RFID TECHNOLOGIES: ANALYSIS OF CURRENT STATUS AND DEVELOPMENT

Artem Dymkov [1, 2]

[1] Institute of Radio and Information Systems (IRIS), Vienna, Austria;

[2] MIREA – Russian Technological University, Moscow, Russia

dymkov@media-publisher.eu

ABSTRACT

Radio communication is a convenient and very common way of organizing wireless transmission of information. It has a long history. In addition to the usual over-the-air television and radio broadcasting, today there are a large number of different technologies with their own characteristics. However, the development of science, as well as the constantly growing demands and needs of a person suggest the emergence of problems, the solution of which leads to the development of new technologies and devices that provide reliable and stable communication in many industries. RFID (Radio Frequency IDentification) technology is one of the most frequently used technologies in the modern world. It uses an automatic data collection system that helps to improve the efficiency of the system. The article analyzes RFID technologies and the possibilities of their application. The purpose of the scientific research is to analyze the main functions of radio frequency identification technology, examples of the implementation and use of this technology are given, the main advantages and disadvantages are described. An assessment is given of the prospects for the introduction of RFID tags in various sectors of the economy. The relevance of the study of the current state is presented and the prospects for the development of these technologies are analyzed.

KEYWORDS: *Radio Frequency IDentification, RFID tags classification*

DOI: 10.36724/2664-066X-2024-10-5-33-41

Received: 20.09.2024
Accepted: 17.10.2024

Citation: Artem Dymkov, “RFID technologies: analysis of current status and development” *Synchroinfo Journal* **2024**, vol. 10, no. 5, pp. 33-41

Introduction

RFID (Radio Frequency IDentification) technology is one of the most widely used technologies in the modern world. RFID technology uses an automatic data collection system that helps improve the efficiency of the system. A combination of a tag and a reader is used for identification. The code is stored in the RFID tag, and this tag is attached to a physical object, making the object unique and identifiable. The object then transmits the code from the tag. Thus, the reader receives information about the object.

RFID technology, in the sense in which we understand it today, appeared in the 1980s, although the history of radio frequency identification takes us back to an earlier period - to the end of the 19th century, when the British physicist James Clerk Maxwell formulated the theory of a unified electromagnetic field. A huge role in the development of the technology was played by the Second World War, when it became necessary to find a reliable way to identify aircraft: whether they belong to friendly aviation or to the enemy. Modern RFID systems are based on the same principles: they either “wake up” by reflecting a signal, as in the case of passive tags (RFID), or they themselves transmit a signal if active tags are used (Real-Time Locating Systems, RTLS). The evolution of RFID technology has led to the spread of solutions for identification (passive identification technologies) and solutions for real-time monitoring (active identification technologies).

Current state and development of RFID technology

RFID (Radio Frequency IDentification) is a method of automatic identification of objects, in which data stored in so-called transponders, or RFID tags, is read or written using radio signals.

This is a rapidly developing technology that offers many advantages over traditional identification devices, such as barcodes, as it can read data from a tag without direct line of sight. This technology is more effective when a longer reading range, fast scanning, and flexible data transfer capabilities are required [1].

Any RFID system consists of a reading device (reader, interrogator) and a transponder (also known as an RFID tag, sometimes also called an RFID tag).

By reading range, RFID systems can be divided into systems:

• s ort-range identification (reading at a distance of up to 20 cm);
• medi m-range identification (from 20 cm to 5 m);
• lon -range identification (from 5 m to 300 m).

Most RFID tags consist of two parts. The first is an integrated circuit (IC) for storing and processing information, modulating and demodulating a radio frequency (RF) signal and some other functions. The second is an antenna for receiving and transmitting a signal.

Already known RFID applications (contactless cards in access control and management systems, long-range identification systems and payment systems) are gaining additional popularity with the development of Internet services.

There are several ways to systematize RFID tags and their systems:

• By op rating frequency
• Ta s of the LF (125-134 kHz); HF (13.56 MHz); UHF (860-960 MHz)
• Near-field UHF adio frequency tags
• By power source
• Passive
• Active
• Semi-passive
• By me ory type
• RO (Read Only)
• W RM (Write Once Read Many)
• RW (Read nd Write)
• By execution

RFID devices provide unique identification of objects scanned by a reader to obtain information recognizing a specific object, such as a serial number. The chip on an RFID device is capable of transmitting up to 2000 bytes of data.

Figure 1 shows the operation diagram of this technology.

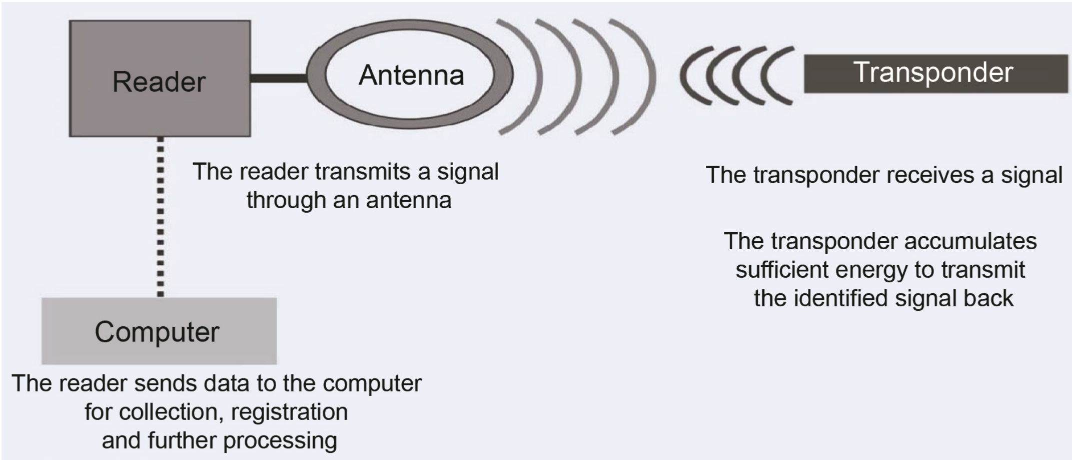

Fig. 1. RFID technology operation diagram

As an example, we can cite the structural diagram of rewritable LF range RFID microcircuit from Microchip ATA5577C (Fig. 2).

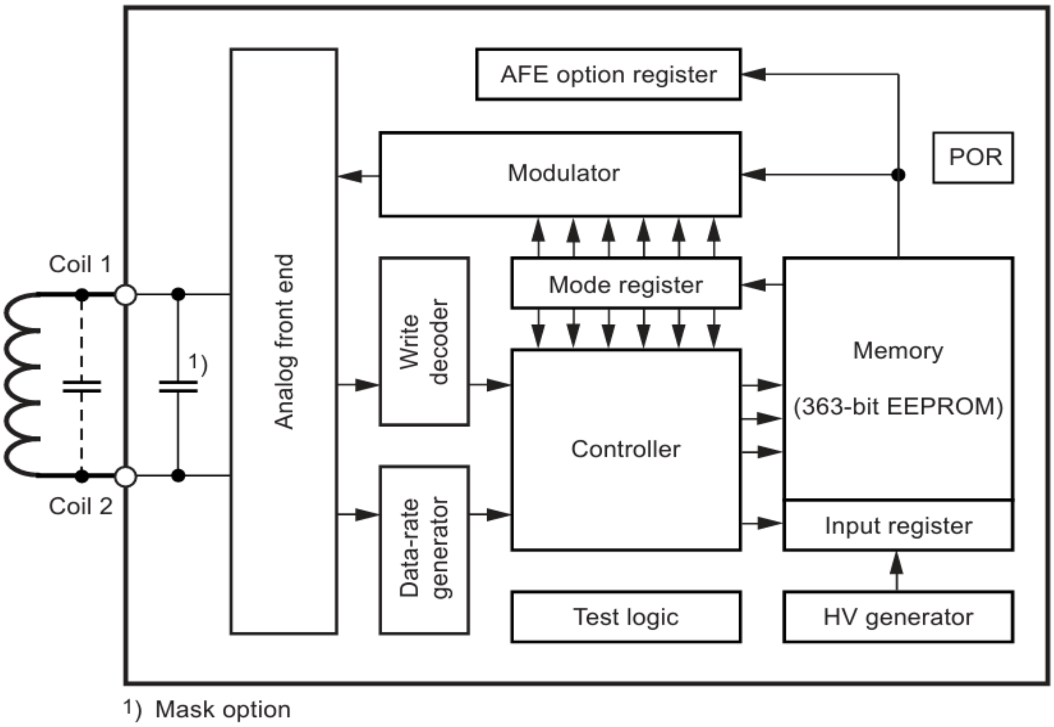

Fig. 2. Structural diagram of the ATA5577C chip

An example of its operation protocol is shown in Figure 3. Technical data for the ATA5577C microcircuit from Microchip are available at https://ww1.microchip.com/downloads/aemDocuments/documents/WSG/ProductDocuments/DataSheets/ATA5577C-Read-Write-LF-RFID-IDIC-100-to-150-kHz-Data-Sheet-DS70005357B.pdf.

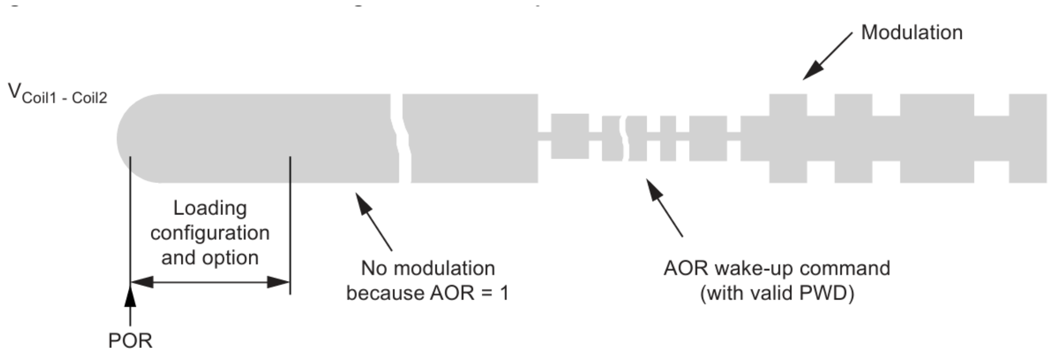

Fig. 3. Example of operation of the ATA5577C chip

Some innovative RFID solutions include:
– RFID deployment kits used in the military at remote stations to track incoming items;
– RFID tag for government postal services to efficiently track and deliver packages;
– RFID smart chips improve recognition and security at international airports;
– ease of hotel and motel booking and visits, billing and payment in stores.

Some of the most significant benefits of implementing RFID technology include:
– efficient informati n processing;
– red ction of excess inventory and in out-of-stock situations;
– high-quali y and fast customer service;
– impr ved forecasting and planning.

RFID technology in the UHF range has become actively used around the world as a tool for mass identification of objects outside the direct line of sight of reading devices at distances of up to 10 m with identification speeds of up to 1000 unique objects per second [8-10]. Frequently used technologies for recognizing objects, goods, materials, along with RFID tags, are QR codes and barcoding.

Based on the data in Table 1, you can see both the advantages and disadvantages of this technology. The advantages of RFID compared to its analogues are: the ability to rewrite – this reduces the cost of purchasing a new RFID tag, there is no need for direct visibility – you can place such tags covertly, a large reading distance and data storage capacity, support for reading multiple tags, resistance to environmental influences, a high degree of security – the inability to change the identifier number that is assigned to the tag during the production process, which guarantees a high degree of protection against counterfeiting.

Table 1

Comparison of RFID technologies with barcode and QR code

Technology characteristics	RFID	Barcode	QR-код
Need for direct visibility of the tag	Possible reading of hidden tags	Reading with line of sight only	Reading with line of sight only
Memory capacity	from 10 to 512 000 bytes	up to 100 bytes	No
Ability to rewrite data and reuse the tag	Exists	No	No
Registration range	to 100 m	to 4 m	to 1 m
Simultaneous identification of several objects	to 200 tags/second	Impossible	Depends on the reader
Resistance to environmental influences	Increased strength and resistance	Depends on the material it is applied to	Depends on the material it is applied to
Service life	More than 10 years	Depends on the printing method and the material it is applied to	Depends on the printing method and the material it is applied to
Security and protection against counterfeiting	Can't be faked	Easy to fake	Easy to fake
Use of both stationary and hand-held terminals for identification	Yes	Yes	Yes
Price	High	Low	Low

Security is also guaranteed by the fact that the RFID tag can password-protect the data recording and reading operations, as well as encrypt their transmission. One tag can simultaneously store open and closed data.

However, this system also has its drawbacks: the cost of implementing RFID tags is higher than that of a barcode and QR code, there is a difficulty in self-production, and there is also susceptibility to interference in the form of electromagnetic fields.

Speaking of international standards, RFID technologies, as an integral part of automatic identification, are developed and adopted by the international organization ISO together with IEC.

The cost of RFID tags is decreasing by 5-10% every year. Obviously, there is a limit to this reduction, since it will always be more expensive to create a tag than a barcode or QR code, its cost is made up of the price of the electronic device, chip, antenna, multilayer structure.

RFID applications use several frequencies: 123 kHz, 13.57 MHz and 850-940 MHz for passive RFID; 423 MHz and 2.55 GHz for active RFID. Global standardization of RFID systems is a serious issue.

Below is a short list of RFID standards: ISO 1024, ISO 1036, ISO 1194, ISO 1443, ISO 1593, IS0 1800, EPC global. These standards govern the communication between the RFID reader and the tag. Standards operate in selected frequency ranges, such as 863-926 MHz for UHF or 13.66 MHz for HF).

The combination of RFID technology and computing technology is called an "RFID system" and consists of the following components:

• Tag/tr nsponder (electronic label);

• Antenna (tag reading medium);

• R ader/interrogator (reads tag information);

• Communication infrastructure (allows the reader/RFID to operate through the IT infrastructure);

• Application software (user database / application / interface).

An RFID tag is a small electronic device, also called a transponder. The tag consists of a simple silicon microchip and an antenna. The tag can be attached to an object, usually an item, a box. The information is collected by the chip and can be transmitted wirelessly. An RFID tag can be active (with batteries), passive (without batteries) and semi-passive (hybrid). The tag has an identification code that can be transmitted to the reader.

RFID antennas are used to collect information about any item. There are many types of RFID antennas such as patch antennas, linearly polarized antennas, whip antennas and adaptive antennas, gate antennas and omnidirectional antennas.

An antenna designer first creates a known antenna and then modifies its physical parameters to obtain an optimal bandwidth. In the past few years, researchers have studied the design of circularly polarized antennas. A dual-polarized antenna can be used. This antenna is suitable for passive operation at 5.4 GHz in RFID applications. Microstrip antennas are used for RFID, which have attractive features such as light weight, small volume, low profile and low manufacturing cost.

RFID technology: areas of application, forecasts and use prospects

RFID is a modern technology that has changed the methods of identifying and tracking objects [2-7]. The areas of application of RFID technology are shown in Table 2.

Table 2

Applications of RFID technology

Areas of application	Application
Warehouse logistics	Allows you to: track goods in the warehouse in real time, which ensures accurate inventory and control; ensure the movement of products to optimize processes; minimize personnel errors when forming orders; reduce operating costs, thanks to automation.
Retail	RFID tags continuously collect information about the location of goods from the distribution center to the retail point of sale for inventory management. Collecting data on customer preferences and purchase history to provide personalized offers and promotions. Implementing self-service checkouts with RFID readers for faster and more convenient payment for purchases.
Manufacturing sector	Accurately track inventory levels to optimize the supply chain and prevent production disruptions. Track the location and condition of production assets (tools, equipment, vehicles) to improve service efficiency and prevent losses.
Food industry	Inventory management, tracking food products throughout the supply chain to ensure consumer safety and regulatory compliance. Using RFID tags with temperature sensors to monitor and maintain food storage and transportation conditions.
Agriculture	Livestock tracking, crop management to optimize resource use, automation of animal feeding and harvesting processes.
Healthcare	Tracking stock levels of medicines and medical supplies to prevent shortages and optimize procurement. Identifying patients, monitoring their movements and ensuring their safety in healthcare facilities, using sensors to monitor patients' vital signs.

The main advantages of using RFID technology:

– Each RFID tag has a built-in unique code that distinguishes it from all the others;

– RF D allows data to be read and written from multiple tags simultaneously, making it more efficient to track large inventories;

– RFID tags can be read without being in line of sight, which allows you to track items in hard-to-reach places;

– Data on RFID tags can be rewritten, allowing information about items to be updated as they move;

– RFID systems can automate the inventory process, saving time and resources;

– RFID uses wireless communication, allowing items to be tracked without the need for a physical connection;

– RFID provides continuous tracking of the item location, allowing operators to track them in real time;

– RFID can automate product inspection on assembly lines, increasing efficiency and reducing the likelihood of errors;

– RFID technology can improve the accuracy and speed of order picking, ensuring that customers receive the correct items.

The main obstacles to the spread of RFID technology are:

– RFID tags can be relatively expensive, limiting their use for tracking low-cost items;

– RFID systems can be sensitive to external factors such as humidity and metal surfaces, which can affect their effectiveness;

– The lack of uniform industry standards for RFID systems can make them difficult to integrate with different technology systems;

– RFID tags can be vulnerable to unauthorized reading and cloning, which compromises data security.

These limitations are gradually being eliminated as the technology advances. The cost of RFID tags is decreasing. RFID systems are being developed to be more resistant to factors such as humidity and metal surfaces. Efforts are underway to develop and implement industry standards for RFID systems, making it easier to integrate them with other technologies. Research and development is aimed at improving the security of RFID systems, including encryption and authentication methods to protect data from unauthorized access. The future of RFID technology looks quite promising, despite some problems that have not yet been resolved, in particular, the shortage of chips and other raw materials. Forecasting shows that the global RFID market will continue to expand. Thus, by 2030, the RFID tag market is predicted to reach $ 54.7 billion with a CAGR of 15.9%. The world is currently seeing the rapid development of chipless RFID tag technology, with the market valued at $0.89 billion in 2019 and expected to reach $3.94 billion by 2025, with a CAGR of 28% over the forecast period 2020-2025.

RFID tags classification by power source, memory type and operating frequency

Classification of RFID tags by power source

RFID tags, depending on the presence or absence of a power source, can be classified as passive, active and semi-passive [6]. Let's consider their features and areas of application.

Passive RFID tags

Passive RFID tags do not have a built-in power source. The electric current induced in the antenna by the electromagnetic signal from the reader provides sufficient power for the operation of the silicon CMOS chip located in the tag and the transmission of a response signal. Commercial implementations of low-frequency RFID tags can be built into a sticker or implanted under the skin.

The compactness of RFID tags depends on the size of the external antennas, which are many times larger than the chip and, as a rule, determine the dimensions of the tags. Due to the range of antenna sizes, tags have different sizes - from a postage stamp to a postcard. In practice, the maximum reading distance of passive tags varies from 10 cm (4 inches) (according to ISO 14443) to several meters (EPC and ISO 18000-6), depending on the selected frequency and the size of the antenna. In some cases, the antenna can be made using a printed method.

Non-silicon tags can be made of polymer semiconductors. Currently, several companies around the world are developing them.

Passive tags of the UHF and microwave ranges (860-960 MHz and 2.4-2.5 GHz) transmit a signal by modulating the reflected signal of the carrier frequency (Backscattering Modulation). The reader antenna emits a signal of the carrier frequency and receives the modulated signal reflected from the tag. Passive tags of the HF range transmit a signal by modulating the load of the carrier frequency signal (Load Modulation). Each tag has an identification number. Passive tags can contain rewritable non-volatile memory of the EEPROM type. The range of the tags is 1-200 cm (HF tags) and 1-10 m (UHF and microwave tags).

Active RFID tags

Active RFID tags have their own power source and do not depend on the energy of the reader, as a result of which they are read at a long distance, are larger in size and can be equipped with additional electronics. However, such tags are the most expensive, and the batteries have a limited operating time. Active tags are in most cases more reliable and provide the highest reading accuracy at a maximum distance. Having their own power source, they can also generate an output signal of a higher level than passive ones, allowing them to be used in environments that are more aggressive for radio frequency signals: water (including people and animals, which mainly consist of water), metals (ship containers, cars), for long distances in the air.

Most active tags can transmit a signal over distances of hundreds of meters with a battery life of up to 10 years. Some RFID tags have built-in sensors, for example, for monitoring the temperature of perishable goods. Other types of sensors in combination with active tags can be used to measure humidity, shock/vibration, light, radiation, temperature, and atmospheric gases (such as ethylene). Active tags typically have a much larger reading range (up to 300 m) and memory capacity than passive tags, and are capable of storing more information for transmission by the transceiver.

Semi-passive RFID tags

Semi-passive RFID tags, also called semi-active, are very similar to passive tags, but are equipped with a battery that supplies the chip with energy. The range of these tags depends only on the sensitivity of the receiver - reader and they can function at a greater distance and with better characteristics.

Classification of RFID tags by memory type

RFID tags can be classified by the types of memory used as follows:

• RO (Read Only) - data is written only once, immediately upon manufacture. Such tags are suitable only for identification. No new information can be written to them, and they are almost impossible to counterfeit.

• WORM (Write Once Read Many) - in addition to a unique identifier, such tags contain a block of write-once memory, which can then be read many times.

• RW (Read and Write) - such tags contain an identifier and a memory block for reading / writing information. The data in them can be rewritten many times.

Classification of RFID tags by operating frequency

RFID tags operate in frequency ranges from hundreds of kilohertz to hundreds of megahertz. The radio frequencies used largely determine their functional parameters and are discussed in more detail below.

LF range tags (125-134 kHz)

Passive systems in this range have low prices and, due to their physical characteristics, are used for subcutaneous tags when chipping animals and people. However, due to the wavelength, there are difficulties with reading over long distances.

HF range tags (13.56 MHz)

13 MHz range systems are inexpensive, have no environmental or licensing issues, are well standardized, and have a wide range of solutions. They are used in payment systems, logistics, and personal identification. The ISO 14443 standard (types A/B) has been developed for the 13.56 MHz frequency. Unlike Mifare 1K, this standard provides a key diversification system, which allows creating open systems. Standardized encryption algorithms are used. Several dozen systems have been developed based on the ISO 14443 B standard, for example, the Paris region public transport fare payment system. Serious security problems were found for the standards that existed in this frequency range: the cheap Mifare Ultralight card chips, introduced in the Netherlands for the OV-chipkaart urban public transport fare payment system, had no cryptography at all; later, the Mifare Classic card, which was considered more reliable, was hacked.

As with the LF range, systems built in the HF range have problems with reading from long distances, reading in high humidity conditions, the presence of metal, as well as problems associated with the occurrence of collisions during reading.

UHF range tags (860-960 MHz)

Tags in this range have the longest detection range, and many standards in this range have anti-collision mechanisms. For a long time, there were no chips that would fully meet these requirements. Currently, the UHF frequency range is open for free use in the Russian Federation in the so-called "European" range – 863-868 MHz.

Near-field UHF radio frequency tags

Near-field tags, not being directly radio tags, but using the antenna's magnetic field, allow solving the problem of reading in conditions of high humidity, the presence of water and metal. With the help of this technology, RFID tags began to be used in the retail trade of pharmaceutical products (requiring authenticity control, accounting, but often containing water and metal parts in the packaging).

Conclusion

The article analyzes the advantages and limitations of using RFID technology, classifies RFID tags. It also compares radio frequency identification technology with bar coding and QR coding technology. The current state and development prospects of RFID technology are analyzed also. To summarize, it can be said that digitalization is really actively penetrating all sectors of the economy. RFID technology is one of many examples. It is possible to highlight the changes associated with digitalization that are currently taking place in industry. Despite the high cost, experts are optimistic about the future prospects for the implementation of radio frequency identification technology, believing that it will subsequently replace bar coding, affect all business processes and change wholesale and retail trade.

REFERENCES

[1] A.O. Fomchenkov, A.A. Kiktev, "Radio frequency identification technology," *Advanced materials and technologies (PMT-2022): Collection of reports of the conference of the Institute of Advanced Technologies and Industrial Programming of the Russian Technological University MIREA*, Moscow, April 11-15, 2022 / Ed. A. N. Yurasov. Vol. 1. Moscow: MIREA – Russian Technological University, 2022, pp. 529-532.

[2] M.M. Kulikov, M.A. Komissarova, I.A. Nazarova, "Prospects for the use of RFID technologies in Russia," *Bulletin of the Rostov State University of Economics*. 2022. No. 4 (80). Pp. 190-197. DOI 10.54220/v.rsue.1991-0533.2023.80.4.026.

[3] A. Subrahmannian and S. K. Behera, "Chipless RFID Sensors for IoT-Based Healthcare Applications: A Review of State of the Art," in IEEE Transactions on Instrumentation and Measurement, vol. 71, pp. 1-20, 2022, Art no. 8003920, doi: 10.1109/TIM.2022.3180422.

[4] S. K. Behera, "Chipless RFID Sensors for Wearable Applications: A Review," *IEEE Sensors Journal*, vol. 22, no. 2, pp. 1105-1120, 15 Jan.15, 2022, doi: 10.1109/JSEN.2021.3126487.

[5] J. Su, Z. Sheng, A. X. Liu, Y. Han and Y. Chen, "Capture-Aware Identification of Mobile RFID Tags with Unreliable Channels," *IEEE Transactions on Mobile Computing*, vol. 21, no. 4, pp. 1182-1195, 1 April 2022, doi: 10.1109/TMC.2020.3024076.

[6] K. Niotaki et al., "RF Energy Harvesting and Wireless Power Transfer for Energy Autonomous Wireless Devices and RFIDs," *IEEE Journal of Microwaves*, vol. 3, no. 2, pp. 763-782, April 2023, doi: 10.1109/JMW.2023.3255581.

[7] J. Xu et al., "The Principle, Methods and Recent Progress in RFID Positioning Techniques: A Review," *IEEE Journal of Radio Frequency Identification*, vol. 7, pp. 50-63, 2023, doi: 10.1109/JRFID.2022.3233855.

[8] T.N. Yelina, S.V. Bezzateev, S.G. Fomicheva, "The use of passive radio frequency tags in decentralized information exchange systems," *T-Comm*, 2023. vol. 17, no.9, pp. 38-47. DOI: 10.36724/2072-8735-2023-17-9-38-47.

[9] R. Chen, X. Huang, Y. Zhou, Y. Hui and N. Cheng, "UHF-RFID-Based Real-Time Vehicle Localization in GPS-Less Environments," *IEEE Transactions on Intelligent Transportation Systems*, vol. 23, no. 7, pp. 9286-9293, July 2022, doi: 10.1109/TITS.2021.3085824.

[10] A. Motroni, F. Bernardini, A. Buffi, P. Nepa and B. Tellini, "A UHF-RFID Multi-Antenna Sensor Fusion Enables Item and Robot Localization," *IEEE Journal of Radio Frequency Identification*, vol. 6, pp. 456-466, 2022, doi: 10.1109/JRFID.2022.3166354.