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RFID potential impacts and future evolution for green projects

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Abstract

Nowadays, several RFID systems are commercially available for numerous applications such as control assess, transportation, supply chain, etc. However, RFID tags and sensors association could provide a lot of new solutions in order to develop notably green projects such as more efficient energy production chain, best control waste, recycling, and other environmental challenges. Furthermore, the development of these novel solutions requires resolving several technical challenges. This paper focuses on the actual and future roles of RFID as technology contributing to green projects.

Keywords: green projects; green radio; RFID; sensors; supply chain.

1. Introduction

Radio Frequency Identification (RFID) is one of the fastest growing wireless technologies this decade, mainly because it presents considerable advantages in terms of flexibility, lifetime and low cost. RFID offers great potential benefits in object identification and tracking in diverse application areas.

But what is/will be the role RFID in green projects? Can RFID be considered as a green technology? What progress and evolution of RFID are expected to respond positively to these two questions?

RFID is above all an information and communication technology. Therefore, it is viewed as having a negative impact on the environment. Moreover, RFID tags are neither biodegradable nor recyclable. Nonetheless, RFID is also a wireless and powerless technology. From the integration of sensor technology to tags, RFID presents new opportunities in many industrial applications. For example, RFID is used in supply chains in order to reduce CO_2 emissions, to optimize perishable goods flow, to better control room temperatures for spoilage reduction and quality improvement, to increase pickups and

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deliveries efficiency, to track the recycling process of recycling the plastics used in automobiles, to improve and enhance the waste management efficiency, to improve energy production chains productivity and management, to offer an alternative to battery power for some types of safety alert devices where hazardous conditions are created by powered equipments, etc. In consequence, actual RFID systems already offer solutions to be more environmentally responsible!

Otherwise, significant investments and research works are focused on the investigation of new materials for tags fabrication (e.g., conductive adhesive, plastics, textile fabric), the enhancement energy harvesting (e.g., embedded printable photovoltaic in RFID tags), the reduction of RFID chip cost (e.g., development of chipless RFID tags), the capabilities for localizing or positioning objects or persons, the development of passive wireless RFID sensors, etc.

This paper presents more in details the following aspects: summary of RFID technology, presentation of green projects integrating RFID, expected progress and actual researches in RFID.

2. RFID technology

2.1. General presentation

RFID technology allows data storage in small electronic transponder circuits that are particularly portable [1]-[2]. Communication between an RFID tag and an interrogator is realized by radio frequency (RF) waves. In consequence, the stored data can be read and written without contact and often through obstructions. A typical RFID system is illustrated by Fig 1. Three fundamental components constitute RFID systems:

- Interrogator (or reader), which sends interrogation signals to an RFID tag that to be identified. Its complexity and configuration depend on the functions to be fulfilled, which can vary quite significantly from one application to another. However, the main reader's function is to provide the means communicating with the RFID tags, and to facilitate data transfer.
- Transponder (or RFID tag), which contains the identification code, and are generally attached to objects in a permanent or not way.
- Middleware software, which is responsible for converting tag data into meaningful information, for resolving potential reader collisions, and for ensuring that multiple or bad reads are eliminated.

The reader is often connected to a host computer offering additional signal processing and which can be connected via Internet for global connectivity.

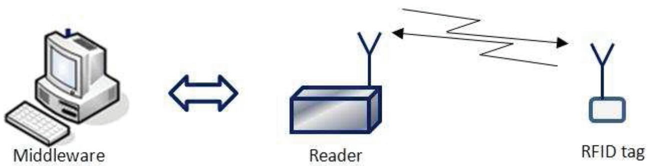

Fig. 1. Architecture of a classic RFID system

In a typical RFID application, RFID tags are attached or embedded into objects in need of identification or tracking. In the most frequent application such as supply chain management, RFID tags simply serve the purpose of UPC (Universal Product Code) bar codes. However compared to bar codes, solutions based on RFID tags have superior capabilities: non-line-of-sight communication, writing capabilities, multiple reads in parallel, durability, security, unique ID codes; but their cost is still much higher. Moreover when combined with sensors, RFID can also help managing objects that are environmentally sensitive (e.g. food, medicine, blood) or non-sensitive (durable products and machines).

Although RFID technology is always in evolution and development, several techniques and standards exist. Table 1 summarizes conventional RFID techniques properties. For each technique, used frequency range, distance range, coupling type, existing standards (mainly set up by the International Standard Organization, ISO), and traditional RFID market segments are presented.

Table 1. Summary of properties RFID techniques

	Frequency range	Distance range	Coupling	Existing standards	Applications
LF	125 kHz	~0.1 m	Magnetic	11784/85, 14223	Smart card, ticketing, access, animal tagging, laundry
HF	13.56 MHz	~1 m	Magnetic	18000-3.1, 15693, 14443A, B, C	Small item management, supply chain, anti-theft, library,
UHF	900 MHz	~2-7 m	Electromagnetic	EPC C0, C1, C1G2, 18000-6	Transportation vehicle ID, access/security, supply chain, large item management
microwave	2.4 GHz	~10 m	Electromagnetic	18000-4	Transportation vehicle ID (road toll), access/security, supply chain, large item management

2.2. Active, semi-passive, and passive tags

According to the powering method, three types of tags can be found: active, passive and semi-passive tags. Active tags embed an internal battery which continuously powers. Unlike, passive tags have no internal power supply. They absorb their energy with RF power continuously provided by the reader for the entire read operation. The communication consists of a query from the reader followed by the tag response. RFID tags backscatter the carrier signal received from a reader, i.e. part of RF power is transmitted back to the reader with appropriative modulation and coding via the tag's chip. Passive tags are the most commonly used tags. They have shorter read range than active tags but they have a smaller size, are cheaper and do not require any maintenance. Semi-passive tags communicate with the readers like passive tags but they are equipped with an internal battery constantly powering their internal circuitry.

3. Examples of some green projects integrating RFID

New opportunities to apply RFID are arising notably from the integration of sensor technology to RFID tags. RFID can play an important role in applications helping to deliver a greener world. Even if RFID is not a green technology itself, its applications are helping to lower the carbon footprint in several situations: improving recycling through refuse management, encouraging the re-sue of containers, reducing vehicle emissions, tracking animals to monitor the impact of climate change, improving the management of natural resources, reducing equipment by better asset management. Some illustration examples dedicated to various applications can be cited.

- Argonne National Laboratory has deployed an RFID onboard sensor suite to track and monitor packages containing nuclear and radioactive materials [3].
- Since 2010, Walmart Stores is working with suppliers of men's jeans and basics to be able to track these items using RFID tags to optimize the management of its inventory and indirectly reduce CO2 emissions.
- Nestlé uses temperature control to reduce spoilage, improve quality, and lower energy-related costs.

- In Paris, more of one hundred thousand trees have an RFID tag under their back allowing an easier monitoring by the municipal officials.
- Verichip sell chips that can be inserted under the skin. Applications include in particular the health sector. Thus, a patient with specific diseases (Alzheimer's, diabetes, etc.) will be able to carry his medical file on him. The subcutaneous RFID can also be used for more trivial purposes, such as payment or opening the door of his home.
- RFID technology can also help producers to establish a green supply chain management system to achieve the goal of environment friendly vehicle and high recycling/recovery rate of their End-of-Lifes. The authors of [4] have analyzed the requirements of Extended Producer Responsibility legislation, automotive supply chain and information tracking system, and then put forward the information flow mode and operation process of information management system based on the supply chain using RFID technology.
- With RFID-based sensors, companies could only know where the product is/was, but can have insight into the conditions faced by that product as it passed through the supply chain. They can then make better decisions regarding the product use (i.e., shelf life disposal, promotional pricing, etc.) ultimately to higher quality and safer products for the consumer and hence more profitable business practices. Two examples are detailed in [5] about bananas from South Africa, and bagged leafy vegetables from the U.S. West Coast.
- A preliminary study in [6] shows that an adequate combination of RFID, geographic information system (GIS) and mobile communication like GSM (Global System for mobile Communication) could offer an interesting solution in order to solve a lot of problems related to solid waste collection, monitoring, minimizing cost and management acceleration. The proposed system is a web-based solution with client-server architecture. GSM and GIS are chosen for the communication between the tracking unit and the server and vehicle position tracking.
- An enterprise as Airfield Architect proposes to put RFID at the service of industrial processes and the supply chain. They stipulates that RFID applications allow to secure work flows, to reduce waste and processing errors, to save time, handling and transportation and therefore to consume less energy. And thus, RFID can help reducing emissions of greenhouse gases.
- A last example could come from the encouragements of NASA in order to aid in the development of passive RFID sensors to be applied to inflatable structures [7]. These researches aim to future space habitats in the international space station and on the moon.

In [8], an analysis completing previous examples in order to appreciate green RFID’s potentials from thirteen case studies is presented. Motivation, execution, challenges and impacts of projects are highlighted. The study shows that the majority of projects were motivated by a mixture of self-interest and pressure to improve environment health. It concludes on the following idea: “whether RFID is green is less important than how RFID can be made greener”.

4. Actual axes of research and expected progress

4.1. Material aspects

Firstly, it is well known that when passive tags are utilized, the readability depends strongly on the material of the object attached to the tag. These variations depend on dielectric constant parameters such as the relative permittivity, the relative permeability, the conductivity, the magnetic loss factor, the mass density, but also more physical characters such as dimensional constraints and volume. A lot of works concerned this subject but materials particular composition plays a crucial role and this has to be completed more precisely. For example, liquid products tagging needs a previous characterization study of the interaction between RF waves and the liquid surface. Otherwise, several solutions have been recently investigated for the design of passive tags over metals based on the use of high permittivity slabs and metallic shields, integrated in the antennas as ground planes [9].

Another challenge is to realize RFID tags with good performance based on varied types of substrates. For example, wearable passive UHF tags design is actually receiving considerable attention. Recently, new magnetic materials have been considered as a shielding plate for an RFID tag [10]. In addition, innovative ferrite-silicone composite promises the achievement of very low profile miniaturized and flexible structures potentially useful for wearable applications.

Finally, a better understanding of material characteristics of tagged objects and substrates will improve the readability and also offer efficient technical solutions and many new applications.

4.2. Sensor tags

The identification information may be enhanced with physical information about local agents as well as about the change in the tagged object itself. Existing solutions rely on RFID active tags and a dedicated specialized sensor. Like RFID tags, wireless sensors can be divided into battery-powered active devices, battery-assisted sensors and fully passive sensors. Thus, RFID can be combined with a sensor to monitor different elements in their environment, including temperature, humidity, shock, and vibration. However, sensor addition increases both tag size and cost. An alternative solution for more compactness and cost-efficiency is the functional integration of the antenna and the sensor component in order to obtain a sensor tag. The challenge is then to use the RFID tag antenna directly as a sensor (fig 2).

Fig. 2. Configuration of RFID tag sensing systems

Several new concepts for sensor tags have been proposed with different and various functionalities. In [11], a sensor design taking into account temperature violations and changing tag antenna properties using a shape memory polymer which is a temperature sensitive material is introduced. In addition, a patch antenna with a relative humidity sensing function is proposed in [12] using a modified polyimide. MEMS (microelectromechanical systems) technology has been also studied to be implemented in passive wireless sensor or tag. This type of wireless MEMS sensors enables very low manufacturing cost, long reading distance, high frequencies and compact size without requiring embedded electronics. One example of such MEMS tag sensors replying at an intermodulation frequency is presented in [13]. In [14], a passive multiprobe sensor using conventional UHF RFID shows the feasibility of impedance-based sensing with RFID probes. Indeed, any physical, chemical or physiological factors which are known to impact the tag antenna impedance (via the dielectric permittivity) can be used to detect changes in local neighborhood. A zero-power RFID-enabled threshold shock sensor is proposed in [15]. This is a latching accelerometer which records an acceleration event above a specific threshold. The presented entire package is designed to provide low cost sensors for monitoring shock loads.

4.3. Energy capture and safety energy

Another challenge in order to improve RFID tag performance is to augment the power that can be rectified from the signal transmitted by the reader. An envisaged solution is the integration of flexible solar cells into printed RFID antennas. In consequence, the antenna simultaneously harvests RF energy, communicates with the reader, and harvests solar energy for auxiliary power. The feasibility of this approach is shown in [16] where a prototype is presented.

Always about energy but with a different aimed application, energy harvesting based on passive RFID technology may offer an alternative to battery power for some types of safety alert devices [17].

4.4. Chipless tags

The main cost of an RFID tag coming from the embedded chip, new solutions using chipless tags without silicon integrated circuit are developed. Chipless tags encoding data can be achieved thanks to three main categories based on time domain reflectometry (TDR), spectral signature encoding and amplitude/phase backscatter modulation [18]. Time domain reflectometry (TDR) based chipless tags are interrogated with a pulse signal and the information is given by the echoes of the pulse sent by the tag. SAW (Surface Acoustic Wave) tags, thin-film-transistor circuit, microstrip tags with discontinuities, are used. Spectral signature-based chipless tags encode data into the spectrum using (multi-)resonant structures. Each bit corresponds to a predetermined frequency. Amplitude/phase backscatter modulation-based chipless tags is realized by controlling the reactive loading of the tag's antenna. The development of these chipless solutions will also require new standards (the two first approaches need larger frequency bands), novel readers integrating pulse generator functions and processing signal capabilities.

4.5. Localization

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 previously cited in part 3.

Classic RFID systems can be used as a proximity location sensor providing coarse-grained location information. The localization accuracy of such systems corresponds to the reader coverage area. These solutions are either imprecise or difficult to deploy and costly. Other approaches based on conventional techniques are used for the positioning in wireless networks. They use properties of triangles to estimate the target's location by trilateration or triangulation. AOA (Angle of Arrival), TOA (Time of Arrival), TDOA (Time Difference of Arrival), POA (Phase of Arrival), PDOA (Phase Difference of Arrival), and RSSI (Received Signal Strength Indicator) techniques are the principal techniques to get the distance estimation. In a theoretical way, most of these techniques can be applicable to RFID [19].

However in practice, these methods can be quite complex requiring high processing power and/or need a dense reference tags networks. Indeed, the RFID localization is firstly constrained by its specific properties and capabilities but also these approaches are severely affected by the propagation environment. The challenge is to find new techniques that work reliably in an arbitrary environment and allows good accuracy (on the order of centimeters). The small available bandwidth makes the problem difficult and this is a subject of current and future research works.

4.6. RFID and 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 multihop fashion extending potentially RFID applications. Several scenarios can be envisaged for combining RFID and WSNs: integration tags with sensors, integration tags with WSN nodes and wireless devices, integration readers with WSN nodes and wireless devices, and a mix of RFID and WSNs [20]. Thus, the integration of RFID and WSNs opens up a large number of applications in which it is fundamental to sense environmental conditions and to obtain additional information about the neighboring objects.

EPGGlobal (governing body for RFID standards worldwide) has also envisioned an architecture called the Internet of Things in which devices with RFID tags dispersed through the Internet can communicate with each other, providing real-time information about their location, contents, destination and ambient conditions [21]. The potential attractiveness of RFID in enabling such a vision is largely based on the key advantages of RFID components relative to other technologies: small form-factor tags that afford the potential for longer life, resulting from optimized low power operations and energy harvesting. For example, inkjet-printed flexible antennas, RF electronics and sensors fabricated on paper and other polymer substrates have been presented as system-level solutions for ultra-low-cost mass production of UHF RFID tags and RFID-enabled wireless sensor nodes or even wireless cognition applications [22].

4.7. Towards RFID biodegradable systems

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.

5. Conclusion

RFID are becoming and will become devices integrating sensing and signal ability able to provide real-time (bio)monitoring and location of people or objects. Though not without issues and challenges, RFID is a promising technology expected to become ubiquitous in the coming years, helping organizations, solving problems in supply chain management, security, personal identification, asset tracking, etc., and also playing an important part in order to propose new solutions for a greener industrial world. Green RFID applications will require advances on multiple fronts: new tag designs inclusive of sensor integration, enhancements to link (encoding, modulation, and diversity), multi-access layers, power management strategy, and integration in future wireless cognitive networks.

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