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THE RFID TECHNOLOGY AND ITS CURRENT APPLICATIONS

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Abstract:

The paper gives an overview of the current state of the art in the radio frequency identification (RFID) technology. Aside from a brief introduction to the principles of the technology, a survey is given on major classes of RFID tags and readers, commonly used frequencies and identifier systems, current and envisaged fields of application, as well as advantages, concerns and limitations of use.

Keywords:

RFID principles, advantages, limitations, applications

1. INTRODUCTION

Although the foundation of the Radio Frequency Identification (RFID) technology was laid by past generations, only recent advances opened an expanding application range to its practical implementation.

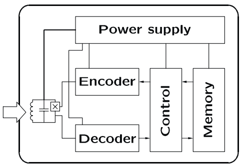
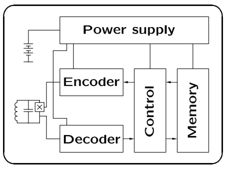
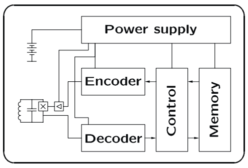
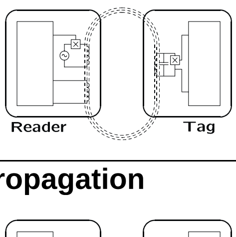
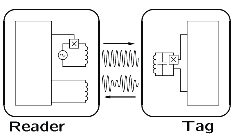
RFID is only one of numerous technologies grouped under the term Automatic Identification (Auto ID), such as bar code, magnetic inks, optical character recognition, voice recognition, touch memory, smart cards, biometrics etc. Auto ID technologies are a new way of controlling information and material flow, especially suitable for large production networks.

The RFID technology is a means of gathering data about a certain item without the need of touching or seeing the data carrier, through the use of inductive coupling or electromagnetic waves. The data carrier is a microchip attached to an antenna (together called transponder or tag), the latter enabling the chip to transmit information to a reader (or transceiver) within a given range, which can forward the information to a host computer. The middleware (software for reading and writing tags) and the tag can be enhanced by data encryption for security-critical application at an extra cost, and anti-collision algorithms may be implemented for the tags if several of them are to be read simultaneously.

One important feature enabling RFID for tracking objects is its capability to provide unique identification. One possible approach to item identification is the EPC (Electronic Product Code) [4], providing a standardized number in the EPCglobal Network, with an Object Name Service (ONS) providing the adequate Internet addresses to access or update instance-specific data. However, currently, ONS cannot be used in a global environment, and since it is a proprietary service, its use is relatively expensive, especially for participants with limited resources such as SMEs. As an alternative, researchers from the Helsinki University [7] have proposed the notation ID@URI, where ID stands for an identity code, and URI stands for a corresponding Internet address. This allows several partners to use the system and still guarantee unique identification. The project 'Identity-Based Tracking and Web-Services for SMEs' (http://www.traser-project.eu) is currently working on further development of this concept.

2. TYPES OF TAGS AND READERS

RFID tags and readers can be grouped under a number of categories. Their classification is presented in Table 1.

Classification of RFID tags	
Passive 	- also called ‘pure passive’, ‘reflective’ or ‘beam powered’ - obtains operating power from the reader - the reader sends electromagnetic waves that induce current in the tag’s antenna, the tag reflects the RF signal transmitted and adds information by modulating the reflected signal
Semi-passive 	- uses a battery to maintain memory in the tag or power the electronics that enable the tag to modulate the reflected signal - communicates in the same method, as the other passive tags
Active 	- powered by an internal battery, used to run the microchip’s circuitry and to broadcast a signal to the reader - generally ensures a longer read range than passive tags - more expensive than passive tags (especial because usually are read/write) - the batteries must be replaced periodically
By the tag’s memory type	
Read-only	- the memory is factory programmed, can not be modified after its manufacture - its data is static - a very limited quantity of data can be stored, usually 96 bits of information - can be easily integrated with data collection systems - typically are cheaper than read-write tags
Read-write	- can be as well read as written into - its data can be dynamically altered - can store a larger amount of data, typically ranging from 32 kBytes to 128 kbBytes - being more expensive than read-only chips, is impractical for tracking inexpensive items
By the method of wireless signal used for communication between the tag and reader	
Induction 	- Close proximity electromagnetic, or inductive coupling—near field - Generally use. LF and HF frequency bands
Propagation 	- Propagating electromagnetic waves—far field - Operate in the UHF and microwaves frequency bands

Classification of readers	
By design and technology used	
Read	- only reads data from the tag - usually a micro-controller-based unit with a wound output coil, peak detector hardware, comparators, and firmware designed to transmit energy to a tag and read information back from it by detecting the backscatter modulation - different types for different protocols, frequencies and standards exist
Read/write	- reads and writes data from/on the tag
By fixation of the device	
Stationary	The device is attached in a fixed way, for example at the entrance gate, respectively at the exit gate of products
Mobile	In this case the reader is a handy, movable device.

Table 1: Classification of RFID tags and readers

3. ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

3.1. Advantages

Though RFID is not likely to entirely replace commonly used barcodes in the near future, the following advantages suggest to additionally apply RFID for added value of identification:

- Tag detection not requiring human intervention reduces employment costs and eliminates human errors from data collection,
- As no line-of-sight is required, tag placement is less constrained,
- RFID tags have a longer read range than, e. g., barcodes,
- Tags can have read/write memory capability, while barcodes do not,
- An RFID tag can store large amounts of data additionally to a unique identifier,
- Unique item identification is easier to implement with RFID than with barcodes,
- Tags are less sensitive to adverse conditions (dust, chemicals, physical damage etc.),
- Many tags can be read simultaneously,
- RFID tags can be combined with sensors,
- Automatic reading at several places reduces time lags and inaccuracies in an inventory,
- Tags can locally store additional information; such distributed data storage may increase fault tolerance of the entire system,
- Reduces inventory control and provisioning costs,
- Reduces warranty claim processing costs.

3.2. Current issues of concern, limitations

Although many RFID implementation cases have been reported, the widespread diffusion of the technology and the maximum exploitation of its potential still requires technical, process and security issues to be solved ahead of time. Today’s limitations of the technology are foreseen to be overcome and specialists are already working on several of these issues.

3.2.1. Standardization

Though the characteristics of the application and the environment of use determine the appropriate tag, the sparse standards still leave much freedom in the choice of communication protocols and the format and amount of information stored in the tag. Companies transcending a closed-loop solution and wishing to share their application with others may encounter conflicts as cooperating partners need to agree in standards concerning communication protocols, signal modulation types, data transmission rates, data encoding and frames, and collision handling algorithms. Currently, two major groups of standards are competing worldwide: one is EPC created by the Auto-ID Center and receiving the support of UCC (Uniform Code Council) and EAN (European Article Numbering), the other is the ISO-specified (International Standards Organization) set of standards.

3.2.2. Cost

The cost of tags depends on their type. In the 2003 report 'RFID Systems in the Manufacturing Supply Chain' [16], ARC Advisory Group predicted the following decrease of tag prices:

	Price in 2003	Estimated price in 2008
Passive UHF tag	57 cents	16 cents
Passive HF tag	91 cents	30 cents

This predicted decrease is still deemed insufficient, as economic use of tags—taking the associated 5–35% decrease of labor costs and zero tag information generation costs into account as well—would require a maximum of 25 cents per tag for high-end products, and 5 cents for common item-level tagging.

Prices of active or semi-passive tags (at least $1 per tag) are even more of a hindrance, allowing their economic application only for scanning high-value goods over long ranges.

3.2.3. Collision

Attempting to read several tags at a time may result in signal collision and ultimately to data loss. To prevent this, anti-collision algorithms (most of them are patented or patent pending) can be applied at an extra cost. The development of these methods, aimed at reducing overall read time and maximizing the number of tags simultaneously read, still goes on [3].

3.2.4. Frequency

The optimal choice of frequency depends on several factors, such as:

a.) Transmission mode. RFID tags basically use two kinds of data transmission, depending on the behavior of electromagnetic fields at the frequency used. In lower frequencies (such as 125–134kHz in the LF band or 13.56MHz in the HF band), inductive coupling is used, while in frequency bands above (UHF with typical frequency ranges of 433MHz, 865–956MHz and 2.45GHz), wave backscattering is the main means of transmission. This also affects the safe reading range, as it is easier to build direction-selective devices with a longer read range in higher frequencies. This may restrict design freedom if either reading range or spatial selectivity are an important issue.

b.) Behavior of tagged goods and environment. Properties of some materials may be an obstacle to RFID application at a given frequency, as they may corrupt data transmission either by absorption or by ambient reflection of the signals. Typically, conductive materials such as goods containing water, or metal surfaces may be the source of problems. However, absorption and reflection being frequency-dependent, failure at one frequency does not rule out applicability at other frequencies. Electromagnetic disturbance can also have external sources, which is also a common—though also frequency-dependent—problem in an industrial environment.

c.) International standards in frequency allocation. Due to historic reasons, the world is divided into three large regions of frequency allocation for various purposes, region 1 containing Europe, Africa, the Middle East and former SU member states, region 2 with North and South America and the part of the Pacific east of the date line, and region 3 with Asia, Australia and the Pacific west of the date line. The industry exerts pressure towards a uniformization of frequencies allowed for RFID, yet there still are notable differences between the three regions, forcing companies planning to employ tags in several regions to restricting themselves to bands shared by all regions concerned. A compromise for tags only modulating the reader signal without actively producing a carrier wave on their own may be their ability to work in a wider frequency range than nominally specified, allowing their usage even in regions where RFID bands are 'close enough'.

3.2.5. Faulty manufacture of tags.

Manufacturing of tags is not yet 100% failure-free today; about 20–30% of tags used in early RFID pilots have been defective [22].

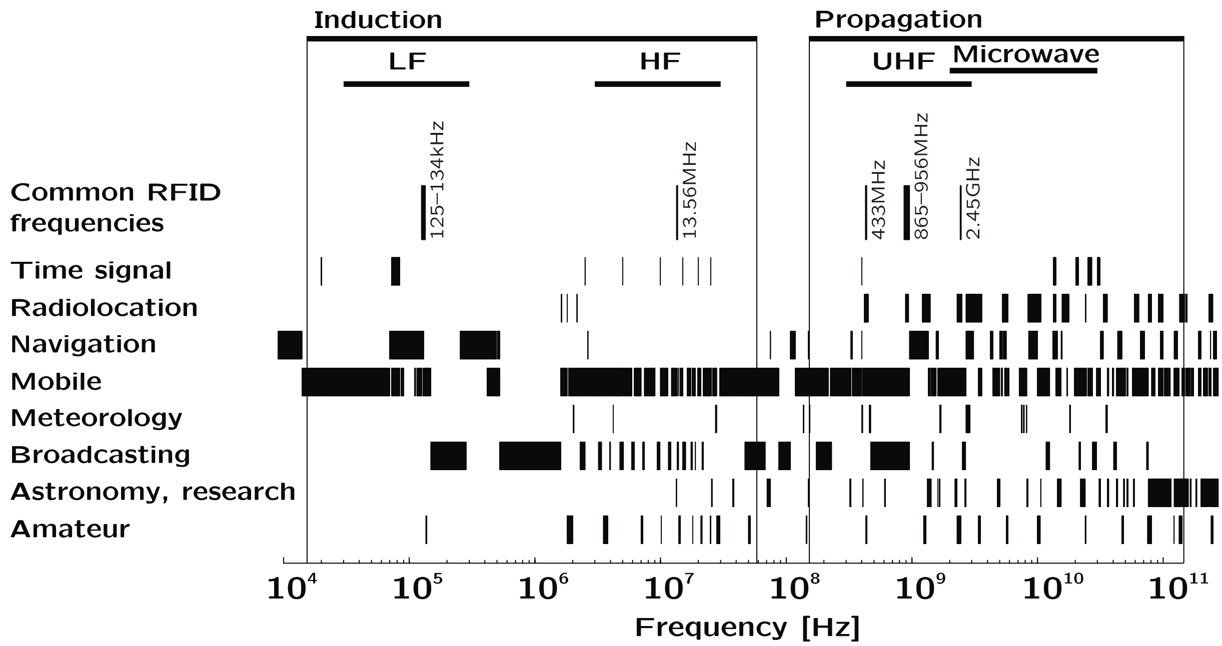


Figure 1: Common RFID frequency ranges and allocation in Region 1

3.2.6. Faulty or deficient detection of tags

a.) Tags may be damaged during usage. A wide range of application challenges can be answered by the multitude of suitable tags, yet none of them is completely invulnerable and the causes of damage may vary from type to type. The result is a read failure which is, in many cases difficult to detect, as is the fact of the damage itself for a hidden tag. This becomes a business issue when, for example, the payment for goods is calculated by the number of detected tags and no measures are taken to compensate for read failures.

b.) Adverse conditions of the environment and improper placement may corrupt reading. As mentioned before, absorption, ambient reflection of the signal and external signal sources (such as security systems, cordless phones, barcode scanners) may introduce read errors. Similarly, improper orientation of tags may impair reading efficiency as most antennas used in tags are direction-sensitive [22].

c.) *Registration of data from tags which pass within range of an RFID reader accidentally.*

d.) Reader malfunction. This eventuality cannot be predicted or completely avoided, making alternative fallback measures (such as barcodes) necessary for the case of reader failure.

3.2.7. Quick technology obsolescence

One of the common concerns of companies implementing RFID today is the rapid obsolescence of the technology, especially in view of the investment cost. Technology is continuously evolving and new protocol standards, faster and more fault-tolerant readers quickly outdate their predecessors.

3.2.8. Security and Privacy Issues

Depending on the field of application—and in some cases, prescribed by law—it may become necessary to prevent unauthorised persons from reading or writing data stored on or transmitted from tags. To this end, encryption must be ensured at all interfaces where data could be intercepted or transmitted (on the medium itself, as well as tag–reader and reader–host communication) [22].

Privacy issues concerning the—possibly hidden—use of RFID tags has been identified as one of the problems by many experts and associations, among them the ‘Caspian’ (Consumers Against Supermarket Privacy Invasion and Numbering), since the beginnings of its application (see [19], [14], [20], and [18]). The main concerns are related to unique item-level tagging of merchandise without knowledge or consent of end users, having ‘the potential to jeopardize consumer privacy, reduce or eliminate purchasing anonymity, and threaten civil liberties’ [19], are: a) hidden placement of tags and unnoticed reading by third persons, b) unique identifiers for all items worldwide could make the link between user and item recordable and retrievable, c) massive data aggregation about items and customers becomes possible, d) tags (especially in the UHF range) can be read from a distance without direct line of sight, e) item-level unique tagging may allow individual tracking and profiling, i.e., linking personal identity with merchandise items without the consent of individuals.

3.2.9. Possible virus attacks

Although not widely reported so far, a study of the Vrije Universiteit Amsterdam [23] has shed light on potential vulnerability of current RFID software if used together with a backend database. Similarly to previously known attacks against SQL systems (such as the Slammer virus), intentionally effected buffer overflow, false end-of-row characters and camouflaged comments can lead to unverified data being interpreted as SQL commands which can perform malicious operations on the database contents or prompt the system to copy the infected data to further tags.

4. APPLICATIONS

Current and proposed uses of RFID span a wide spectrum of application areas (e.g.: see Figure 2), and a fully comprehensive overview would certainly surpass the limits of this paper. It is, however, easy to see that the nature of a given use of RFID can be put in either one of three groups:

1*) item instance or item class identification,*
2) location identification,
3) data transfer from or to the RFID tag.

4.1. Instance or class identification

If RFID tags are only used for the purpose of item type or instance identification, usually, a database is maintained in the background to provide or receive the additional information needed. Augmented with this support, destination or way of handling can be determined for the given item, an already proven concept in a number of logistics solutions (several shipping and postal services, such as UPS, FedEx, USPS and Finland Post [8]). Also, examples in manufacturing demonstrate the benefits of RFID, such as with identifying individual car bodies in customized automotive production (BMW's car body identification in their Dingolfing factory [5]), tracking of manufacturing (pre-delivery tracking and location of cars in Volkswagen's Wolfsberg facility [12]) or even architectural construction processes (Skanska Finland applies Enterprixe's 4D production model solution), automatic retooling of work-cells for the given item, and fail-safe identification of samples for quality control (Schreiner's LogiData control system applied by Auto5000 GmbH, a supplier of Volkswagen [15]; RFID-based administration of quality control at Ford's Essex engine plant in Windsor, Ontario [12]; RFID-based identification of material test samples at the MTR Corporation of Hong Kong which builds and operates urban railways [12]). In the agriculture, farm animals can be identified using RFID tags, and a retrieval service for lost pets also relies on RFID implants as the means of identification ('Home Again' pet retrieval service [13]). Also, RFID tags are widely relied on in security systems which grant access to facilities etc. depending on the given user's level of authorization (even an example from a Chinese party congress is known [12]), while in other cases, even passports are equipped with tags (Department of Homeland Security is already testing RFID-equipped passports at several locations worldwide [15]). Speaking of security, RFID is also commonly used in anti-theft protection and RFID-based house arrest supervision is also contemplated [9]. Another subclass of identity-related application examples contains the cases where the database in the background is not only queried upon reading a tag but also updated, e.g., to keep track of inventory changes (commonly used in warehouses, but future application is envisaged even for such cases as intelligent refrigerators which keep track of food supplies). In many cases, the short time lags and failure-free ID entries or even the resistance of RFID tags to adverse conditions (extreme temperatures, dirt, chemicals etc.) contribute substantially to the success of the application [5].

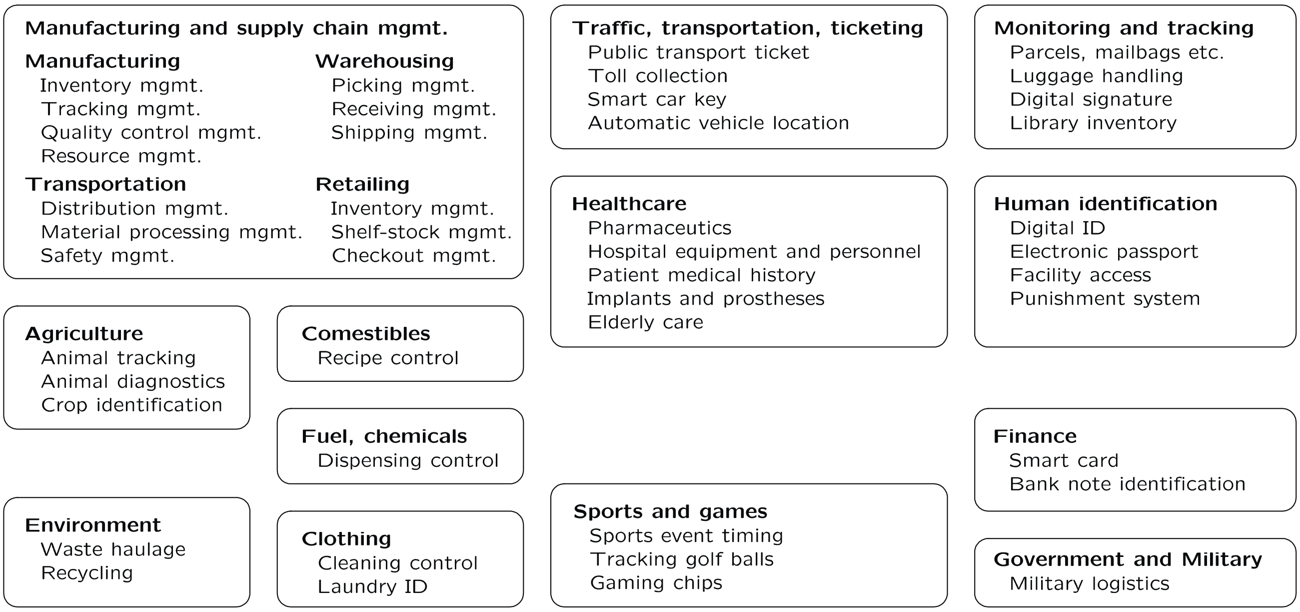


Figure 2: Examples of application areas

4.2. Location identification

If a given reader is assigned to a known location, it is possible to track the current place of a given uniquely identifiable item. Numerous logistics companies and some postal services have already integrated such RFID-based features into their tracking services (several shipping and postal services, such as UPS, FedEx, USPS and Finland Post [8]; automatic vehicle location systems in public transport control in Vejle, Denmark [10]; location of rolling stock at the Swiss Federal Railways), and similarly, the physical location of work pieces is being kept track of in several manufacturing facilities, too (e.g.: in Dell's facility in Xiamen, China [12]). The RFID tags to be read for localization can be either attached to containers or items, or they can identify the transporting vehicle itself. Aside from the benefit of providing exact information (as opposed to the risk of incomplete, delayed or corrupted data if entries are made manually), reading RFID tags does not require a long halt in the transportation process, making thus delivery more efficient. Also, farm animals can be efficiently localized using RFID tags while a similar tracking principle is applied in some prisons as well. Other location-specific application examples are envisaged using direction-selective readers. These aim to find the exact location of a tag in a wide area, such as golf balls on a golf course [9].

4.3. Transfer of further data

In the third application group, not only an identity is extracted from the tag but also auxiliary data are read or written. Data read from the tag usually contains information which would be difficult impractical or impossible to obtain from a remote or pre-recorded database, or measurement results. Some products may provide instructions for proper handling this way (envisaged are cases where tags in food packaging would instruct an oven about the optimal cooking time [2], or tags in clothing would select the right program for a washing machine [17]), while in a number of already implemented uses, tags provide medical measurement data e.g., about eye-ball pressure (sensor and transmitter integrated into artificial lens implant [6]). Writing data to a tag usually adds information about the processing of the given item (or delivery progress in transportation), and in a few cases, a new identity is assigned to the tag by rewriting (such as for reusable containers, pallets etc., as in a pilot project at the Finnish Post [8]). An interesting application is envisaged for washing machines where read-write tags in clothes also record how many times the given piece has been washed and select the proper washing program to adapt to aging of the fabric [17].

5. CONCLUSION

The paper gave an overview of the current state and trends of RFID technology. Even though numerous limitations and unresolved issues still hinder the widespread application of RFID, it can be already seen that especially enterprises in complex supply chains will benefit from RFID, once the application difficulties are overcome.

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