# Application of Radio Frequency Identification in IoT Field

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RFID (radio frequency identification) technology appeared nearly 70 years ago. Deployed more widely only from the early 2000s, it is now booming and its development is still accelerating. As its name indicates, its original function was the identification (of objects, animals, people) and its applications were then essentially aimed at traceability, access control and logistics. If this type of use is still relevant today with more and more new application contexts and more and more efficient RFID tags, RFID has also evolved by integrating new capabilities. These new tags, known as augmented tags, include an information capture function. With the explosion of connected objects and the emergence of the Internet of Things (IoT), this old technology that is RFID still has a promising future and will probably be more and more present in our private and professional environments in all fields: logistics, industry, agriculture, building, health and even space.

healthcare | identification | Internet of Things | RFID | RFID sensor tag

## 1. Introduction

The Internet of Things (IoT) paradigm is about connecting a huge number of devices through various access technologies to exchange information and communicate. The IoT aims to enable multiple functionalities such as identification, location, tracking, monitoring and management in various contexts: privacy, smart homes, industry, health, wearables, 5G/6G mobile communications [1][2][3], and more recently, the use of connected thermal cameras to detect potential COVID-19 infections and sensors to monitor office occupancy levels. Related studies have shown for a few years now that the ubiquity and penetration of IoT will be enormous. The COVID-19 crisis has even generated a wave of digital transformation that will further accelerate its development in the coming months and years, so much so that the IoT market is expected to exceed one trillion by 2024.

Faced with such a craze regarding the technological challenges to be met, the application aspects that were expected and the potential revenues that would be generated, IoT systems have spread very quickly and continue to develop even though several fundamental aspects were initially “forgotten” and/or are emerging.

First of all, there is not yet an international standard dedicated to IoT that would allow a better technological harmonization and then further accelerate the deployment of connected objects all over the world. Unfortunately, this observation is repeated again and again. Economic pressures mean that products are put on the market as soon as possible and without any international harmonization. Thus, and this is particularly true in the field of wireless technologies, regulations, when they are put in place, are either an afterthought or the devices are endowed with a certain complexity, useless from a “pure” technological point of view, but which allows portability in different geographical areas of the world. For example, the deployment of ultra large band (UWB) technology [4] is an emblematic illustration. In addition to the industrial conflicts opposing the defenders of multi-band OFDM (orthogonal frequency division multiplexing)-type approaches and those defending the original idea, i.e., exploiting new waveforms of the pulse type, the difficulties in agreeing on the regulation of the radio spectrum at the international level have been a brake on its development; the frequency band authorized by the FCC (Federal Communications Commission) in the United States, a band between 3.1 GHz and 10.6 GHz [5], has been greatly reduced elsewhere in the world, without harmonization, and this has called into question the very interest in the use of very narrow pulses. More recently, the opening of new frequency bands dedicated to UHF (ultra-high frequency) RFID (radio frequency identification) technology in Europe illustrates this phenomenon with regulations that vary from one country to another, knowing that regulations for this technology are already different from one continent to another. With the congestion of the radio frequency spectrum, specific to each country, it has therefore become extremely difficult today to find common international frequency ranges that are available, although this is a real issue. A second weakness concerns security, privacy and data protection. As before, although the problem is known in several other contexts, the “need” (for economic reasons) to bring connected devices to market has not allowed for upstream regulation on these security aspects. Whether IoT systems are public or enterprise, the unstructured and fragmented nature of security regulations is and will be a barrier to their unanimous adoption. Finally, in addition to this lack of standardization, current IoT ecosystems still lack real-time intelligence, which relies heavily on edge computing and the artificial intelligence of objects. However, given the emergence of artificial intelligence in all domains, there is no doubt that this gap will be quickly filled and that this aspect will remain an area for continuous improvement.

By analogy with the well-known OSI (open systems interconnection) model, the IoT can be seen as consisting of five main layers: the sensing layer, the access layer, the network layer, the support layer and the application layer. Thus, the IoT includes multiple technologies: nanotechnologies, sensing and identification technologies, network communication technologies, data fusion technologies, cloud computing technologies, and so-called smart technologies.

## 2. RFID Technology: From Identification to Sensing

Since the advent of the electronic article surveillance (EAS) anti-theft system, which is still widely used, the first emblematic commercial application of which appeared in the 1970’s, RFID technology has found many applications in a wide range of fields such as industry [6][7][8][9][10][11], agriculture [12][13][14], health [15][16][17][18] but also in our everyday life [19][20][21]. At the same time, its applications continue to diversify. From identification (its original function), RFID is used, for example, for access management, logistics and tracking of goods, people and animals, locating lost luggage in airports, and timing of sporting events. In recent years, a major development has been the integration of the sensor function within the tag. It has allowed an extension of the field of applications of RFID, for example, the monitoring of machines or perishable goods, and especially sensor networks and the IoT.

After having recalled the principles and the specificities of RFID technology, in particular the case of passive RFID, it will be shown why RFID proves to be a relevant choice to deploy the first (identification but also detection or recovery of information) or the last meters (identification but also control or command) of the IoT.

# 3. RFID Sensor Tags

## 3.1. Quick Look at the Types of RFID Sensor Tags That Exist

Today, there is a plethora of RFID sensor tags, at least in the literature, because commercial solutions, if they exist, are still few. Generally speaking, like any sensor, an RFID sensor tag is able to detect changes and events, and they are useful in all situations where measurements need to be captured remotely and automatically.

Tags could detect changes in movement, stress, strain, vibration, tilt, etc., often to control the state of a structure, as varied as that may be (tightening of a screw, building, aircraft wing) [22][23][24][25][26], humidity, temperature, moisture [27][28][29][30][31][32][33][34], corrosion and chemicals [35][36][37][38][39], and also pressure, light level, audible feedback, or biometric data, etc. Note that most of these measures can be absolute or relative, for example, to detect the passage of a threshold.

It is also interesting to note the use of specific materials when the tag becomes a sensor tag (without added sensors). For example, for temperature or humidity the information capture can be based on relatively simple to use materials such as polyvinyl-alcohol (i.e., PVA) polyimide film (i.e., Kapton). Even if the context of the article [40] aims at chipless solutions, the principles being ultimately quite similar, many examples of materials that can be used, associated with their different characteristics, are given.

In addition to these rather classical sensor applications, the potential field of use is extremely vast and will only grow in the future. For example, researchers can cite recent and original studies that have focused on ice detection [41], solutions for metallic environments integrating both European and American standards [42], and even the use of RFID to monitor the health of astronauts [43].

Some authors refer to this type of tag as an “augmented tag”, whose capabilities then go beyond the mere identification functionality, in this case, with the sensor function being the most frequent function [44][45].

The second part presents the main approaches to transform a tag into a sensor tag, and also gives some elements of comparison with other techniques dedicated to passive wireless sensing. With an applicative look, specifically considering health, the third part aims to illustrate and show in a given context the types of sensors implemented.

## 3.2. Principles of RFID Sensor Tags

There are two main types of architectures to design an RFID sensor tag [46]: either the tag integrates one (or more) additional sensor, an independent sensor that is connected to the tag or even integrated into its chip, or the sensor function is integrated into the tag by a judicious design adding to the chip but more often to the antenna the role of sensor by also using it as a transducer [47][48][49][50].

In the case where the tag is associated with a sensor, one of the main limitations lies in the ability to maintain the passive nature of the tag and sensor assembly. It is necessary to power the attached sensor autonomously: either by using the rectifier circuit of the tag itself, but this is then to the detriment of the tag's performance (part of the energy is diverted), or by using a dedicated energy recovery device that exploits the energy from other sources such as solar, thermal, kinetic or electromagnetic [50][51][52][53]. The other solution, which is technologically simpler, is to add an onboard battery dedicated to the sensor part at the expense of the 100% passive character. Based on this approach, several sensor-tag platforms are now available such as the well-known wireless identification and sensing platform (WISP) which is a programmable, microcontroller-based sensor tag, compatible with the EPCglobal UHF RFID standard [54] and comparable platforms from academic labs [39][55] and commercial manufacturers [56][57][58]. This principle allows a priori better performance in terms of measurement ranges and accuracy, or at least allows the capabilities of the sensor associated with the tag to be fully exploited.

The second approach, which consists of inserting the sensor function into the tag itself, is an ingenious alternative that makes it possible to preserve the passive character. However, it suffers from the fact that the characteristics of the backscattered signal are altered in terms of the detection of information (identifier + sensed quantity), which reduces the reading range and even the reading capacity. To overcome these problems, solutions aim at dividing and/or modifying the coding of the information returned by the tag in order to separate the two information channels (identification and detection), for example, phase modulation for the sensor and amplitude modulation for the communication or specific modulation frequency for the sensor [59]. A hybrid analog–digital platform has also been proposed that uses digital backscatter for addressing and control, and an analog backscatter mode for high-speed transmission of sensor data [60].

More generally, techniques exploiting RFID to generate sensors are also constrained or limited by time factors, for example, the time needed to acquire data while the device is in motion [61]; or the variation of the phase of the signals (a property exploited for localization purposes), which it is a priori necessary to overcome for the purposes of capturing information (eliminating any calibration) [62].

It is also worth noting that due to mass production printing techniques and the advances in fabrication of integrated circuits, the cost of a RFID tag can be very low, less than $0.10. However, RFID tags with more capabilities and complexity can cost more than $100. This is why it seems more judicious to design simple RFID sensor tags which are not, for instance, microcontroller-specific in order to manage sensing operations or specific connections for external sensors. Generally, in the field of RFID, it is more interesting to keep the tags simple (with an attractive cost) and to put the complexity on the side of the readers (which can be a little more expensive and which, moreover, are not—or are less, in the portable case—confronted with the problem of power supply).

If there is a lot of research work on RFID sensors, the commercial availability of these RFID sensor tags is still quite limited, which shows that technological advances are still expected to facilitate their manufacture in large numbers, to promote their deployment and limit costs.

### 3.3. Focus on the Use of RFID Sensor Tags for Health

To illustrate the evolution and variety of RFID sensor tags, this part focuses on RFID applications in the health field. Indeed, the healthcare industry [63] and academic research [15][16][17][18][64] reflect very well the ever-increasing interest of this technology and its contributions. In other words, the healthcare field is representative of the diversity of passive RFID sensors and the variety of their applications, so it is highlighted here. Moreover, a proof of this fact is that tagging medical instruments and devices is one of the fastest-growing application areas for RAIN RFID in healthcare.

The healthcare sector already relies on a number of RFID applications:

- The identification of people, which means that throughout their journey, and whatever the length of their stay, patients are identified, and even located, especially at-risk patients who do not have authorization to leave; moreover, all care, prescribed treatments, and consumed drugs are automatically recorded.
- The identification of medical files, allowing for their traceability in order to ensure the management, archiving and storage aspects automatically and efficiently, for greater security.
- The traceability of organic tissues, samples and blood products is also automated, and consequently, made reliable.
- The management of large equipment and their maintenance in operational condition is also simplified; they can be located with a follow-up of their state (for example, ready for use, not cleaned, in service or not); the traceability of equipment throughout their life cycle is also favorable to the planning of renewals, investments, and even recycling procedures.
- Inventories, stock management and procurement are also greatly simplified, whether for drugs or medical prostheses, but also for small equipment (syringe pumps, syringes, surgical tools, etc.).

In the medical field, there are two main families of sensors depending on the positioning of the sensor which is located outside the human body (on an object, an equipment, on the person; in this last case, researchers find the notion of wearables, which is strongly developing today, in the medical field but also for monitoring people in dangerous environments, for example, and even for the leisure of individuals) or inside the human body. In this last case, from a technical point of view, compared to other types of applications, it is necessary to design adapted implantable antennas [65][66] and consider the specific propagation channel [67]. In the first case, a device outside the human body, the main technical specificity is where the device is still on a human body and researchers then find ourselves with the same issues as those of the wearable. It is then the antennas on textile support or adapted to textiles need to be developed [68][69], and in the case of RFID there is a need to integrate the sensor function [70][71][72].

Finally, more than ever with these types of wireless communication applications, it is advisable to adopt a precautionary principle, especially for fragile people (such as newborns) with respect to exposure to electromagnetic fields, the effects of which are still poorly known, even if regulations exist [73].

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