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Research on Intelligent Shelves Based on RFID Technology

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Abstract: ***Intelligent shelves are the foundation of intelligent warehouse system management. As an intelligent storage management technology application, RFID technology can achieve efficient and precise management of material shipment, logistics, warehousing, stacking, inventory and outbound through wireless radio frequency identification communication.With the continuous maturity of technology, at present, it is the opportunity for traditional warehousing enterprises to transform into intelligent warehousing enterprises. The application and development of intelligent shelves will also be a hot spot in the fierce competition of the warehousing industry.With the development of industrial automation and intelligence, the research and application of intelligent shelf technology is urgently needed.This article analyzes the communication principles and advantages of RFID systems, as well as the technological research in intelligent shelves, with the hope of further improving the application level of RFID technology and promoting the intelligent development of warehousing systems.***

Keywords: Intelligent shelves; Warehouse management; System design; Application of RFID Technology.

1. INTRODUCTION

RFID technology has a profound impact on the construction and application of intelligent warehousing systems. Warehousing enterprises need to have a deep understanding of the application principles and advantages of RFID technology, deepen its application in warehousing, inventory, and outbound of goods, and accurately control the key points of RFID technology application. Only in this way can RFID technology be organically combined with intelligent shelf systems.Intelligent shelves are the foundation of intelligent warehouse management. Smart antennas are installed on RFID shelves for product classification, and shelf readers are combined with shelf electronic tags and mobile handheld devices to complete tasks such as inventory and search.Intelligent shelf management has a wide range of applications, suitable for logistics warehousing, enterprise warehouses, medical consumables management, intelligent retail, smart stores and many other fields.From inbound operations to outbound usage, real-time data uploading facilitates problem tracing for managers, forming an integrated intelligent shelf management system. Shen et al. (2025) [1] developed an LSTM-based AI system for precise anesthetic dose management in cancer surgeries, while Wang et al. (2025) [2] advanced autonomous driving through end-to-end AI solutions. For financial forecasting, Guo et al. (2025) [3] proposed a hybrid ensemble method with focal loss to handle imbalanced datasets, complemented by Weng et al. (2024) [4]'s adaptive framework for multi-task model fusion. Customer experience analysis was enhanced by Dai et al. (2020) [5] through text sentiment analysis of after-sales services. Network technologies progressed with Xing et al. (2024) [6]'s fuzzy spatiotemporal graph neural networks for traffic forecasting and Wu et al. (2024) [7]'s differential privacy techniques for NLP applications. Public safety innovations included Yu et al. (2024) [8]'s crime prediction model using graph convolutional networks, while financial analytics advanced through Fang et al. (2024) [9]'s comparative study of sequential deep learning models. LLM capabilities were expanded by Gao et al. (2024) [10] through retrieval-augmented generation and Xi et al. (2024) [11] via reinforcement learning integration. Financial security was strengthened by Wang (2024) [12]'s ensemble learning approach to fraud detection. Computer vision applications progressed with Lyu et al. (2024) [13]'s optimized CNNs for 3D object recognition, while sustainability efforts were supported by Wu et al. (2025) [14]'s analysis of digitalized supply chains for carbon neutrality. Personalized AI generation was advanced by Liu et al. (2025) [15]'s cloud-device collaboration framework, while mathematical reasoning in LLMs was improved by Liu et al. (2025) [16] through hallucination detection. Contextual understanding was enhanced by Liu et al. (2024) [17] via coreference resolution, and task planning capabilities were expanded by Liu et al. (2024) [18] through their multi-tool clustering approach.

2. RESEARCH BACKGROUND OF INTELLIGENT SHELF SYSTEM

In modern enterprises, with the diversification of product varieties, higher requirements have been put forward for material storage management in shelves.When materials stored on traditional shelves are stored in and out of the

warehouse, they are often randomly placed on shelves with available space, without considering the characteristics of the goods and demand. This leads to a high number of shelf handling times, long handling distances, and a large workload during the picking process, resulting in low efficiency and easy errors, seriously affecting the daily management and economic benefits of enterprise warehousing.With the increasing informatization of management methods, RFID technology has been applied to bind electronic tags to materials, replacing manual reading with automatic reading of information from material electronic tags to improve the accuracy of inbound and outbound records.Therefore, designing an intelligent shelf classification management system with simple and efficient operation, intuitive storage location, and convenient query is of great significance.

3. INTELLIGENT SHELF RFID TECHNOLOGY COMMUNICATION PRINCIPLE AND ADVANTAGES

3.1 Communication principle of intelligent shelf RFID system

RFID technology is essentially a way of identifying RFID electronic tags through readers supported by wireless radio frequency identification communication technology.In this technical mode, the warehouse keeper terminal will first issue a query command to the reader;At this point, the reader will perform two operations: encoding and modulating the query command, and transmitting the query data signal to the tag through a wireless radio frequency electromagnetic channel under the action of the antenna.The RFID electronic tag itself is embedded with a circular antenna, which can receive signals and then compare the received signals with the specified values. When the RF signal strength is higher than the recognition specified value, the electronic tag function is activated to complete the signal demodulation and decoding operation, and form a certain return signal with significant differences from other communications. Through the antenna cycle scanning recognition action, the identification information symbol returned by the tag can be captured at the reader end, and the symbol can be demodulated and decoded. Under the constraint of the backend middleware program, the decoded data information can be analyzed to obtain the corresponding combination that meets the query command, and then realize the system management of stored materials.

3.2 Advantages of RFID technology application in intelligent shelves

In RFID system communication, ultra-high frequency control and inductive coupling management are two extremely important welding processes.As for ultra-high frequency, it mainly achieves data exchange through the principle of electromagnetic emission.It should be noted that in ultra-high frequency propagation, electromagnetic energy continuously decays at a speed equal to the square of the distance.In the data transmission between the reader and RFID chip, it is mainly controlled and managed through load modulation. In the same carrier signal control, it is necessary to separate the two synchronous modulations. In the FDMA processing stage, the reader needs to divide the frequency into multiple channels and keep each channel in the 300KHz frequency range.In specific project applications, for the layout of the reader antenna, it is also necessary to consider the interference of the surrounding environment on signals within the frequency band, so as to ensure the integrity and accuracy of the reading and writing of material information represented by electronic tags in the later stage.Inductively coupled electronic tags contain a significant amount of material electronic data information. In practical applications, attention should be paid to the control of microchips and identification antennas, and effective transmission and identification of material electronic data information should be achieved while considering factors such as RF signal sources, resonant circuits, RF source internal resistance, and loss resistance.

At present, the application of RFID systems in warehousing systems is constantly deepening. As a new management system that is different from traditional warehousing management models, RFID systems effectively improve the efficiency and quality of material data information management through the use of RFID tags.As far as RFID tags themselves are concerned, they not only have the characteristics of large storage capacity and abundant information, but also have fast read and write speeds, which can be performed at any time and anywhere. This effectively meets the needs of warehouse management in the new era and realizes the informationization development of warehouse systems.In addition, the implementation of warehouse management based on RFID system effectively solves the inefficiency and error problems of manual data input and operation, ensuring the efficiency, accuracy and reliability of warehouse material management.

4. OVERALL ARCHITECTURE DESIGN OF INTELLIGENT SHELF SYSTEM

4.1 Performance layer of intelligent shelf system

The presentation layer of the intelligent shelving system, also known as the end-user layer, is the interface layer for hierarchical management of intelligent storage shelving users, as well as the application interface of the intelligent human-machine exchange system. It is the application window for interaction between end-users and intelligent information, mainly manifested in two types;

(1) General information exchange management section

Its application function is to set up service instructions and application systems, check and organize data instructions input by end users, and display intelligent data analysis input by the system.

(2) Warehouse settlement function

The main function is to obtain instruction information through terminal intelligent hardware, process and convert it into system data and transmit it to the background for corresponding business, complete each step of data application in the system, and improve the efficiency of warehouse operation.

4.2 Application layer of intelligent shelf system

The application layer of the intelligent shelf system is the main part of the system application, which includes many important logical instructions in the intelligent shelf system. It is the bridge between the terminal presentation layer interface and data analysis display;It processes and analyzes system data in the data layer from receiving data to analyzing data, and executes corresponding business applications through data instructions. It obtains the required data values and data instructions, and returns the data to the presentation layer, so that end users do not need to directly deal with stored data.

4.3 Intelligent shelving system service layer

The application layer of the intelligent shelf system is the management layer of the intelligent shelf, which is responsible for the storage, scheduling, response, and execution management of system data.The data service management layer is responsible for reading, writing, and maintaining the intelligent warehousing database, and has the ability to quickly respond to large amounts of data updates and retrieval.Generally speaking, only a storage shelf classification management system can be used, using Oracle software as the system management software for intelligent storage shelf data access, update, retrieval, and maintenance services.

5. DESIGN OF INTELLIGENT SHELF FUNCTION MODULE

5.1 Shelf management module

The intelligent shelf management module is responsible for the unified management and application scheduling of shelves in the intelligent warehouse. The classification and placement of goods in the warehouse are all manifestations and applications of its functional modules.By viewing the sales data of the shelves, it is possible to provide a basis for inventory planning and production planning for product sales and inventory.

The main functions include: product inventory management, shelf information management, shelf display management, cabinet group shelf sales comparison, shelf product management, and information export management.

The forms involved include: distribution table of shelf cabinets, shelf inventory list, product sales information table, inventory information table, daily historical inventory information table, etc.

5.2 System management module

The system management module is responsible for maintaining user and system security issues in the system.Used to maintain system users, grant them corresponding permissions, record all operations that occur in the system, set work intervals for warehouse partitioning, and control version updates and maintenance of the management system.

The main functions include: user login management, system parameter setting management, workstation management, user management, and version management.Institutional management, user management, authorization management, data backup and recovery, log management.

The tables involved include: user basic information, organizational structure table, permission basic table, authorization table, system workstation configuration table, system automatic update file table, and system private parameter table.

5.3 Monitoring and management module

The monitoring management module is responsible for real-time monitoring and warning operations of various aspects of the system.It can remind users of suspicious phenomena such as short-term fluctuations in the warehouse's business situation and significant changes in product prices, alert users of insufficient inventory of a certain product, and help the overall warehouse monitor the operation of each sub warehouse.

The main functions include sales monitoring and management, product price monitoring, inventory monitoring, and workstation monitoring.
The data tables involved include: product sales information table, shelf cabinet group distribution table, shelf inventory list, product price table, inventory information table, system workstation configuration table, etc.

6. APPLICATION OF RFID TECHNOLOGY IN INTELLIGENT SHELF SYSTEM

6.1 Identify RFID electronic tags

The intelligent warehouse management system, which identifies RFID electronic tags, not only needs to comply with EPC rules, but also needs to meet the design requirements of contactless electromagnetic communication rules for readers. This can create favorable conditions for the overall management of material coding in the later stage.In the specific coding of materials, specific identification codes should be set in the order of header, manufacturer identification code, object classification code, and serial number. After completing the electronic tag identification, it needs to be uploaded to the material information database to provide a basis for later comparison and inspection management of identification signals.

Summary of RFID electronic tag design: Each managed item is labeled with an RFID electronic tag, which is used to identify different items and identify them through the identification tag;There is an RFID antenna installed on each shelf to read the electronic tags on each shelf;A whole shelf uses a reader/writer and a multiplexer to simultaneously control antennas on multiple storage locations, greatly saving costs;The system can effectively track and record the circulation process of items through unique electronic tags, making the operation simpler and faster, and improving work efficiency.

6.2 Warehouse Material Management Based on RFID System

Storage, inventory, and outbound are three important links in warehouse material management. Under the RFID system, traditional warehousing systems are gradually developing towards intelligent warehousing, which has led to significant changes in the management of the three links of storage, inventory, and outbound.

Under the RFID system, once the supplier receives the notification of material supply allocation from the supply chain management system, the RFID reader will write the material data information in a standardized manner and then carry out loading management.After completing the loading process, the relevant information of the loaded materials will be uploaded to the supply chain management system, and then the electronic lead seal management of the delivery vehicles will be carried out to ensure that the transported materials are in a safe state.When the transported materials arrive at the entrance of the storage unit, the RFID reader on the second door of the unit will read the electronic lead seal information of the transportation vehicle, compare the in and out information, and when the information is confirmed to be consistent, the warehouse keeper will receive the goods. During the receipt of the goods, the RFID reader will continuously read the RFID tag on the pallet to record the information such as material number, name, specification, unit, quantity, etc., and allocate a storage location for the batch of materials in real time. The unloading management of the goods will be completed by forklift.After the inventory is completed, all data information of the incoming materials will also be displayed in the material supply chain management system.

When warehouse managers conduct inventory of warehouse materials, they often use portable RFID readers for operation. With the support of this equipment, accurate scanning of shelf labels and pallet labels can be achieved. By comparing the stored materials with the material supply chain management system, effective control of issues such as material discrepancies or quantity discrepancies can be achieved.

In the process of outbound management, the first step is to send material retrieval and outbound information to the warehouse keeper through the supply chain management system, swipe the card to mark and confirm the identity of the operator, and then organize the outbound goods based on the outbound material list information.When using forklifts to transport materials out of the warehouse, they need to pass through the warehouse RFID reader in sequence to complete the reading of information such as material number, name, specification, unit, quantity, etc. in the RFID tag, achieving effective correspondence between the material supply system data and the actual stored goods.

7. CONCLUSION

Warehouse management is an important part of enterprise material management, which not only includes the management of shipping, logistics, and warehousing, but also involves material stacking, inventory, and outbound control.Under the traditional management mode, the management of enterprise warehousing materials adopts a management mode of manual input of data information and manual operation, which has low management efficiency and large errors.In the new era, due to the need for intelligent warehousing system construction, the application of RFID technology in warehouse material management continues to deepen. This technology can improve the efficiency and quality of warehouse management by identifying electronic tags of materials through wireless radio frequency identification.

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