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Research Article

The Monitoring System of Marine Refrigerated Containers Based on RFID Temperature Tags

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Abstract: In this study, we develop the monitoring system of marine refrigerated containers based on RFID temperature tag to make up for the shortcomings that the traditional system only depended on supply air temperature or return air temperature of the container to reflect the cargo temperature. The RFID temperature collection tags, the RFID reader and the software are designed and developed. Results of the inside temperature monitoring experiment showed that the system featured multi-points real-time monitoring, 100% readability, long reading distance and rapid reflection of the temperature variation, which may effectively solute the problem of cargo damage caused by uneven temperature distribution inside the container.

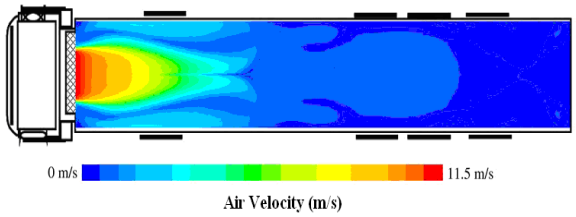
Keywords: Monitoring, refrigerated container, RFID, temperature tag

INTRODUCTION

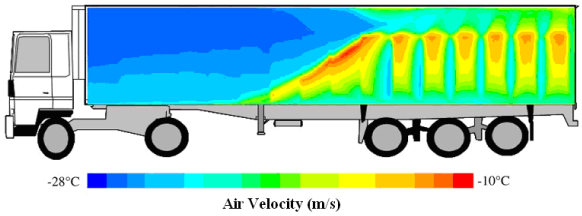
The multi-point inside temperature parameters are a comprehensive reflection of the operation condition of marine refrigerated containers and the traditional refrigerated containers achieve the purpose of monitoring the cargo temperature through supply air temperature or return air temperature. Meanwhile, the owner of the cargo will also take the temperature curve on the temperature record paper plate as the sole criterion for the inspection of cargo. However, influenced by the factors such as the type, the quantity and the stack form of the cargo, temperature and flow rate fluctuation area often exist inside the container and even the dead space of air jet. This phenomenon was also found in Moureh's research of vehicle-mounted refrigerated containers [] and part of their simulation results is shown in Fig. 1.

By the simulation results we can see that when loaded with goods, the uneven distribution of temperature field and velocity field of the refrigerated container was obvious. Once the temperature-sensitive cargo is in these places, it is fatal. But at the same time, the supply air temperature or the return air temperature are within the normal range, so the alarm system will not be activated. In this case, cargo damage incidents will certainly occur.

For the above reasons, we combined RFID technology with temperature sensors and developed the inside multi-point temperature monitoring system of marine refrigerated containers, which may not only reflect the operation status of the refrigeration unit and the cargo condition, but also overcome the shortage of traditional single point temperature measurement. The



(a) Equal velocity line of air supply area



(b) Equal temperature line of temperature sensitive area

Fig. 1: Distribution of air velocity and temperature fields in vehicle-mounted reefer container (Moureh and Flick, 2004)

system can be used to collect the temperature information for perishable foods, medicine and any temperature-sensitive items and provide timely data for medical diagnostic tests and procedures (Want, 2006; Wang *et al*., 2008).

In this study, we develop the monitoring system of marine refrigerated containers based on RFID temperature tag to make up for the shortcomings that the traditional system only depended on supply air temperature or return air temperature of the container to reflect the cargo temperature. The RFID temperature collection tags, the RFID reader and the software are

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designed and developed. Results of the inside temperature monitoring experiment showed that the system featured multi-points real-time monitoring, 100% readability, long reading distance and rapid reflection of the temperature variation, which may effectively solute the problem of cargo damage caused by uneven temperature distribution inside the container.

DEVELOPMENT OF THE SYSTEM

System structure: The components of the inside temperature monitoring system of marine refrigerated containers based on RFID are shown in Fig. 2. The hardware of the system, including the RFID temperature collection tag, the RFID reader, mainly completes the task of data collection. These data are the real-time temperature information at different locations inside the container. The software of the system, including the database, the interface, etc., mainly finishes the receiving and storage of the collected data. The two parts are connected by RS-232 to realize data transmission.

The temperature sensor is integrated with the chip of the tag and the collection of temperature and the communication between the tag and the reader are both in a wireless way. Therefore, the laying of signal line can be reduced and the sampling points can be flexibly arranged.

RFID temperature tag: Currently there are several types of RFID tags (Dong *et al*., 2007; Lang, 2006), including active and passive tag, reader-only tag and read-write tag, low frequency tag, intermediate frequency tag, UHF frequency tag and microwave tag, etc. In consideration of the communication distance, the active tags in which the button butteries are built are used. In terms of the package form of the tag, the card-type tags are used, the arrangement of which is flexible and either can be attached on the cargo to monitor the cargo temperature or the container to monitor the multi-point temperature inside the container.

Different from the conventional one, we developed the RFID tag integrated with a temperature sensor, which not only has the characteristics of RFID tags, but also has the function of wireless temperature collection. Structure of the temperature collection RFID tag is shown in Fig. 3.

Temperature of the monitoring point is changed into a voltage signal by the sensor U1 and then transformed into the digital signal by A/D converter U3 when it is compensated and adjusted by the conditioning circuit U2. The microprocessor packages the temperature data and position of the monitoring point and sends them to wireless transceiver circuit U5 and transmit them through RF antenna U6. Power supply circuit U7 gets the power supply through the button batteries inside the tag to achieve its active design. Photos of the RFID temperature collection tag is shown in Fig. 4.

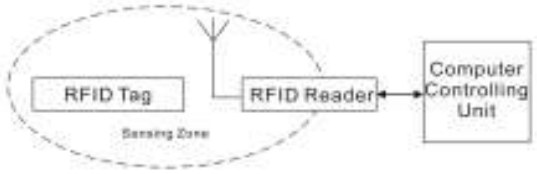


Fig. 2: Structure of the inside temperature monitoring system based on RFID

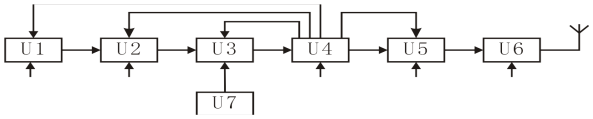
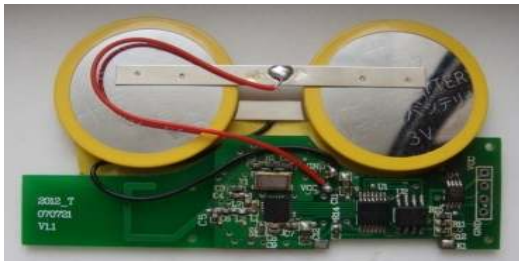


Fig. 3: Design of the RFID temperature collection tag
U1: Temperature sensor; U2: Signal conditioning circuit; U3: A/D converter; U4: Microprocessor; U5: Wireless transceiver circuit; U6: RF antenna; U7: Power supply circuit

(a) Card-type RFID tag



(b) Circuit board of RFID tag

Fig. 4: Photos of the RFID temperature collection tag

RFID reader: There are various types of RFID reader in terms of production form and function, such as low frequency reader, intermediate and high frequency reader, UHF reader and microwave reader, reader-only reader and read-write reader, fixed reader and handheld reader.

With a view to the relatively long distance between the refrigerated container slot to the control room, the 2.45 GHz frequency band of the reader was selected because high frequency band had relatively high energy and was suitable for long distance applications. Besides, the wireless communication of 2.45 GHz industrial band does not need the approval of the Wireless Control Committee or to pay the cost of spectrum occupancy. For the inside temperature monitoring system of marine refrigerated containers, the RFID reader only needs to be installed in the control

Fig. 5: Photos of the RFID reader

room, so the fixed reader was developed. In order to lower the total system cost, the most common RS-232 port was used for the RFID reader to communicate with the computer.

Photos of the RFID reader is shown in Fig. 5 and the reader and antenna are encapsulated in one shell.

During the transportation of temperature-sensitive cargo, the RFID tags on the goods packing can faithfully record the temperature change and transfer these data to the data management system and stored them in real time.

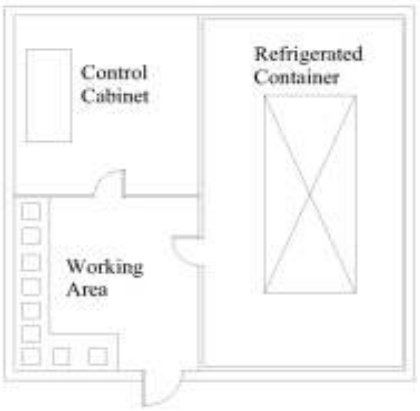


Fig. 6: Schematic diagram of the equipment layout

Inside temperature monitoring experiment:

Experimental facilities: The instruments and equipments used in the experiment included the 20-foot Thermo King refrigerated container, 12 RFID temperature collection tags, 1 RFID reader, the monitoring computer and other support equipments.

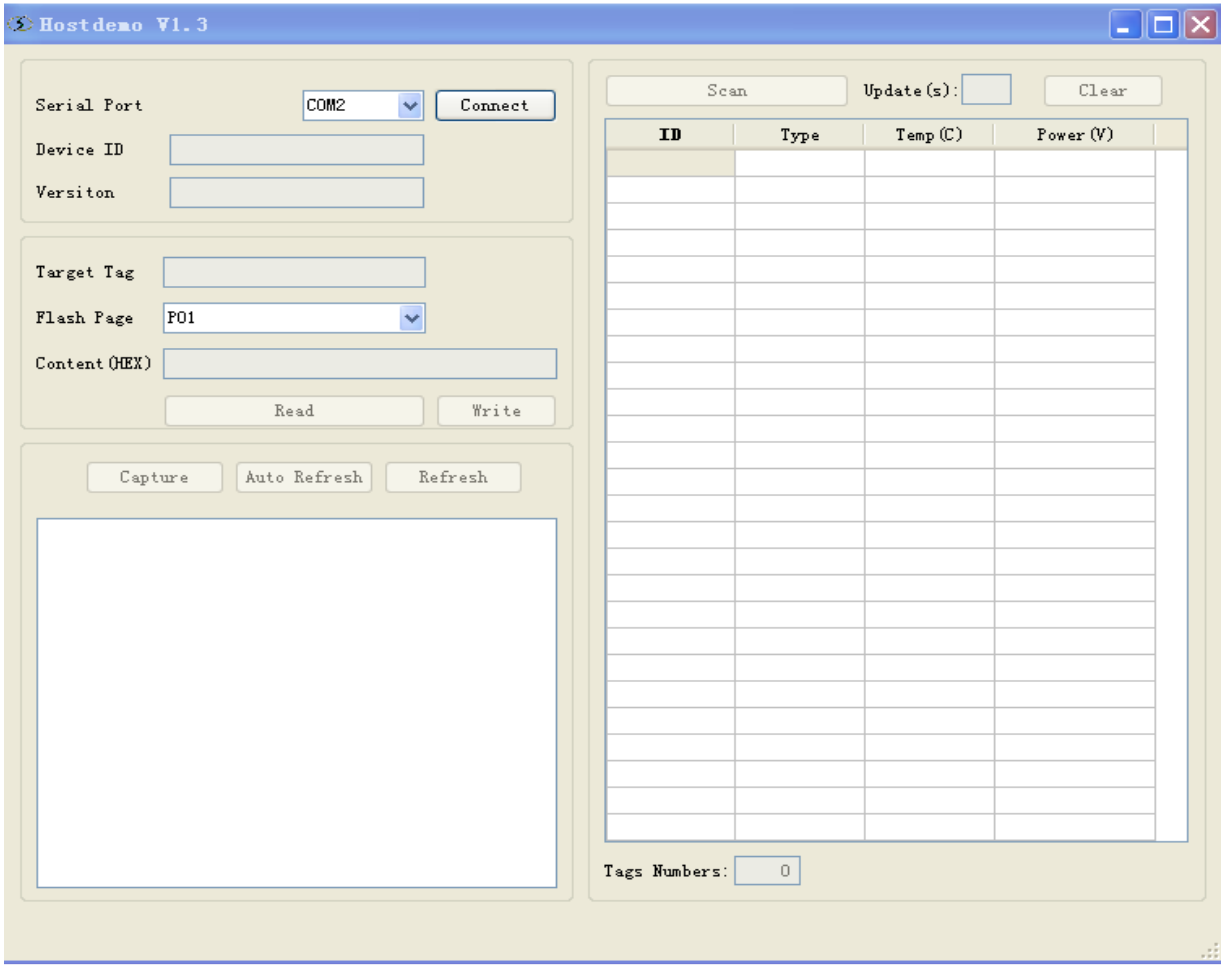
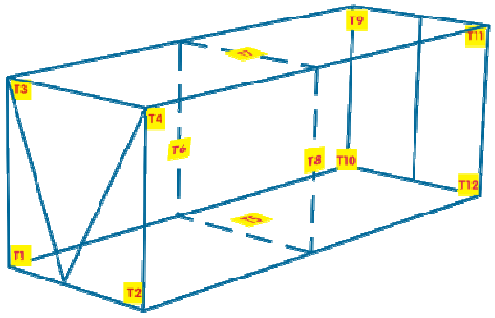
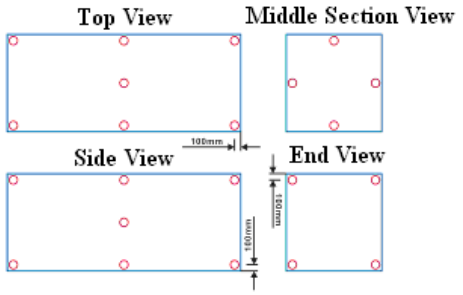


Fig. 7: Interface of the monitoring system



(a) Stereogram of the arrangement of tags



(b) Plan of the arrangement of tags

Fig. 8: Arrangement of the RFID temperature tags

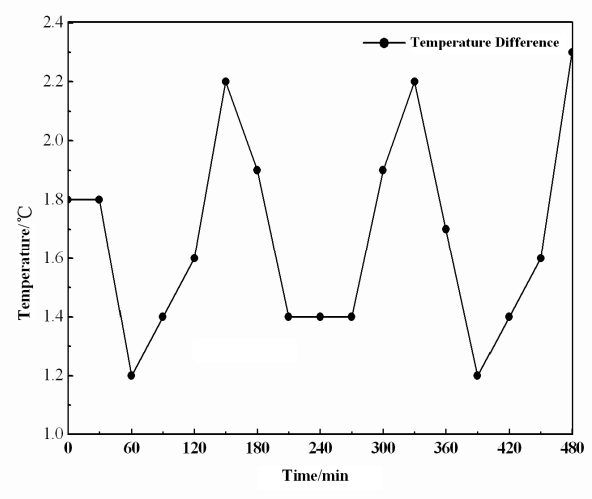
The computer and the RFID reader were in the control room and the RFID tags were fixed inside the container. The distance between the container and the control room was more than 10 m, shown in Fig. 6. Data was displayed and stored through the monitoring software and the interface is shown in Fig. 7.

Eight of the RFID tags were fixed in 8 corners of the refrigerated container and 4 of the tags were fixed in centers of the 4 vertical walls of the refrigerated container to collect the inside temperature, the arrangement of the tags is shown in Fig. 8.

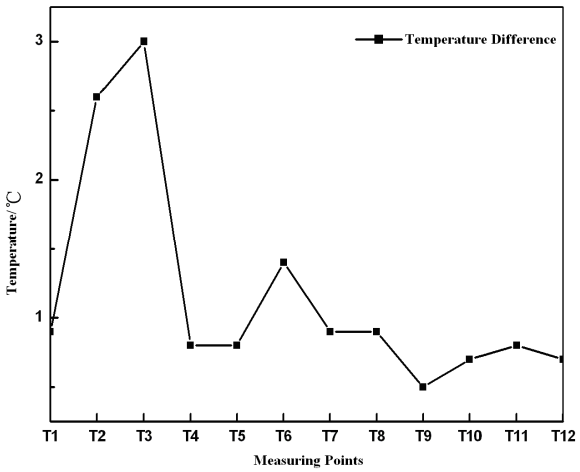
EXPERIMENTAL RESULTS AND ANALYSIS

The experiment was carried out when the container was not fully loaded and the ambient temperature was set to 15°C, the inside temperature of the container was set to -20°C. After operation condition of the container was stable, the data was recorded and saved.

During the test, the readability of 12 RFID temperature collection tags by the RFID reader reached 100% and the effective working distance between the reader and the tags satisfied the requirement of more than 10 m. The temperature collection time interval was adjustable and when the set data collection interval was 5 sec, no delay occurred, which can meet the design requirements. Figure 9 shows the maxim temperature difference among the testing points and the data



(a) Different testing points at the same time



(b) The same testing points at different time

Fig. 9: Maxim temperature difference among the testing points inside the container

collection interval was set to 30 min, the whole test period was 8 h.

According to Fig. 9, in respect of the maxim temperature difference among the 12 tags at the same time, the largest was 2.3°C and the smallest was 1.2°C; and the maxim temperature difference of the same testing points at different time ranged from 0.5 to 3°C. The data was got on the condition that the container was not fully loaded and the ambient temperature was stabilized at about 15°C. However, during the transportation, affected by the factors such as the type, the quantity and the stack form of the cargo and climate change outside the container, temperature fluctuations and uneven distribution of the temperature field will aggravate and the goods quality will deteriorate. For the 40-foot refrigerated containers, the uneven temperature distribution must be more serious.

CONCLUSION

The monitoring system of marine refrigerated containers based on RFID temperature tags was developed and according to results of the inside temperature monitoring experiment, the system featured multi-points real-time monitoring, 100% readability, long reading distance and rapid reflection of the temperature variation The monitoring system has the advantages that are incomparable:

The real time temperature change inside the container is automatically monitored, once the temperature fluctuations are beyond the permitted range, the system will alert and the engineer may take corrective measures before the cargo encounter danger and avoid accidents.

Due to the multi-tag identification technology of RFID, more sampling points can be set to collect temperature and the tags can even be placed inside the goods, which is more flexible and no blind spots exist.

The system features wireless collection and wireless communication, so the laying of signal line is reduced and cost is saved, meanwhile the environmental impact to the data is decreased.

The inside temperature monitoring system based on RFID may play its powerful role in the safe, reliable and economical transportation of marine refrigerated containers.

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