An Intelligent Cargo/Warehouse Management System

Zhongheng Sun[1], Yue Zhou[1], Xun Sun[1], Wenzhuo Fan[1], Wenxuan Zhou[1]

[1]Maynooth International Engineering College, Fuzhou University, Fujian, China
E-mail: ZHONGHENG.SUN.2022@MUMAIL.IE, YUE.ZHOU.2022@MUMAIL.IE, XUN.SUN.2022@MUMAIL.IE, WENZHUO.FAN.2022@MUMAIL.IE, WENXUAN.ZHOU.2022@MUMAIL.IE

Abstract

This paper presents a low-cost and user-friendly warehouse management system developed using Arduino and ESP8266 hardware. The system accurately monitors temperature, humidity, and harmful gas concentration, and acts as an intrusion detector in a warehouse environment. It also includes functions for managing and detecting goods using RFID chips and for automatic delivery using unmanned intelligent vehicles. Data is uploaded to a cloud-based relational database in real-time. The system provides a cost-effective and efficient solution for warehouse *management.*

Keywords: Arduino, ESP8266, Warehouse management system, RFID chips, Unmanned intelligent vehicles

1. Introduction

In today's fast-paced business environment, efficient warehouse management plays a crucial role in maintaining a competitive edge [1], [2]. The ability to monitor and control warehouse conditions accurately has a significant impact on the quality of stored goods and overall operational efficiency [3]. To address these needs, the development team has developed a highly extensible, comprehensive, user-friendly, quick-to-deploy, and cost-effective warehouse management system [4].

The system offers real-time monitoring of temperature, humidity, harmful gas concentration, and intrusion detection, ensuring optimal storage conditions and enhanced safety measures [5]. The collected data is seamlessly uploaded to the cloud, enabling easy access to the warehouse conditions from anywhere.

Besides monitoring capabilities, the system also uses ESP8266 and RFID chips to enable efficient goods management and detection. By scanning the RFID chips [6] attached to goods boxes, the system can obtain detailed information about the goods which includes quantity and type. This information is then uploaded to a cloud-based relational database [7], providing real-time visibility of inventory levels and facilitating streamlined inventory management.

Moreover, an experimental proportionally scaled small car model is constructed. The small car can automatically perform point-to-point transportation of goods. Through the integration of routing algorithms, the system optimizes the routing of small cars, ensuring efficient and timely transportation of goods from one location to another without the need for human intervention. This automation reduces manual labor and enhances operational efficiency.

The warehouse management system offers a cost-effective and efficient solution that aligns with the demands of modern business operations. By leveraging cloud computing, RFID, and unmanned intelligent vehicles, a comprehensive platform that enhances warehouse productivity, accuracy, and adaptability is provided.

Figure 1 shows the overall structure of the system. The monitoring system and management system return the monitored data to the cloud platform, which then transfers the data to the control section for cargo management.

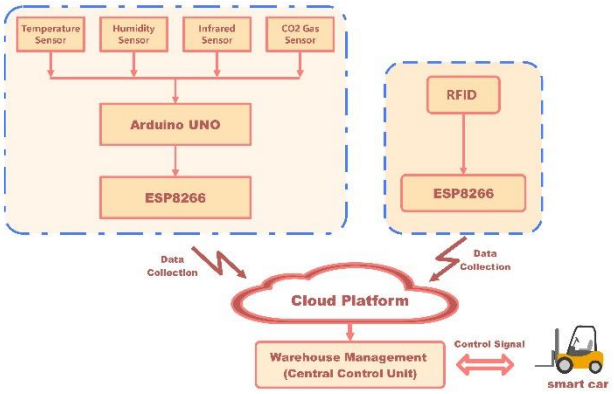

Figure 1 Overall system architecture diagram

2. Technical Background

The IoT-based warehouse monitoring and management system, utilizing Arduino and ESP8266 hardware, offers a comprehensive solution for real-time monitoring of crucial warehouse parameters. By continuously tracking temperature, humidity, harmful gas concentration, and intrusion detection, the system ensures optimal storage conditions and enhanced safety measures.

To enable seamless data integration and management, the system leverages the Alibaba Cloud IoT platform. This cloud-based infrastructure allows for the efficient uploading and storage of data, providing a centralized hub for monitoring and analysis. The platform also facilitates easy integration with third-party applications, thanks to Alibaba Cloud's well-documented APIs, enabling rapid expansion and deployment of new features.

In addition to real-time monitoring, the system incorporates a cloud inventory management system based on RFID recognition. By utilizing RFID technology, the system enables efficient and accurate goods tracking and management. Each item is equipped with an RFID tag, which allows for quick and reliable identification, inventory updates, and location tracking. This streamlines the

inventory management process, reduces manual labor, and minimizes errors.

To facilitate the movement of goods within the warehouse, the system included smart delivery cars. In our experimental system, a proportional scaled small car model is implemented. This automatic car operates based on predefined algorithms and navigates through the warehouse to transport goods to their designated locations. The cars are also able to operate manually using control from Android devices. By automating this process, the system minimizes human intervention, reduces handling costs, and improves overall operational efficiency.

The integration of IoT in warehouse management systems has enabled users to manage their data in real time and proceed with accurate inventory tracking, demand forecasting, and other crucial operations.

To develop the software for the system, Arduino IDE is utilized and Arduino UNO and ESP8266 development chip are used and programmed using C language and Arduino language, creating a robust and reliable software solution that connects seamlessly with the Alibaba Cloud IoT platform using the WebSocket protocol. This protocol ensures low latency, long-lasting connections, and power-efficient environment monitoring.

3. Literature Review

Zhang, B. et al. developed an intelligent warehouse management system utilizing the L298N chip, RC522 for near-field communication, and W5500 module for network communication [8]. The MSP430F5529 microcontroller acts as the central control unit, overseeing tasks such as motor control, data reading, and network communication. The system facilitates smart cargo management, including card activation, encrypted data transmission, and remote monitoring. This innovation streamlines warehouse operations, saving resources, optimizing space, and ensuring reliable security. Particularly beneficial for small to medium enterprises and courier companies, it enhances efficiency and reduces costs.

Christos Spandonidis et al. developed a smart container monitoring system based on the Internet of Things [9]. Key challenges such as weight reduction, fire smoke detection, hardware safety, and logistics maintenance are addressed. By integrating low-cost, low-power sensors, the system is able to track container status and detect critical events such as fire/smoke, impacts, and accidental misuse. Provides better and safer control over cargo loading/unloading operations and flight processes. The experimental results show that the system can make a breakthrough in the current technical level of container technology and aircraft cargo operation.

Xu Zhijie et al. took account of clear and real-time video streams simultaneously [10]. They put forward hybrid multichannel video stream transmission strategies for a remote surveillance system, in which high-quality panoramic video and real-time interactive video are combined together to satisfy surveillance system requirements of high data stream quality and interactive operation.

4. Monitoring System Design

For the monitoring system, Arduino Uno and ESP8266 in conjunction are chosen with the Arduino IDE to implement its functionality. The Arduino Uno is a microcontroller board based on the ATmega328P, while the ESP8266 is a low-cost Wi-Fi microchip with a full TCP/IP stack and microcontroller capability. These devices were chosen for their ease of use, low cost, and versatility compared to other options. Figure 2 and Figure 3 show the monitoring system.

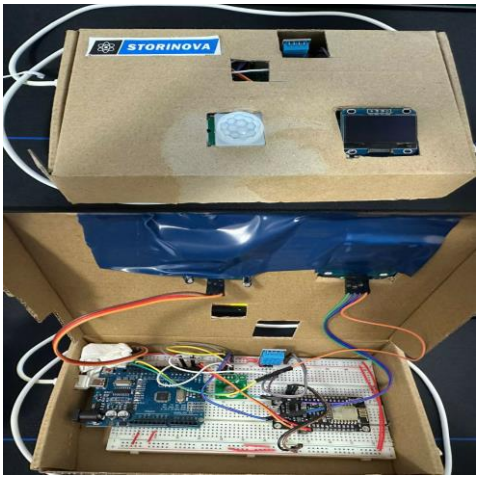

Figure 2 Picture of the monitoring system

In terms of specific functionality, a DHT11 temperature and humidity sensor, an infrared human body sensor, and a harmful gas concentration sensor is connected to Arduino Uno. The DHT11 sensor measures temperature and humidity using a capacitive humidity sensor and a thermistor. The harmful gas sensor detects the presence of harmful gases such as carbon monoxide and methane. Both sensors are connected using serial ports by the software serial port function of Arduino. The infrared sensor detects the presence of humans by measuring changes in infrared radiation. It uses an analog input to transmit data to the Arduino.

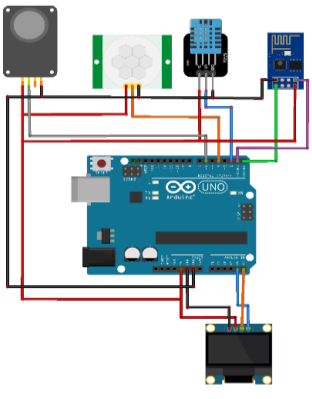

Figure 3 Hardware implementation map of the monitoring system

After reading data from the sensors, the Arduino UNO board hardware serial port transmits the data in real-time to the ESP8266 for processing and transmission. The ESP8266 is responsible for processing the data and transmitting it to a cloud server for storage and analysis.

For the logic design of the ESP8266, MQTT and WebSocket protocols are used for transmitting data. MQTT is a lightweight messaging protocol for small sensors and mobile devices, while WebSocket is a protocol for full-duplex communication over a single TCP connection. ESP8266 chip will receive data from the Arduino serial port in bit storage format and perform simple frame header and tail check and bit processing. Then the ESP8266's 2.4G Wi-Fi module is used for establishing a connection to a provided wireless network and to establish a connection with the Alibaba Cloud server using the MQTT protocol over WebSocket. The data is uploaded and displayed in real-time on a front-end page. Figure 4 shows the front-end web page and Figure 5 shows the Hardware implementation diagram of management module.

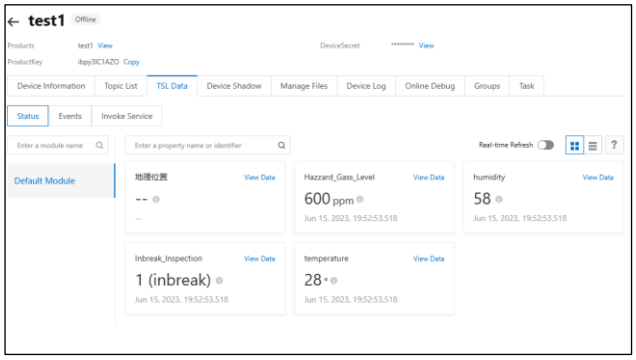

Figure 4 Picture of the front-end web page

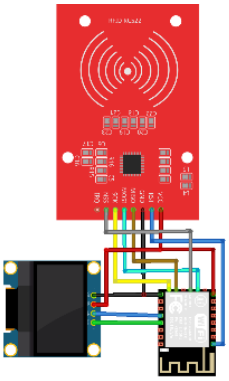

Figure 5 Hardware implementation diagram of management module

5. Management System Design

RFID technology is applied to scan and track goods within the warehouse. The scanned information is then uploaded to a cloud platform, where it is organized into visualized tables, enabling real-time management. Additionally, a feature on the platform that allows us to send instructions to automated cars is implemented by the team, enabling them to transport goods efficiently. Figure 6 shows the management module and small car are shown below.

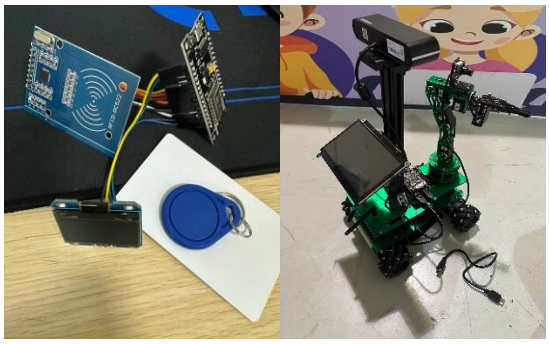

Figure 6 Photos of the RFID system and car

The implementation of RFID technology in the warehouse management system has significant positive impacts on management efficiency. By scanning RFID tags attached to each item, users are able to accurately track the quantity, name and other relevant information of the cargo. This data can then be transmitted to the cloud-based back-end server, where it is processed and transformed into user-friendly visualizations. This allows warehouse managers and personnel to have a clear overview of inventory levels, stock movement, and overall warehouse performance at any given time.

Furthermore, users can send instructions to the cars, directing them to specific locations within the warehouse to pick up or deliver goods. The system optimizes the routes of the car and ensures that goods of the same category are stored together, maximizing efficiency and minimizing the time required for manual handling.

With the integration of real-time data analytics and automated car operations, the smart warehouse solution provides a comprehensive and efficient approach to inventory management. The combination of RFID technology, cloud-based computing, and automation streamlines processes, reduces errors and enhances overall productivity. As a result, warehouse operations become more agile, cost-effective, and adaptable to changing business demands.

In summary, the warehouse management module leverages RFID scanning, cloud-based data processing, and intelligent delivery car systems to enable real-time inventory tracking, visualization, and streamlined operations. This intelligent solution empowers businesses to achieve higher levels of efficiency, accuracy, and scalability in their warehousing processes.

6. Effectiveness Validation

To verify the effectiveness of the system, the team conducted an on-site verification. The average number of backlogged items in the warehouse for incoming/outgoing shipments is recorded over two weeks, as well as the number of instances where the warehouse's humidity and temperature exceeded the standards (the temperature and humidity test data is collected every hour in a day). The system was not installed in the first week and then installed in the second week. Data changes in these two weeks were monitored and analyzed, and the results are shown in Table 1. The graph of average data for using the warehouse management system as shown in Figure 7.

Table 1 The effect of using our warehouse management system

Items / Time	Number of backlogged items		Temperature and Humidity Exceedance Incidents Times	
Time	Before	After	Before	After
Day1	10	5	7	5
Day2	8	3	7	4
Day3	9	4	8	4
Day4	6	2	11	1
Day5	11	4	9	1
Day6	8	1	9	3
Day7	8	1	7	2
Total	60	20	58	20
Average	8.57	2.86	8.29	2.86

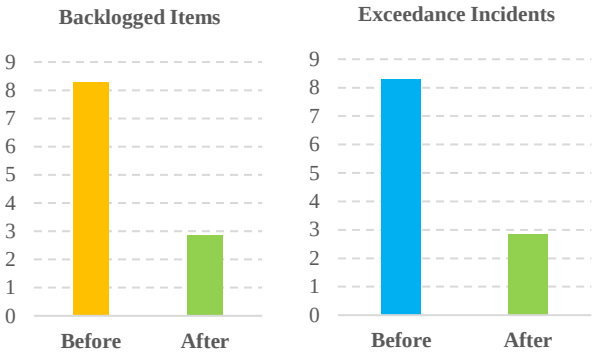

Figure 7 Graph of average data for using the warehouse management system

7. Backend Cloud Service

The backend cloud service offers a comprehensive set of features designed to streamline and optimize users' operations. With a wide range of functionalities, the service serves as an effective tool to enhance the efficiency and effectiveness of management and monitoring processes.

The main function of the cloud service is storing and displaying data. It provides a secure and reliable storage infrastructure that ensures all the data are safely preserved. The intuitive user interface allows for easy access to stored data, enabling quick retrieval and analysis. By centralizing the data of cargo to the cloud service, users can eliminate the hassle of managing multiple data sources and improve data consistency.

Moreover, the cloud service is designed to handle connections between different terminals and data sources, which facilitates seamless integration with various data stream outputs, enabling real-time data synchronization and updating. This functionality ensures that users have instant access to real-time information, enabling timely decision-making and accurate analysis.

One of the most prominent features of the cloud service is its algorithmic path calculation capability. This feature enables users to exercise semi-automatic control over robots or unmanned cars within their operations. The service can calculate optimized paths for the robots, guiding them to transport goods to designated locations with minimal human intervention. By automating this process, handling costs can be significantly reduced, errors minimized, and overall operational efficiency improved.

In addition, the cloud service acts as a transition layer, allowing for seamless integration with third-party secondary data analysis and prediction services. By leveraging these external resources, users can gain deeper insights into their data, identify patterns, and make more informed decisions. This integration enhances the analytical capabilities of the system, enabling users to extract valuable insights and drive continuous improvement in their operations.

8. Conclusion

The study successfully developed a cost-effective, user-friendly and expandable warehouse management system using Arduino and ESP8266 hardware, which has unique advances compared with similar systems [11]. It accurately monitors temperature, humidity, gas concentration, and intrusions. The system utilizes RFID chips for goods management and detection and unmanned intelligent vehicles for automated delivery. Real-time data is uploaded to a cloud-based database, providing an efficient and cost-effective solution for warehouse management [12], [13], and also being effective for monitoring and making decisions for controlling the carbon footprint of the venue under monitoring.

Overall, this system enhances operational efficiency, safety, and reliability. Further research can expand its functionality and applicability in warehouse management.

Acknowledgement

This work was supported by Maynooth International Engineering College, Fuzhou University.

References

[1] S. L. Ullo and G. R. Sinha, "Advances in Smart Environment Monitoring Systems Using IoT and Sensors," Sensors (Basel), vol. 20, no. 11, p. 3113, May 2020. doi: 10.3390/s20113113.

[2] A. Čolaković, S. Čaušević, A. Kosovac and E. Muharemović, "A Review of Enabling Technologies and Solutions for IoT Based Smart Warehouse Monitoring System," in I. Karabegović (Ed.), New Technologies, Development and Application III. NT 2020. Lecture Notes in Networks and Systems, vol 128. Cham: Springer, 2020. doi: 10.1007/978-3-030-46817-0_73.

[3] Afzal, M. "IoT Based Real Time Warehouse Monitoring using Sparkfun ESP8266 Thing Dev and Cayenne MyDevices," Conference Paper, April 2018.

[4] D. Parida, A. Behera, J. K. Naik, S. Pattanaik and R. S. Nanda, "Real-time Environment Monitoring System using ESP8266 and Thing Speak on Internet of Things Platform," 2019 International Conference on Intelligent Computing and Control Systems (ICCS), Madurai, India, 2019, pp. 225-229, doi: 10.1109/ICCS45141.2019.9065451.

[5] Zafar, S., Miraj, G., Baloch, R., Murtaza, D., & Arshad, K. (2018). An IoT Based Real-Time Environmental Monitoring System Using Arduino and Cloud Service. Engineering, Technology & Applied Science Research, 8(4), 3238-3242.

[6] M. Kamrul Hasan et al., "IoT-Based Warehouse Management System," ResearchGate, Oct. 2022.

[7] M. K. Hasan, M. Junjie, A. K. M. Ahasan Habib, A. Al Mamun, T. M. Ghazal and R. A. Saeed, "IoT-Based Warehouse Management System," 2022 International Conference on Cyber Resilience (ICCR), Dubai, United Arab Emirates, 2022, pp. 1-6, doi: 10.1109/ICCR56254.2022.9995768.

[8] Xu Zhijie, Wang Geng. A Hybrid Real-time Video Streaming Remote Surveillance System Based on Mobile Robot[C]//International Conference on Computer Networks and Communication Technology (CNCT 2016). Advances in Computer Science Research (ACRS). Paris: Atlantis Press, 2017, 54:458-466.

[9] Spandonidis, C., Sedikos, E., Giannopoulos, F., Petsa, A., Theodoropoulos, P., Chatzis, K., & Galiatsatos, N. (2022). A novel intelligent iot system for improving the safety and planning of air cargo operations. Signals, 3(1), 95-112.

[10] Xu Zhijie, Wang Geng. A Hybrid Real-time Video Streaming Remote Surveillance System Based on Mobile Robot[C]//International Conference on Computer Networks and Communication Technology (CNCT 2016). Advances in Computer Science Research (ACRS). Paris: Atlantis Press, 2017, 54:458-466.

[11] J. Zhang et al., "Design and application of Internet of things-based warehouse management system," International Journal of Production Research, vol. 56, no. 15, pp. 5217-5235, Aug. 2018.

[12] Jarašūnienė, A., Čižiūnienė, K., & Čereška, A. (2023). "Research on Impact of IoT on Warehouse Management". Sensors (Basel), 23(4), 2213.

[13] W. C. Tan and M. S. Sidhu, "Review of RFID and IoT integration in supply chain management," Operations Research Perspectives, vol. 9, p. 100229, 2022, doi: 10.1016/j.orp.2022.100229.

Authors Introduction

Mr. Xun Sun

He is currently pursuing Bachelor of Electronic Engineering as 3rd year student in the Department of Maynooth International Engineering College, Fuzhou University, China. His research interests are embedded system development.

Miss. Yue Zhou

She is currently pursuing a Bachelor of Electronic Engineering as 3rd year student in the Department of Maynooth International Engineering College, Fuzhou University, China. His research interests are AI vision.

Mr. Wenxuan Zhou

He is currently pursuing a Bachelor of Electronic Engineering as 3rd year student in the Department of Maynooth International Engineering College, Fuzhou University, China. His research interests are embedded systems and hardware technology.

Mr. Zhongheng Sun

He is currently pursuing Bachelor of Electronic Engineering as 3rd year student in the Department of Maynooth International Engineering College, Fuzhou University, China. His research interests are integrated circuit development.

Mr. Wenzhou Fan

He is currently pursuing Bachelor of Electronic Engineering as 3rd year student in the Department of Maynooth International Engineering College, Fuzhou University, China. His research interests are integrated circuit development.