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Ultra-high Frequency RFID Tag Based on Functional Nanomaterials and Its Application in Smart Library

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Abstract: As times change and technology advances, people are increasingly enjoying the convenience brought by modern technology, and the library industry is no exception. Now more and more libraries have begun to adopt RFID technology. Compared with the traditional "barcode + magnetic stripe" technology, the application of RFID technology for book management is a huge innovation and upgrade. RFID has many features, which can allow libraries to provide more and more humanized services. So, this paper mainly studies the application of RFID technology in the field of libraries, taking the UHF RFID tags currently prevalent in large libraries as the main point of this research. It builds a security system for borrowing and returning management, so as to better manage the library. The results show that most of the experimental groups that pass the safety gate have a goodness of fit exceeding 0.9. The intelligent management of books can be effectively realized based on UHF RFID tags.

1. Introduction

Today, most libraries use barcode + magnetic stripe technology to manage their collections. Bar code technology liberates the library from the shackles of manual records to a certain extent, and greatly improves the efficiency and quality of library services. However, with the advent of new technologies and new ideas, barcodes have become somewhat obsolete. The biggest disadvantage of barcode technology is that it requires contact to scan a book, and only one book can be scanned at a time. To scan a book's barcode, a librarian must first locate the barcode, place a reader in front of it, and press the scan button. In China, some university libraries applying RFID technology have introduced RFID technology. However, compared with European and American countries, there are still many drawbacks, lack of independent intellectual property rights, and no scale advantage.

One of the keys to network technology, RFID technology has a wide range of applications. The technology has become a current popular research topic due to its many advantages. Among them, employee attendance information has always been an important part of enterprise management. Radio Frequency Identification (RFID) provides a new solution to such problems due to its strong anti-jamming capability and non-invasiveness. Bai R used CRFID and RNN deep learning network to discriminate book actions during reading, so as to determine the degree of readers' demand for books, and to provide a basis for library book purchasing and readers' personalized service. It was concluded from the experimental results that the method can recognize readers' perceived needs in different reading stages [1]. Abdelkarim M presented a new design of a small split-ring resonator antenna using meander-line technology. The antenna adopts a simple impedance matching method and is suitable for UHF-RFID tags. And the antenna has good impedance matching with the RFID ASIC without any external matching network [2]. Mathew J proposed a new miniature UHF RFID tag antenna (26.4 × 24 × 1.6 mm3) for broadband operation on the UHF RFID band. It has good read range characteristics. It can tune the resonant frequency by changing the gap width between the folded arms to achieve the maximum read range within the allocated frequency band in the desired region without affecting its overall size [3]. The research results of the above scholars provide some guidance for the research of this paper. However, its research content is only partially related to the research topic of this paper, and most of it is the application research of RFID tags. And most of them are based on high frequency, and there are few studies on the combination of ultra-high frequency tags and smart libraries.

The innovation of this paper lies in two points. One is based on the combination of RFID technology and library without manual intervention. It realizes the effective management of smart library through this technology. The second is to use ultra-high frequency bookmarks, which are more advantageous in price, volume and read and write speed, as electronic tags, which can effectively reduce construction costs. The two basic forms of anti-collision algorithms are described.

2. Application Method of RFID Technology in Smart Library

2.1. The Principle of RFID Technology and its Application in Smart Library

(1) Principle of RFID technology

RFID technology is suitable for various harsh environments. Oil stains, dust, etc. have little effect on the technology [4]. Moreover, this technology can realize long-distance reading [5].

(2) Application of RFID technology in smart library

The variety, quantity and rapid circulation of library materials mean that traditional manual or semi-automatic and semi-manual services can no longer solve the problems faced by libraries, and are far from meeting the needs of readers and managers [6]. The emergence of RFID technology has opened a window to solve this problem, and formed a characteristic library RFID management system.

2.2. RFID System Operating Frequency

The electromagnetic spectrum is usually divided into different frequency bands in order of frequency from low to high [7]. It has four categories: low frequency, high frequency, ultra-high frequency, microwave [8].

High frequency RFID is near field communication. Energy and data are transferred between the reader and the tag based on inductive coupling [9]. Inductive coupling is based on Ampere's law of circulation and Faraday's law of electromagnetic induction [10]. Ampere's cycle law states that when the current in the antenna coil changes, an alternating magnetic field is generated around it. When a tag enters an alternating magnetic field, Faraday's law of electromagnetic induction induces an induced voltage in the tag's antenna coil. This voltage is rectified, filtered and rectified and converted to DC voltage and supplied to the tag [11].

When a RFID tag enters the changing magnetic field generated by the antenna coil of the reader, an induced voltage is generated in the coil of the tag, which enables the tag to obtain operating energy [12]. Faraday's law of electromagnetic induction states that the induced voltage is proportional to the rate of change of the magnetic flux through the coil [13] and is related to the following factors:

$$Y = -\frac{L\phi}{Ls} \tag{1}$$

In the formula, Y represents the induced voltage on the tag antenna, and the magnetic flux passing through the tag coil is represented as ϕ. L is the distance between the reader antenna and the tag.

$$Y = -Q_2 \frac{L\beta}{Ls} \tag{2}$$

Among them, β represents the magnetic flux passing through the single-turn coil of the tag antenna. Q_2 is the representation of the number of turns of the antenna coil in the label.

$$Y = -[\frac{\upsilon_0 d^2 R_1 Q_1 Q_2}{2[d^2 + L^2]^{3/2}}]\frac{LR}{Ls} = -E\frac{LR}{Ls} \tag{3}$$

E is the mutual inductance coefficient in the formula, namely;

$$E = \frac{\upsilon_0 d^2 R_1 Q_1 Q_2 M}{2[d^2 + L^2]^{3/2}} \tag{4}$$

The above formulas give a clear demonstration of the energy received by the tag and the connection of key parameters between the reader and the tag antenna.

3. RFID Tag Experiment in Library System

3.1. Comparison of High Frequency (HF) and Ultra High Frequency (UHF)

As the Internet of Things technology develops, RFID tags are more and more widely used in the intelligent management of libraries. The RFID tags currently used in libraries are mainly high frequency (HF) and ultra-high frequency (UHF) tags [14]. The application comparison of the two is depicted in Table 1:

Table 1: Contrast of HF and UHF tags

category	high frequency	UHF
label type	Magnetic Field RFID Tag	Electromagnetic wave RFID tag
frequency band	13.54MHz	850MHz~910MHz
distance	≤1 m	4-6 meters,up to 10 meters
read and write speed	slower	faster
volume	larger	Small and easy to carry
Storage capacity	little	Big
safety	generally	strong
Scope of application	library with few books	big library

Due to its low cost and technological advantages, the future development of IoT and logistics will mainly rely on UHF technology. UHF tags can accomplish many tasks that high-frequency tags cannot. The future development of libraries will still depend on technology, as UHF technology will be used more and more [15].

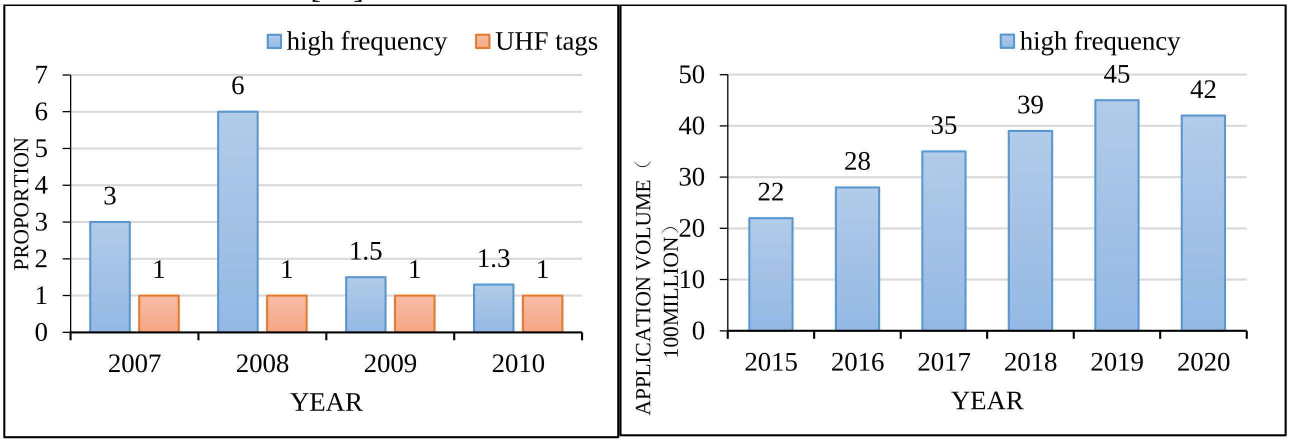


Figure 1: Selection of library RFID frequencies and the amount of UHF tags used in recent years

As shown in Figure 1, the application of ultra-high-frequency tags has been increasing. By 2019, the number of ultra-high-frequency applications reached 4.5 billion, and it will only decline in 2020 due to the impact of the epidemic.

3.2. UHF RFID Anti-collision Algorithm

The collision problem of RFID system is divided into two categories: tag collision and reader collision. This paper discusses the second most likely situation in the actual system: tag collision. Within the RF field range of the reader, if multiple tags send data to the reader at the same time, the reader will not be able to correctly identify the information, that is, tag collision occurs, as shown in Figure 2.

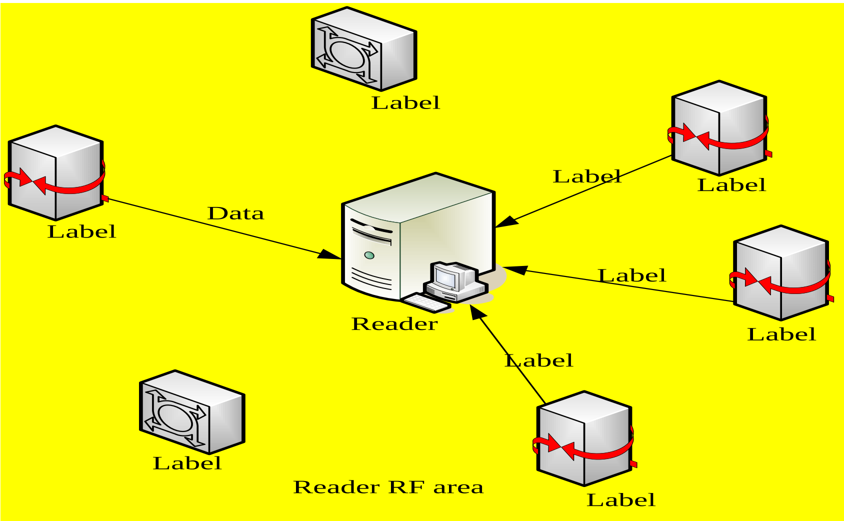


Figure 2: Label collision model

In the RFID system, the multiple access technology method that allows multiple accesses without problems is called the anti-collision method. There are many anti-collision methods commonly used in RFID systems.

As shown in Table 2, some of these algorithms have their own advantages and disadvantages.

Although the recognition speed is faster, it increases the cost of the reader due to the complexity of its antenna technology. Therefore, the space division multiplexing method has not been widely used in the RFID multi-tag collision avoidance system.

Table 2: Comparison of Four Common Algorithms

Algorithm comparison	Advantage	insufficient
SDMA	Fast recognition	Complex antenna technology
FDMA	Effectively resolve label collisions	Readers are expensive
CDMA	Signal transmissions do not interfere with each other	low bandwidth utilization
TDMA	The algorithm is easy to implement and has good stability	low channel utilization

Currently, the two main types of anti-collision algorithms are extensions of time division multiplexing techniques.

(1) The first is the pure ALOHA algorithm. This is the simplest RFID tag collision avoidance algorithm.

The basic idea of the pure ALOHA algorithm is to use an anti-collision mechanism of collision monitoring and random backoff, using a tag-driven model. A collision occurs when different tags react to the reader in partially or fully overlapping epochs. When the reader detects a collision, it sends a command to the tag to stop the current response. Instead, it waits a random amount of time before responding to the reader, reducing collisions. The algorithm is depicted in Figure 3.

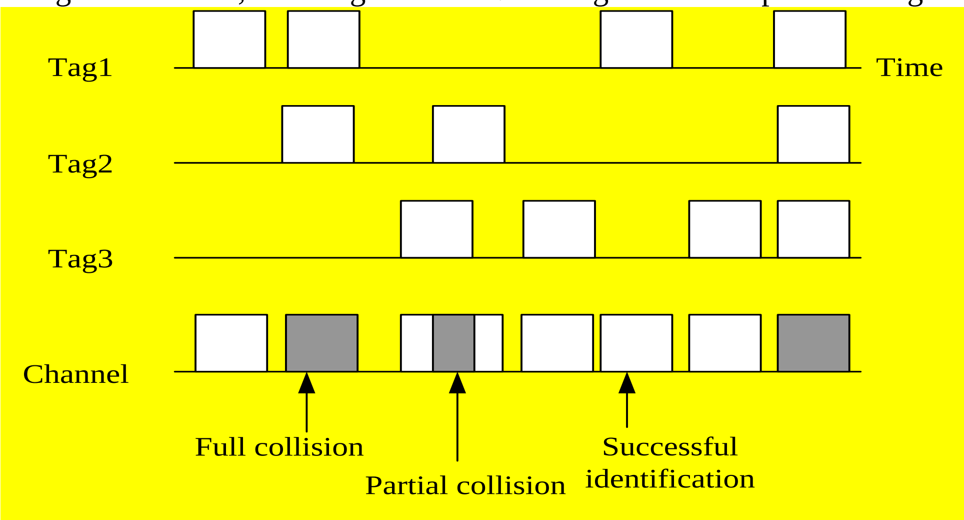


Figure 3: Schematic diagram of the process of pure ALOHA algorithm

The tag reading process of the pure ALOHA algorithm is as follows:

1) The tags in the active state within the query range of the reader randomly select a time point to respond to the reader.

2) The reader decodes the received signal and checks whether there is an illegal signal in the received signal. If it exists, a collision occurs, if not, the reader successfully recognizes the tag.

3) If a collision occurs, the reader uses a random back-off mechanism to send commands to delay the response of the tag in the current response state.

(2) The second anti-collision algorithm is the binary tree search algorithm. The algorithm is a deterministic anti-collision algorithm. The identification process is shown in Table 3.

If there are i tags in the reader storage area, the number of queries to successfully identify a tag from the i tags is;

$$X = \log_2 i + 1 \tag{5}$$

If the tag ID length is C, then the traffic is;

$$\mathrm{Traffic} = C_{GM}(i) \cdot C \tag{6}$$

$$\mathrm{Traffic} = C[i + \log_2(i!)] \tag{7}$$

On the basis of the basic algorithm, some scholars have explored the polynomial tree anti-collision algorithm. One of the binary collision avoidance algorithms, the query tree algorithm, was found to be a basic collision avoidance algorithm that reduces the scope of queries by grouping them.

Table 3: Identification process of the algorithm

query parameters	response tag	response information	identification label
11111111	A, B, C, D, E	1xxxxxx1	without
10111111	A, C, E	101xxxx1	without
10101111	E	10101111	E
11111111	A, B, C, D	1xxxxxx1	without
10111111	A, C	101101x1	without
10110101	A	10110101	A
11111111	B, C, D	1xxxxxx1	without
10111111	C	10110111	C

3.3. Improved Algorithm

This subsection introduces improvements to the Dynamic Dispersive Shrinking Binary Tree (DDS-BT) algorithm. This algorithm is a standard anti-collision algorithm for UHF RFID tags. This algorithm is widely used to solve the problem of multi-label collision, but its disadvantage is the low recognition efficiency. Based on the Manchester coding characteristics of DDS-BT algorithm, this paper proposes an improved DDS-BT anti-collision algorithm. The general idea of the algorithm is described as follows.

(1) For Manchester-encoded RFID tags, the bit value of each RFID tag is either '0' or '1'. Therefore, if the reader detects the serial number of an RFID tag with only one collision bit, then both tags can be directly identified.

(2) If the reader detects an RFID tag with N collision bits in the serial number, in this case, the bit data information of the N collision bits is unknown to the reader, and the other bit data information is known to the reader. Therefore, reading/writing only needs to identify these N unknown collision bits through the anti-collision algorithm.

If multiple labels need to be identified, the binary tree anti-collision algorithm is used. The algorithm counts the number of reading/writing queries from the root node to the total number of leaf nodes of the tree. In order to find a tag among i tags, the reader needs to send many query requests. If the average number of queries of the binary tree algorithm is C, the formula is as follows.

$$C = \log_2 i + 1 \tag{8}$$

Among them, i represents the number of RFID tags.

Figure 4(1) is a statistical graph of the mean time complexity of the improved DDs-BT algorithm. As the number of tags increases, the mean value of time complexity also increases to a certain extent. However, compared with the unimproved algorithm shown in Figure 4(2), the increase in time complexity is much smaller. In the case of 300 tags, the average time complexity of the improved algorithm is about 4. The average complexity of the algorithm before the improvement has exceeded 8 at 250 labels. The improved algorithm can reduce the time complexity of the algorithm very well.

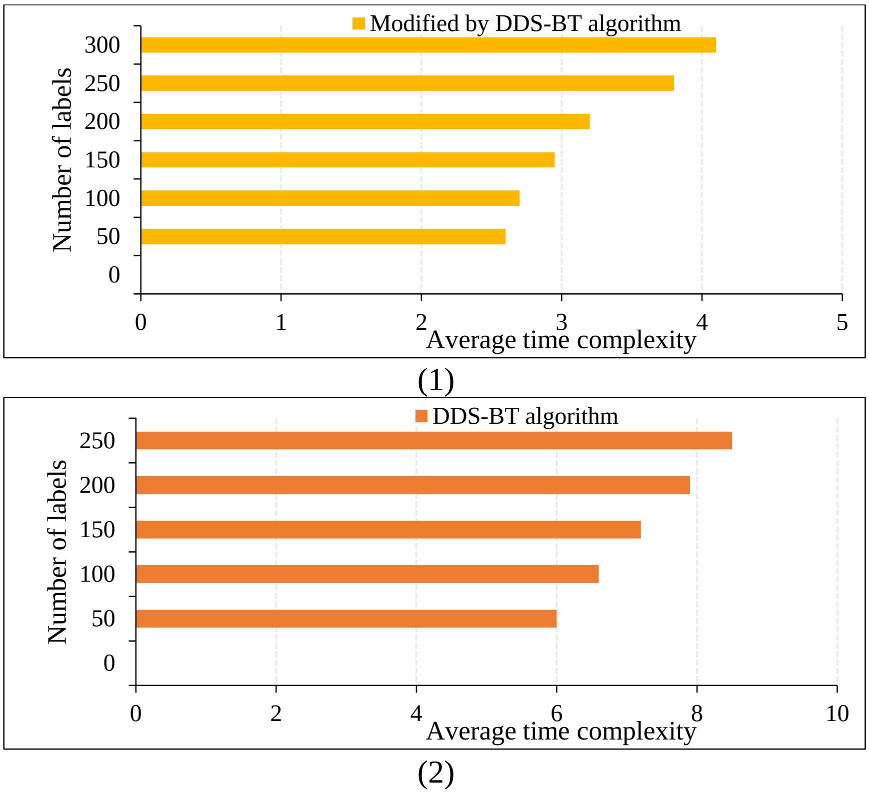


Figure 4: Time complexity comparison between the improved algorithm and the unimproved algorithm

4. Intelligent Management of Smart Library

4.1. Intelligent Management of Smart Library Based on RFID Technology

(1) Self-service borrowing/returning system

The self-checkout and return system is the most important part of a smart library and one of the functions most frequently used by our library users. This self-service book lending system can be seamlessly connected with the current library management background of the Port Authority Library. It can provide self-service for teachers and students of the college, including book borrowing, book return, book inquiry and renewal, and violation handling. The design of the book self-checkout and return system module removes most of the burden from the counter service system.

(2) Librarian's workstation

The librarian workstation is a comprehensive processing station for the circulation business of the library. Library staff can use it to complete RFID tagging of books, borrowing and returning books, ordering books and dealing with violations.

Library staff can also use the screen to view and change information and security check bits on labels, register library cards and deal with violations.

(3) Smart security of books

Since security and anti-theft are important issues for all libraries, as well as an important guarantee to prevent book loss, the intelligent security detection system is an important tool for smart libraries. The library's intelligent security detection system can provide services for reader identification, camera monitoring, book detection and hazard alerts. It can also provide card-based reader access, protection from unauthorized book removal, book theft alerts, real-time surveillance and camera recording.

4.2. Implementation of Borrowing and Returning and Anti-theft Module

The self-borrowing hardware system includes a computer host, monitor, RFID antenna and wireless network card. The RFID reader activates the RFID antenna to read the RFID tag and transmit the data to the host. The host computer is connected to the library network through a network card and accesses the database to retrieve book information and display it on the monitor. The machine is directly controlled by the user through an infrared-sensing touch screen.

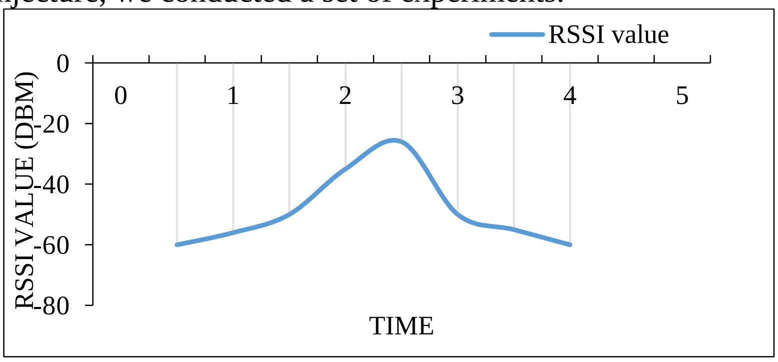
For self-checkout machines, the process of book scanning is relatively simple. The reader puts the book into the white scanning area of the self-checkout machine, and then clicks the refresh button, the system starts the reader to read the label and transmits the data to the host. The book reading work of the smart security door is similar to this, the difference is that the smart security door is always activated for book scanning.

4.3. Signal Strength (RSSI) of Security Doors

In the application scenario of the library's smart security door, when books are carried through the security door, the position of the books relative to the reader antenna is getting closer and closer. The distance between the book and the reader reaches a minimum value until the book passes through the security gate. Therefore, the trend in RSSI should be the same as the change in distance. The study found that when the tag was farther away from the antenna, the RSSI value changed less with distance. But when they are closer, the RSSI value varies more with distance. This feature is consistent with that of the normal distribution. The formula for the normal distribution is shown.

$$B = X \cdot C^{-(\frac{A-y}{e})^2} \tag{9}$$

To verify this conjecture, we conducted a set of experiments.



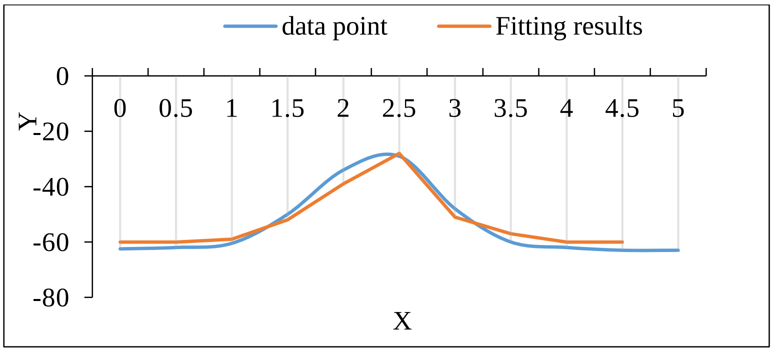


Figure 5: The signal curve of the tag passing through the safety gate and the fitting result of the normal distribution

In Figure 5, the RSSI value of the tag tends to increase as the book approaches the security door. As the book moves away from the safety gate, its RSSI value changes very slowly, basically hovering between 50 dbra and -60 dbm. When the book came within 0.6-0.8 meters of the security gate, its RSSI value changed significantly, jumping from -50 dbra to around 30 dbm in 0.7 seconds, then holding steady. After the book started moving away from the security door, the RSSI value dropped again and the previous pattern of approaching the security door was repeated. The entire curve conforms to the characteristics of a Gaussian distribution.

The MATLAB fitting results shown in Table 4 are that the coefficient of determination between the fitted curve and the original data points is R-squared=0.96. When the book passes through the smart security gate, the RSSI value sequence of the RFID tag in the book basically conforms to the normal distribution of the above parameters, indicating that the curve fitting can accurately describe the RSSI value returned by the RFID tag in the book.

Table 4: Comparison of label R-square values for passing and failing security gates

	by group	failed category
Average R-square	0.92	0.75
Maximum R-square	0.96	0.95
Minimum R-square	0.79	0.51
R-square median	0.94	0.73

Most of the experimental groups that pass through the safety gate have a goodness of fit over 0.9 from Table 4. On the other hand, most noise groups have a goodness of fit between 05-0.8. The difference is still quite obvious. Therefore, 0.8 was chosen as the threshold, and the R-squared value was lower than 0.8 to alert, and higher than 0.8, to not alert.

5. Conclusions

The main research focus of this paper is the design and development of RFID technology and a series of intelligent library borrowing and returning systems based on UHF RFID technology. The whole system is divided into two modules: borrow and return and anti-theft module and query module. The borrowing and anti-theft module is used by readers of the library, and its main function is to facilitate readers to borrow and return books. The module consists of a self-checkout machine and a smart security door. This article focuses on the loan and return system and the anti-theft module. This paper also proposes the relationship between RSSI and distance variation using UHF tags, the main purpose is to reduce the false alarm probability of smart security gates. Research on smart security gates mainly focuses on the algorithm of library security gates based on RSSI characteristics to reduce the ratio of multiple reads. It utilizes the characteristics of UHF RSSI tags:

When the tag is far away from the reader antenna, the RSSI value changes slowly with the distance, while when the tag is close to the reader antenna, the RSSI value varies significantly with distance. The RSSI value of the tag signal is fitted with the above features. According to the fitting results, those tags that were only accidentally read and not passed through the safety gate by the reader were excluded. This improves the accuracy of smart security gates.

In traditional libraries, borrowing and returning books is a time-consuming and labor-intensive process for both users and library staff. With barcode technology, the time a reader takes to borrow a book is proportional to the number of books borrowed, that is, the more books are borrowed, the longer the time. The RFID-based self-checkout system can lend out several books at a time, greatly reducing the burden on staff. The self-checkout/return subsystem includes a user interface module, a book scanning module, a library card scanning module and a database module.

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