Proceedings of the 3rd International Conference on Mechatronics and Smart Systems
DOI: 10.54254/2755-2721/141/2025.21610

Principles and Applications of Radio Frequency Identification Systems

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Abstract: With the rise of the Internet of Things, the application market of Radio Frequency Identification (RFID) technology has further expanded and has enormous development prospects. This article mainly introduces the main components and working principles of RFID technology, classifies RFID tag antennas according to different frequency bands, and provides typical large-scale application cases combined with different RFID systems. Analyzed the advantages of RFID compared to original tags, briefly described the technical problems encountered in the development of RFID technology, and discussed the directions for further research on the difficulties currently encountered, as well as the future development prospects and directions of RFID. This article studies the principles of RFID technology and summarizes its characteristics, thus identifying the reasons for its broad development prospects. Finally, it can be inferred that if the characteristics of RFID technology are cleverly combined with the current development of the Internet of Things, the current technological development can be further optimized.

Keywords: Radio frequency identification, technical shortcomings, composition

1. Introduction

This article conducts research on the principles, current research status, and future development of Radio Frequency Identification (RFID) technology. RFID is currently widely used in various fields such as logistics, healthcare, transportation, and public libraries. The application of this system is beneficial for reducing labor costs, improving work efficiency and error rates in various workplaces, optimizing the performance of RFID technology in various aspects, promoting the development of intelligence in various industries, reducing various development costs, and promoting economic development. This article introduces the advantages and current technical shortcomings of RFID technology research by combining relevant literature on RFID technology at home and abroad, providing reference ideas for future research.

2. Composition and Principle of RFID Technology

RFID is a basic term for technologies that use radio waves. It is the ability to identify thousands of tagged items per second concurrently via wireless transmission. Thus compared to traditional bar code systems, multiple RFID tags can be read simultaneously, tags are able to cope with harsh and

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dirty environments, electronic information can be over-written repeatedly, and RFID tags can be automatically tracked, eliminating human error [1].

2.1. RFID Composition

As shown in Figure 1, it mainly consists of three parts: reader, electronic tag, and signal antenna.

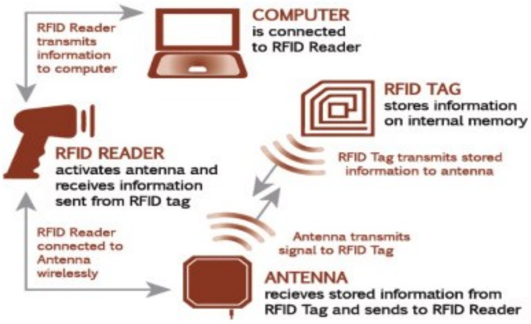

Figure 1: RFID system composition [2]

2.1.1. Reader

The reader is composed of a power supply, a reading and writing template, an RF module, and an antenna. It is a device responsible for reading the information of RF tags.

2.1.2. Electronic Tags

Electronic tags consist of memory, a control module, an RF module, and an antenna, and are attached to the items that need to be identified. The memory is the data carrier of electronic tags, which stores data through chips. The RF module of electronic tags communicates signals and transmits data through antennas and readers. Passive electronic tags require the electromagnetic field generated by the recognizer during the recognition process to obtain energy. The operating frequency of electronic tags has a significant impact on the object recognition distance, recognition range, RF efficiency, data perception capability, and data communication quality of wireless radio frequency identification (RFID) systems.

2.1.3. Antenna

In RFID systems, readers and electronic tags both have antennas with similar functions, which are devices that receive or radiate the RF signal power in the form of electromagnetic waves. The main function of the antenna is to provide a carrier for RF signal output and signal return between the reader and electronic tag [3].

2.2. RFID Principle

The working principle of RFID is to activate the RF module on the tag by sending an excitation signal from the reader to the RF tag. The RF tag receives the instructions sent by the reader through the antenna to perform the corresponding functions, and the information stored in the tag is sent back to the reader through the RF module. The reader receives and decodes the information sent by the radio frequency module through the communication module, and then transmits the information to other systems for further processing [4].

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3. RFID Classification and Practical Applications

3.1. RFID Classification

According to the different frequency bands applied, RF tag antennas can be divided into four types: low frequency, high frequency, ultra-high frequency, and microwave frequency bands.

3.1.1. Low-frequency RFID System

The main working frequency of the low-frequency RFID systems is 125kHz or 134kHz, which is used for short-range recognition, and the reading distance is less than 10cm. The amount of transmitted information is low, and multiple tag recognition cannot be performed at the same time, and it can be applied in short-range application scenarios such as cafeteria meal cards.

3.1.2. High-frequency RFID System

The main working frequency of the high-frequency RFID system is 13.54MHz, with a wavelength of about 22 meters. It mainly uses passive tags and belongs to near-field RFID technology, with a recognition distance of less than 1 m. It is mainly used in fields, such as access control, electronic payment, and intelligent shelf management.

3.1.3. Ultra-high Frequency RFID System

The working frequency range of the ultra-high-frequency RFID system is 860-960 MHz, and the working mode used is electromagnetic backscatter coupling. The radio frequency identification distance is relatively long, generally greater than 1m, usually 4-6m, and passive can reach about 10m. The information data transmission rate is fast, and a large number of tags can be read simultaneously. It can generally be applied in logistics management, library management systems, and other fields with long-distance identification requirements;

3.1.4. Microwave RFID System

The main working frequency of microwave RFID system is 2.45 GHz or 5.8 GHz, the reading distance is greater than 10m and the sensitivity to the environment is high. It can be applied in fields such as ETC and real-time positioning systems [5,6].

3.2. RFID Applications

Compared with those traditional tags used in the past, the electronic tags used in RFID have unique advantages that greatly improve work efficiency and optimize the transmission data.

3.2.1. Logistics Management

As shown in Figure 2, establishing a comprehensive logistics management system centered on RFID mode for distribution centers can not only generate revenue, but also improve efficiency: the use of RFID technology can reduce the labor costs of enterprises and make logistics transportation more automated. In addition, the two main challenges of retail trade, that is, goods out of stock and wastage, have also been solved; because RFID tags can uniquely identify commodities and provide real-time feedback, they can update product information in real time to obtain expected benefits and reduce the working time of labor force. In addition, they can also improve the quality of inventory and increase the throughput of distribution centers by timely adjustment through real-time access to logistics

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information. This kind of logistics management model using RFID technology has higher progressiveness and security than the traditional model.

Its advanced nature lies in the use of radio waves to carry out non-contact, long-distance, dynamic multi-target, mass simultaneous transmission of identification data, which can realize the real "one thing, one code" mode of transferring logistics information, and greatly shorten the time for tracking items and sharing data. In order to solve current security issues, RF chips also use encryption technology. One of the best examples of RFID technology today is that Walmart saves $8.35 billion in labor costs every year, and also saves more than $2 billion lost due to theft [7].

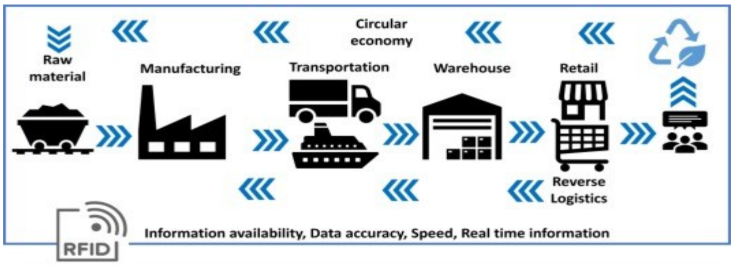

Figure 2: Applications of RFID in logistics management [8]

3.2.2. Electronic Toll Collection Systems

ETC is the non-parking charge, mainly through the RFID electronic tag and the RFID reader of the toll station, to achieve the mutual exchange of information between the two. The control computer needs to strictly identify vehicles in a timely manner according to the various information stored in the RFID electronic tags, and automatically deduct transportation fees, thereby achieving the goal of non-stop toll collection and automated toll collection.

Throughout the design process, the system's start switch needs to be set as the vehicle detector. Once the vehicle enters, it should be detected in a timely manner and send corresponding signals to the main control CPU of the RFID reader. Then, the video recognition system should be started in time to identify and charge for the arriving vehicles. Compared with ultrasonic detectors, ground-sensing coil detectors have higher accuracy and are not affected by the environment. In principle, they mainly bury inductive coils on the ground. After the vehicle enters the ETC channel, the resonant frequency of the circuit will increase. The change in detection frequency can be used to determine whether the vehicle has passed. For ultrasonic detectors, they need to be placed at the top of the lane, and the antenna of the RFID reader also needs to be placed at the top, so that the two can affect each other [9].

3.2.3. Intelligent Library

RFID technology has the advantage of wide applicability, which can be utilized in public library access control systems, personnel information collection and processing, book information processing, and other work. From the perspective of characteristics, RFID technology mainly relies on electromagnetic waves for information communication, and can complete the collection and identification of information under non-contact conditions [10]. Applying it to public libraries can be suitable for various indoor and outdoor work environments. It can pass through non-metallic items, such as plastic and paper, has strong anti-interference ability, and quickly completes the collection and processing of information such as books and personnel. Readers holding RFID borrowing cards will pass through the access control system, recording personal information. At the same time, books containing RFID tags will sound an alarm when they pass through the access control system without borrowing, improving the security of the library. It can be seen that the future smart library will fully

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realize intelligence through the combination of the Internet of Things, and improve the use efficiency and management efficiency of the library.

4. Optimization and Future Development of RFID Technology

4.1. RFID Technology Optimization

The performance of RFID technology systems largely depends on the performance of tag antennas, so when optimizing RFID technology, the first consideration should be to optimize all aspects of tag antennas.

Due to the fact that the characteristic impedance of general communication antennas is mainly manifested as resistance, in the design, its reactance should be minimized as much as possible to approach 0; that is, impedance matching should be done well to reduce the energy loss of the antenna, achieve optimal antenna performance, and increase the reading distance of the RFID system. The input impedance Z_i of the antenna is the ratio of the signal voltage to the signal current at the input end of the antenna, and is represented as the real part of its impedance component by R_i and the imaginary part of its impedance component by X_i. The impedance formula is:

$$Z_i = R_i + j * X_i \tag{1}$$

One challenge in analyzing the design of RFID antennas is impedance measurement. In RFID systems, in order to achieve maximum energy transfer, the wireless input impedance is usually designed as the conjugate of the tag chip impedance. Generally, the characteristic impedance of communication antennas is only the resistance component, without the imaginary part reactance component. Therefore, in the antenna design process, the best requirement is to have no reflected waves, and the input impedance of the designed antenna must be pure resistance, that is, $Z_i = R_i$. However, in actual antenna design, it is impossible to have pure resistance. To achieve this, by paralleling a capacitor and an antenna, it is necessary to minimize reflected waves as much as possible in order to improve the matching degree between input impedance and characteristic impedance [11].

4.2. RFID Future Development

Overall, the main markets for RFID applications in China are in the fields of identity recognition, traffic management, military and security, asset management, and logistics and warehousing. In the use of RFID, retail and transportation logistics occupy the absolute main force. The sum of the two accounts for about 40% of the entire market. Walmart, Metro AG, Zara and other retail and clothing leaders have been fully applied.

The application of RFID tag technology in the retail industry has successfully helped enterprises improve production and sales efficiency, increase profits, and also change the user's consumption experience [12].

In addition, in the field of unmanned retail, the parallel development of RFID technology is artificial intelligence technology, including machine vision, deep learning, sensor fusion technology, etc. In the future of the unmanned retail field, RFID technology can be combined with artificial intelligence technology to improve the safety performance and maturity of unmanned retail. With the development of the times, the Internet of Things technology has become a hot spot of technological innovation, and RFID technology is the foundation of the Internet of Things perception layer technology. Therefore, the future development of RFID will continue to be closely integrated with the Internet, and the technology will continue to develop and mature. The future development of RFID must be closely integrated with the Internet of Things, and RFID technology will make great contributions to the economic development of our country [13].

5. Conclusion

RFID technology, as a self-identification technology, can transmit and identify data without contact. It was put into use in the UK as early as World War II and has received widespread attention since its development, gradually integrating into our lives. This article introduces the technical principles, practical applications, current defects encountered, and directions for improvement. In order to use this technology more widely, RFID technology has been constantly adjusted to improve its accuracy and optimize its performance. However, due to the limited number of current literature, the summary of how to optimize the shortcomings of RFID technology is not comprehensive. Therefore, this article only analyzes impedance matching. In fact, the miniaturization of RFID tag antennas without affecting their original performance stability is also an aspect that can be improved. Reducing the tag size and coordinating small size with excellent performance can greatly reduce costs and further expand the application field of this technology. With the increasing application scope, RFID also needs to meet more diverse market demands. In future research, tag antennas with different shapes and performance may need to be designed for different scenarios. At the end of this article, it is analyzed that this technology serves as the foundation of IoT perception layer technology and is closely related to the development of IoT technology. Therefore, it can be inferred that future research on this technology may also focus on how to optimize and improve RFID technology to help solve the difficulties encountered in the current development of IoT.

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