFID technology result from more and better information in the whole supply chain which leads to an increase in efficiency and the ability to eliminate manual handling processes.

RFID reduces the cost of collecting data at the front end but if a company is not able to analyse this information and to draw correct conclusions from the results, RFID technology offers no real advantage. Europe needs to take the chances RFID technology offers as it is operating on a world-wide market with average wages that are high compared to important upcoming new markets like China. Regarding RFID, other countries (particularly the USA) are already one step ahead of Europe as they were with the adoption and diffusion, and the investments in IT years before.

Because RFID normally uses already existing infrastructure in companies or in a supply chain, it has to be admitted that the economic impacts of RFID will not be that significant compared to the emergence of IT years before – at least in this early stage of adoption.

Many companies use RFID because they are mandated to which is especially true for suppliers. Such rudimentary integration of RFID will not result in an increase of efficiency and productivity, maybe it will lead to higher efforts. The supplier bears the costs and, in contrast to that, the mandating customer generates the benefits of the use of RFID. Clear cost/benefit sharing models have to be put in place.

RFID is identified as an enabling technology since the technology does not provide much value on its own. It rather provides organizations with opportunities to develop data collection applications that can create value. Though there is no “one size fits all” RFID solution, value creation with RFID strongly depends on two main factors, namely the identification of a viable business model and the depth of RFID assimilation [7].

In an efficiency-centered business model, RFID can be used to achieve transaction efficiencies by reducing transaction costs for all participants. Cost reduction is mainly enabled from labour reduction, reduced coordinated costs and information asymmetry, and enhanced transaction transparency. The benefits from cost savings spill over customers in the form of lower prices. As an example, instead of manually scanning each individual case, Gillette is using RFID to automatically scan pallets’ contents at the receiving door. This enabled Gillette to reduce pallet receiving time from 12 seconds to 5 seconds, thus making the receiving process more efficient [8].

The diverse nature of RFID cost and benefit factors obligates researchers to employ a variety of cost–benefit models. Conventional models are appropriate for preliminary analysis or can be used with uncertainty-based models which counts for the corrupting influence of variability. Decision-making models on the other hand should be used as a supplementary tool for selecting among multiple alternative tracking technologies or system settings, as well as to generate a hierarchical structure of elements that affect the investment decision [9, 10].

4. SECURITY ASPECTS

As RFID is adopted for more applications, vandalism and other attacks against RFID will likely occur, stemming from temptation, dishonesty, civil disobedience, and a perverse sense of humour. But despite these differences, modern RFID security and privacy threats can still be grouped into familiar categories [11].

*Sniffing***.** RFID tags are indiscriminate— they are designed to be readable by any compliant reader. Unfortunately, this lets unauthorized readers scan tagged items unbeknownst to the bearer, often from great distances. People can also collect RFID data by eavesdropping on the wireless RFID channel. Unrestricted access to tag data can have serious implications. Collected tag data might reveal information such as medical predispositions or unusual personal inclinations, which could cause denial of insurance coverage or employment for an individual.

Tracking. RFID technology facilitates clandestine monitoring of individuals’ whereabouts and actions. RFID readers placed in strategic locations (such as doorways) can record RFID tags' unique responses, which can then be persistently associated with a person's identity. RFID tags without unique identifiers can also facilitate tracking by forming *constellations*, recurring groups of tags that are associated with an individual. RFID technology also enables monitoring entire groups of people.

5. APPLICATIONS

5.1. General Applications

Transportation is just one of the many industries that could benefit from a network of static RFID readers. For example, *rental cars* with RFID tags fixed to their windshields could store vehicle identification numbers, so rental companies could perform automatic inventories using RFID readers installed in parking lots. This network of readers could also help the companies locate their cars.

The *airline industry* could also exploit static readers. While only a very small percentage of bags are misrouted, airlines still incur a significant cost to recover and deliver misrouted items. Embedding RFID tags in luggage labels could eliminate the need for manual inspection and routing by baggage handlers. A network of readers placed along conveyor belts could read the tags' routing information and provide feedback to a system that could then direct the bags onto the correct path.

In the *healthcare industry*, tags could help reduce operational problems. A nurse could read a patient's tag to learn about his or her medical history and determine the time and dosage for an administered drug. A networked RFID reader attached to a hospital bed could also read the tag and, if combined with centralized patient records, display any known drug-induced allergic reactions for the patient [12].

RFID tags could be attached to packages to improve the efficiency of *postal work*. A pickup courier could drive by a mail box, and a mobile RFID reader mounted on the vehicle would determine if there were any packages to pick up so that the courier would not have to stop at an empty box.

Packages in a warehouse could also be labelled with RFID tags so that a robot with a built-in RFID reader could perform an *inventory check* simply by moving through the building.

Retailers are experimenting with inventory-control and payment systems. Today, people spend a considerable amount of time at checkout counters—removing items from their cart, placing them on a belt for scanning, and then returning them to the cart. Trials are underway to explore a cart integrated with an RFID reader and a wireless mobile computer authorized to make payments as customers add items to the cart.

Mostly, tags can only store and communicate static data. Interesting possibilities arise when RFID tags incorporate a sensor to obtain information about the physical world. A tag could return dynamic environmental data along with an object's identity. An RFID sensor tag attached to an airplane part could record the stress and shock experienced during the flight. The *maintenance* crew could read this information using a handheld reader and dynamically update the plane's maintenance schedule, depending on its condition.

Integrating sensors with RFID tags could also provide a snapshot of wide-area *environmental factors* found in our physical surroundings. If we could efficiently network together tag readers that could communicate with RFID sensors in their locality, we could make real-time queries about the physical world and measure environmental effects at a finer resolution than ever before. This could lead to better forecasts, new business models, and improved management techniques.

5.2. Specific Applications

Automatic payment. Automatic payment is a popular RFID application. Various industry sectors have conducted trials of RFID-enhanced cashless payment technology, from RFID-augmented credit cards to public transportation tickets. Electronic toll collection is widespread: the active transponder attaches to a car's windshield or front license plate. As the car drives over a toll road, the transponder sends account information to equipment in the toll collection lanes. The toll then automatically deducts from a prepaid account.

Animal and people tracking. RFID-tagged animals are already common. Applications vary from identifying runaway pets to tracking cattle. Various parties have used RFID-based animal tracking to monitor cows, pigs, cats, dogs, and even fish to control outbreaks of animal diseases such as avian influenza ("bird flu") or bovine spongiform encephalopathy ("mad cow disease"). RFID has also been used to track people. Manufacturers have created wearable RFID wristbands, backpacks, and clothing to track prisoners, schoolchildren, and even the elderly.

Healthcare applications. RFID applications in healthcare could save important resources that can contribute to better patient care. RFID applications could reduce the number of errors by tagging medical objects in the healthcare setting such as patients' files and medical equipment tracking in a timely manner. RFID based timely information about the location of medical objects would increase the efficiency and effectiveness of paramedical staff leading to improved patients' experience.

Security and Control Applications. RFID tags can be attached to the equipment/user personal/official belongings such as company ID cards and vehicles. By applying RFID application in secure zones, not only permission can be granted to and revoke for the users/persons in particular zone but also record individual access and the length of their stay. It is also good for audit trial.

Patrolling Log Applications. RFID is also used for auditing and controlling security persons themselves. Application provides checkpoints for patrolling the security guards. Checkpoints are basically a RFID tag which a security guard needs to scan during their sequential patrol through the reader. The reader maintains the record of the time and point at which the security guard swapped his card. This will not only help security firms administration to check the performance of its security guards but also used as a reference to track events.

Toll Road Applications. RFID applications make the toll collection/charging better with improved traffic flow, as cars/vehicles cannot pass through toll stations without stopping for payment. RFID is used to automatically identify the account holder and make faster transactions. This application helps to keep good traffic flow and to identify traffic patterns using data mining techniques that can inform the administration or decision support systems.

Green Projects integrating RFID. New opportunities to apply RFID arise notably from the integration of sensor technology to RFID tags. RFID can play an important role in applications helping to deliver a greener world. RFID applications are helping to lower the carbon footprint in several situations. Localisation: the addition of a positioning or localization functionality could give a new impetus to RFID technology because location sensing systems have a great deal of potential in several applications such as cognitive radio, sensor networks, internet of things, and several green applications. Wireless Sensor Networks: RFID and Wireless Sensor Networks (WSN) technologies are two complementary technologies. Combining both technologies presents a number of advantages. Indeed, RFID tags can replace some of the sensor nodes in WSNs and offer cheaper solutions. In addition, RFID technology provides the possibility of tracking objects. Alternatively sensors can provide various sensing capabilities to RFID tags, push logic into nodes to enable RFID readers and tags to have intelligence, and afford the ability of operating in multi-hop fashion extending potentially RFID applications. It should be also noted that most RFID tags are not biodegradable. They contain metallic components, plastic or other petrochemical based materials. Moreover, as tags become smaller, the different parts of tags are difficult to separate and so to recycle. Recent researches tend to design a completely biodegradable tag notably dedicated to medical applications and food supply chain [13].

RFID in Construction. RFID has been applied in the field of construction. The environment and working conditions are very different for each constructive action. Therefore, a particular RFID system is implemented for each context [14]. Materials are diverse according to the sort of construction; i.e., weather is different depending on the location, and the chosen solution varies if works are carried out indoors, outdoors or buried. Once the building construction is planned, different materials are moved from fabrication to the job site. In the last few years, RFID technology has been gaining importance in this supply of components, the decisions about the use of RFID systems in supply chains being an important issue [15].

6. CONCLUSIONS

It is expected that RFID will have a significant grown in healthcare, retail, food safety and maybe other markets. Maybe the market has not been booming according to what has been expected ten years ago, but it is growing steadily. A big growth in passive RFID tag market is expected due to adoption in the retail market. Also a growth in the pharmaceutical market is expected in anti-counterfeiting applications.

From a manufacturing viewpoint, a new class of extremely thin, flexible RFID tags can be produced which can be combined with printed sensors, printed batteries, thin-film photovoltaic solar cells, and other technologies. The key to good tag performance is the antenna design. The antenna helps determine where and how a tag can be used, and how well it performs. In the nearby future more development is to be expected to make better designs for antennas. As tags will be used for intelligence, it means that tags with an increased memory size are to be expected, but also at a lower cost. The integration of sensors will increase. It will help companies to better monitor and manage assets and shipments. Passive sensors for temperature, moistures, pressure, vibration and other factors will be combined with RFID to provide even more intelligence form the edge of the enterprise. Plenty of new applications are thinkable with information flowing from countless tags, but of course this stream of data needs to be managed well. Most probably cloud-based applications and services are able to take the IT support away from the point of activity.

While RFID has been in the world for quite some time, it faces some challenges to survive in the future.

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