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Development of RFID Automatic Warehouse Management System for Steel Coil

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In order to track and manage the steel coil logistics produced by CSC, and provide effective and reliable steel coil ID information, to avoid mixing or misplacement issue, resulting in customer complaints and affecting the reputation of the company. The research group designed and developed a RFID metal tag, the antenna was built by printing meander line radiating elements with a resonant frequency to meet the range of UHF RFID. Besides, the antenna has a proper directional radiation pattern and gain which can be applied on site. Furthermore, the research group developed and built the Crane RFID system, which can provide real-time automatic identification of steel coils. The system included RFID antenna, reader, and wireless transmission ability. For solving and overcoming the problem of multi-path interference caused by RF signals, we also developed an algorithm which was based on decision tree that applied the RF strength and density.

Keywords: UHF RFID, Antenna, Tag, ID Tracking

1. INTRODUCTION

Logistics is one of the key parts of the steel production supply chain, and warehouse logistics also plays a role in distribution, the logistics process is shown as Fig.1. The steel coils of CSC have been fully equipped with RFID tags for the desired tracking and inspection system. However, the inspection system would ensure and confirm the coil id information until reaching the shipping terminal. All of the coils must rely on overhead cranes and their coil handling grabs to lift, lower and transport to achieve the operation for warehouse storage, as well as internal relocation and loading/unloading processes. So, the research group designed and developed an automatic identification management system for the steel coil, as shown in Fig.2. In order to provide a sufficient real-time coil information system to the user, with an online automatic id checking ability.

In addition, there is quite a distance between the production and distribution warehouse of steel coil. The Warehouse Management System (WMS) did not integrate between production and the distribution warehouse, which caused information discontinuity. In the past, following the department standard job procedures (SJP), the truck driver would write the id number on the coil by hand, for crane driver processing double confirm. Therefore, considering the benefits and effectiveness, this study developed the RFID automatic warehouse management system for distribution warehouses to provide an effective and reliable steel coil ID identification system.

2. EXPERIMENTAL METHOD

In order to reach the research targets, this project plans to install an RFID system on the existing crane and its coil handling grab. When the crane is used to lift and move a steel coil, the identification condition would be triggered and the process would be completed in a quick and effective manner. Then, the coil ID information and location results will be showed on the display screen for monitoring. So, by improving the logistic efficiency, avoiding safety endangers incidents and preventing coil misplacement issues.

This study plans to install the RFID system on the crane to read the correct id of the steel coil in real time, and wirelessly transmit the data to WMS for identification. In this study, we designed the exclusive RFID antenna and readers, which are respectively installed in the crane coil handling grab, which in turn can sustain a long-term stable operation. As Fig.3 shows, the design and implementation can be divided into four parts:

Fig.1. The process of logistics of steel coil.

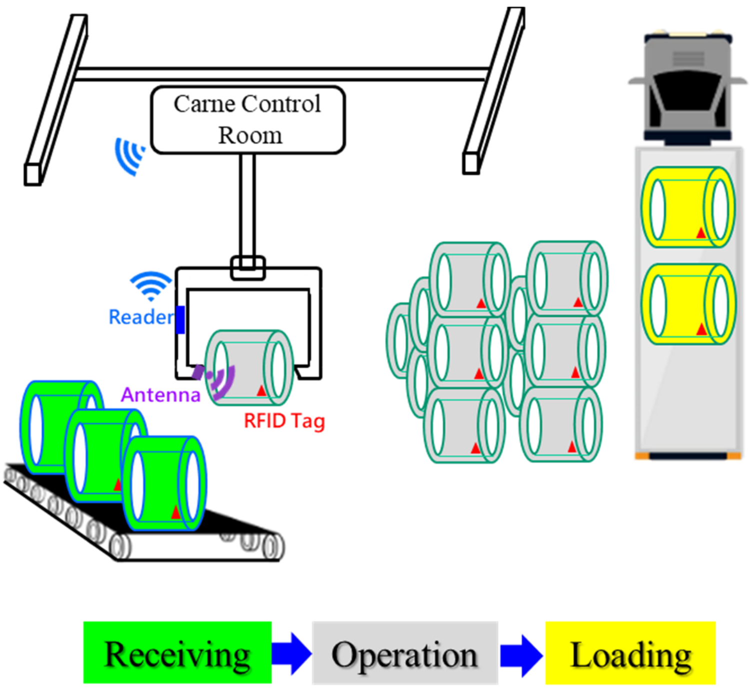

Fig.2. The overview of the system configuration.

1. The development and integration of WMS and identification system.
2. The design and implementation of RFID antenna.
3. The design and implementation of RFID reader.
4. The development of automatic identification method.

2.1 System Integration of WMS and identification system

The crane task and operations are based on the information from the warehouse management system

(WMS). Therefore, the RFID data with the identification system must be integrated and established with the WMS (as shown in Fig.4), the adaptability of the identification system also provides instant and intuitive information of the steel coil ID to the operators. When the crane starts to lift the coil, the RFID system will read the id and send to the crane guidance system (CGS) via zigbee wireless communication, allowing the WMS to identify the correctness of coil id. Resulting in automatic identification instead of human inspection and improving the logistics efficiency.

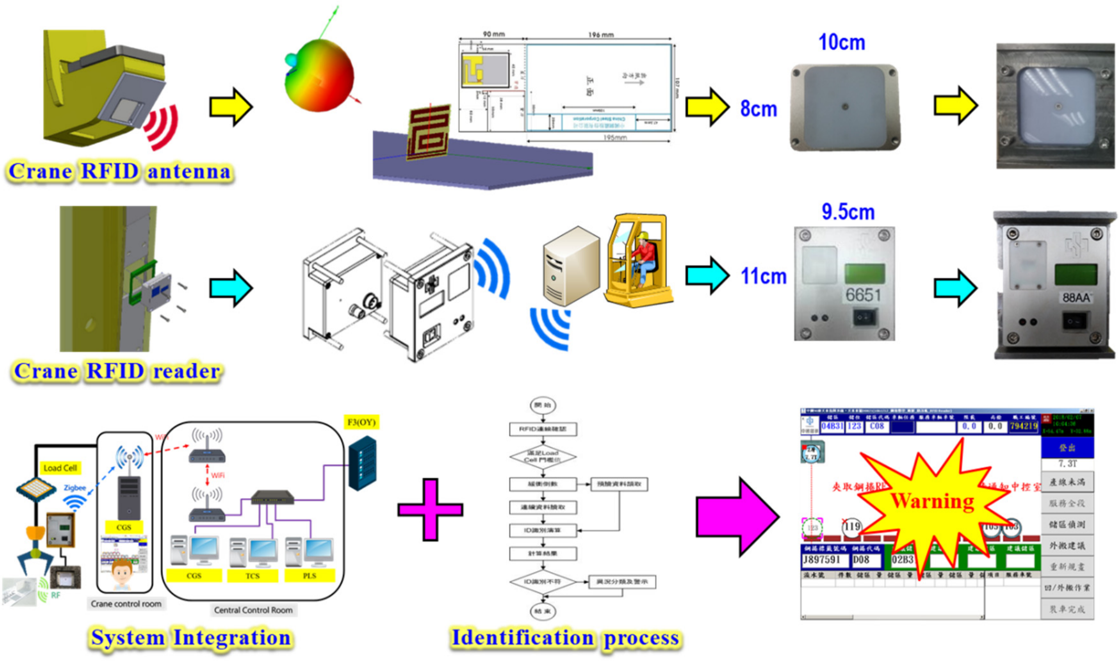

Fig.3. The major units of system design and development.

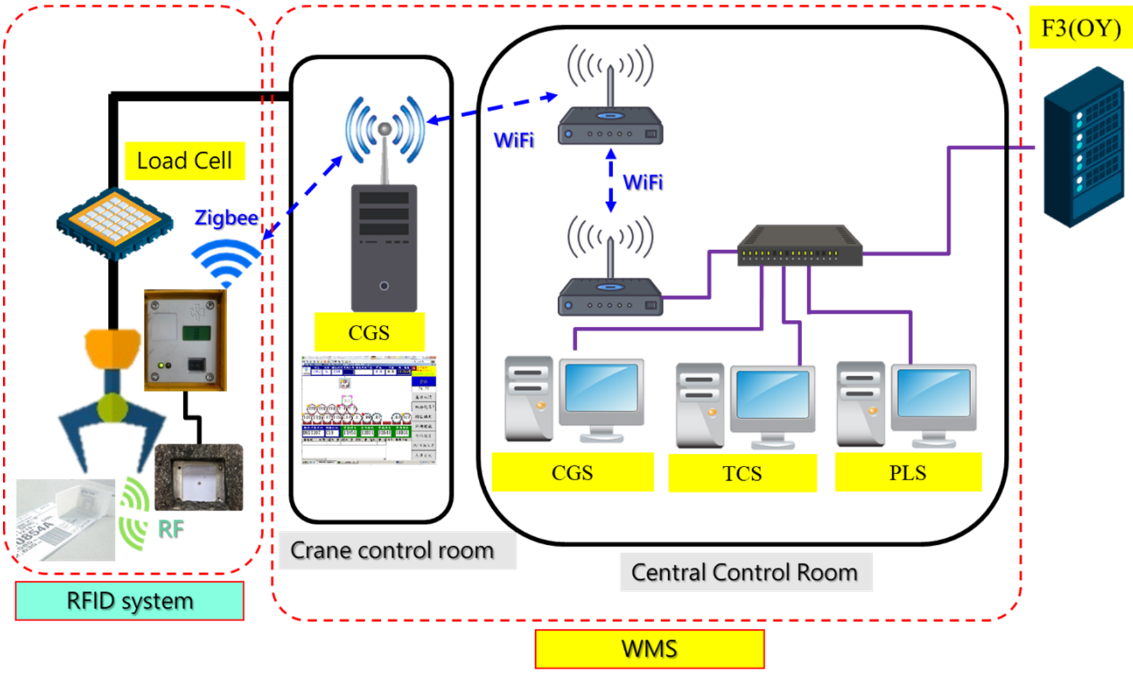

Fig.4. System Integration of WMS and RFID system.

2.2 The design and implementation of crane RFID antenna

Since there is no suitable third party antenna products available that can meet the required characteristics, the research group designed and developed a specific type for crane use only. For the signal transmission distance of the antenna is positively correlated with the gain, the gain (K) of the antenna is compared with its input and output power. Its magnitude is determined by the formula $K= 4\pi A / \lambda^2$, where A is the effective area of antenna equivalent, λ is the wavelength of the radio wave at a fixed value. Fig.5 shows, the relationship of the distance between the antenna and tag, the output power and antenna gain can be expressed by the following equation: $P_r = P_t \times G_t \times G_r \times [\lambda/(4\pi d)]^2$, where P_r is the received power sensitivity and P_t is Transmit output power, G_t is the antenna gain of the transmitting end, G_r is the sensitivity of the receiving end antenna, and d is the distance between the antenna and the tag. Therefore, even if the gain and relative distance are fixed, the readability can be improved by adjusting P_t. Due to the restriction of the installation space, the antenna area would be limited. Considering the linear distance between the antenna and tag was about 50 to 70 cm on average, the research group implemented the applicable antenna.

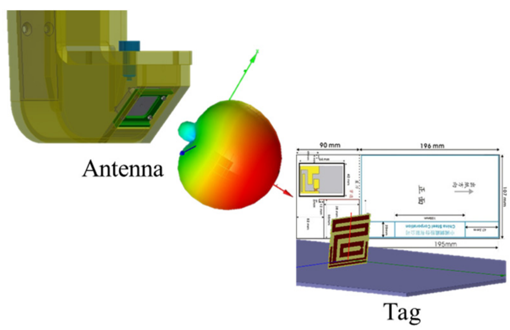

Fig.5. The relative status between the antenna and tag.

2.3 The design and implementation of crane RFID reader

Because of the limitations of the overhead crane's data connection not being able transmit data through physical circuit to the crane control room, the RFID reader needed to be compact enough whilst being able to transmit data through wireless communication. The research group tried to design a wireless communication which can avoid inference with stable operation. Furthermore, the coil handling grab attachment of the crane would change occasionally; the reader on the coil handling grab must easily process the system pairing for hardware maintenance. Considering the above status, we developed a prototype reader for connecting to the antenna, and transmitted data via a workable wireless protocol (Fig.6).

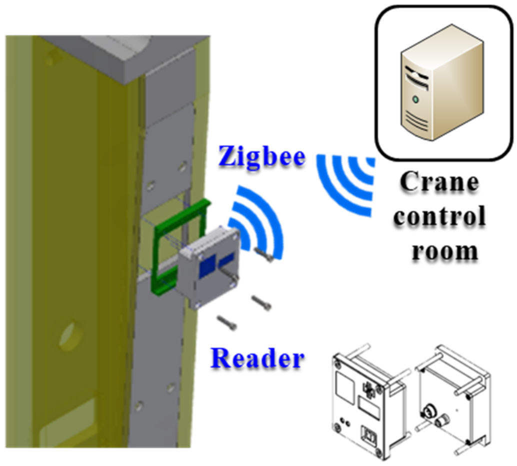

Fig.6. The hardware configuration of reader.

2.4 The development of automatic identification method

There are a large number of steel coils in the warehouses. When the steel coil was to be grabbed by the coil handling grab, the other neighboring steel coil tags would also be read by the reader due to the RF (radio frequency) characteristics. Therefore, an automatic identification process is vital for identifying the correct target coil ID, the process is shown in Fig.7. First, the threshold value of the load cell of the crane is used to detect whether the steel coil has been hoisted, then the RFID data will be collected from the reader through zigbee receiver. Based on the collected data, the system applies a decision tree algorithm to analyze and identify the RSSI (Received Signal Strength Indication) with the reading times, and compares the result to level 2 information. Finally, the system will display the message and results on the screen to notify the users.

3. RESULTS AND DISCUSSION

For testify the system performance and capability, we applied an on-site test on the products storage unit in Lin-Hai and Jia-Xing sites which are steel coil distribution warehouses. The proposed system was verified and evaluated from tag reading, wireless data transmission, and identification.

3.1 The simulation and characteristic of steel coil RFID tags

The characteristics of UHF RFID passive tag had been developed and simulated by HFSS according to the attached situation of the inner diameter of steel coil, as

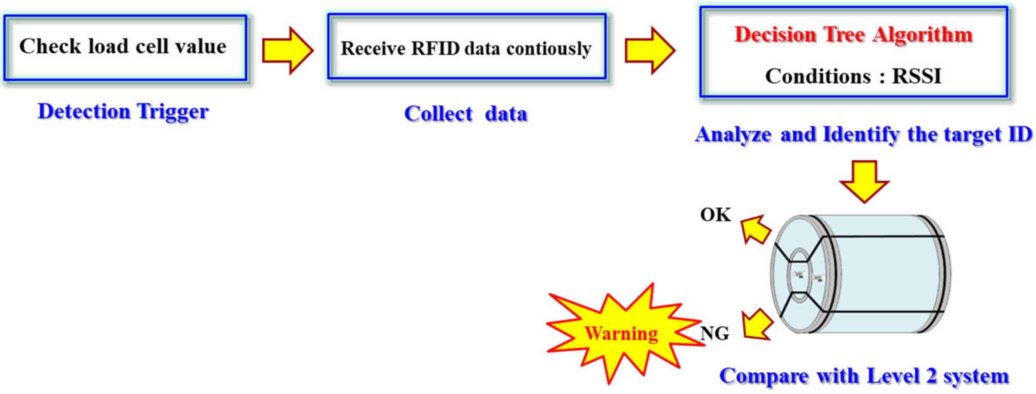

Fig.7. The flow of automatic identification process.

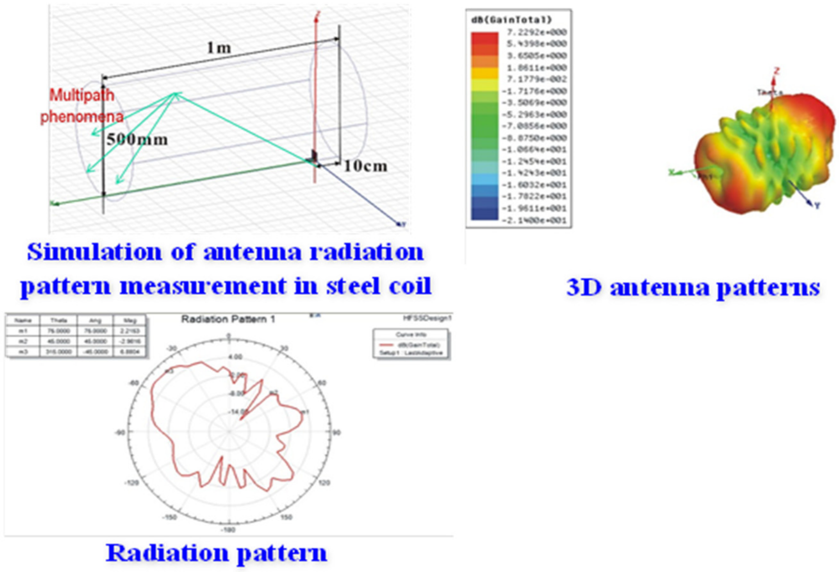

Fig.8. The simulation result of steel coil tag by using HFSS.

shown in Fig.8. Due to the limitation of mountable positions by manpower, the RFID tags are mostly located at the edge of the inner diameter of the steel coil, and therefore the radiation pattern around the inner diameter has a large difference. Considering that the radio frequency (RF) signal produces a multi-path effect in the inner space of the steel coil, the RF strength response performance of the tag would be different.

3.2 Implementation RFID reader and antenna

For extending the range of reading capability, we used coaxial cable to connect the reader and antenna. The antenna was designed and implemented by embedding in the underside of coil handling grab arm for reaching the target coil tag as close as possible. The reader was located in the side of crane coil handling grab arm and transmitted data through zigbee. Since zigbee's network has multiple transmission channels as Wi-Fi, the frequency band in this project was industrial scientific medical band (ISM) 2.4GHz. According to past research and practical verification(3-4), it can avoid the problem of co-existence with Wi-Fi causing co-frequency interference. In order to avoid mutual interference, we applied the 25th and 26th channel as the major data transmission channel. After the test result, the reader with antenna can now work normally, even when the performance of each tag is not the same, we can regulate the RF parameter and adjust the angle of the antenna to achieve readability. And now the reader can successfully transmit data continuously to WMS.

3.3 Identification system for Single Coil Test

From the test result of coil tag (J430270) as shown in Fig.9, the left side is the whole process of received signal strength indicator (RSSI) distribution, and the right side is the reading times for the whole period. The periods of collecting data can be divided into three statuses: reaching, clamping, and raising up the coil. When crane coil handling grab is in a positioning period, the variety of RSSI was relative stable but not gaining a better signal effect. The clamping period, the coil handling grab will start to clamp the coil, the RSSI and reading time become more identical. The lifting period means the coil has been lifted into the air, and the RSSI has the phenomena of a hopping effect. Above this, we applied the characteristic of RSSI and reading times to the decision tree algorithm to distinguish the target and coil around. It does improve the correctness of identification.

3.4 Verification for a Series of Coils

It can be seen from the actual RF measurement information that there may be differences of (RSSI) between different tags (A-D), as shown in Fig.10 (left). When the crane coil handling grab starts to clamp the target coil, the system will collect the pre-clamp data for improving the recognition performance and reducing the identification period, as shown in Fig.10 (right).

The test result shows that the system could identify the id of different steel coils by RSSI effect. In addition, we also simulated the many types of abnormal events (including id misplacement, empty id tags, and level 2 error information, etc.), and the system could detect and display the information correctly. Both simulation and experimental results verify that the performance of the RFID automatic warehouse management system is as expected.

The results of this study are

1. Completed the simulation and characteristic test of steel coil RFID tags.
2. Completed the prototype design and development of RFID reader and antenna.
3. Developed the RFID automatic warehouse management system.

4. CONCLUSIONS

This research developed a RFID automatic warehouse management system for steel coil. It can reduce the potential safety risks caused by either the truck driver or operator, avoid the misplacement of steel coils, and improve the logistic efficiency through the coil information linkage of truck pallet and steel coil position. The system has been built and verified in all of the steel coil distribution warehouses, and the recognition rate can be maintained at a 98-100% average.

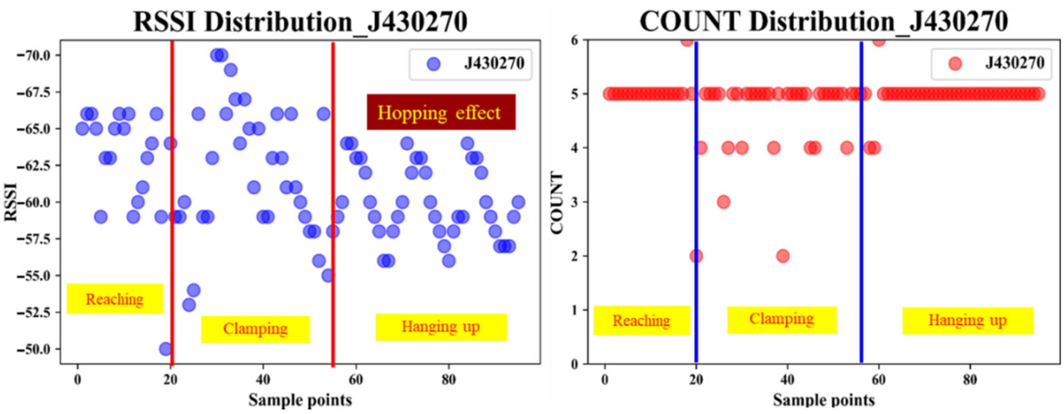

Fig.9. The distribution of RSSI (left) and reading times (right) within the same tags.

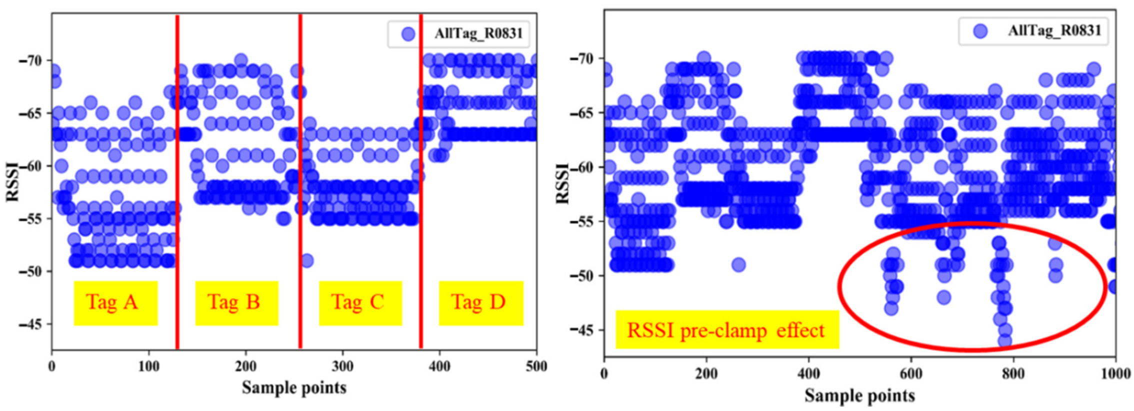

Fig.10. The RSSI measurement information between different tags (left) ; The RSSI effect in clamping periods (right).

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