DEVELOPMENT OF MATERIAL TRACKING SYSTEM USING WIRELESS TECHNOLOGY IN HIGH-RISE BUILDING

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ABSTRACT : There is a need for effective tracking and control of material loading and delivery time especially during the finishing-work phases to eliminate the need for lay-down space on the site. Hence, it is essential to monitor the relevant information regarding material procurement in construction sites, and it is also the key factor for successful site control and the adoption of the Just-in-Time concept for high-rise building construction. The purpose of this study is to test RFID's readability in order to develop a finishing material monitoring system through the application of RFID technology.

Key words : RFID, finishing material, material monitoring system, procurement, readability test

1. GENERAL INFORMATION

1.1 Requirement and purpose of the study

One of the major issues in the field of construction is the difficulty of securing adequate space for the vertical movement and stacking of materials within construction sites, particularly those located in the center of the city, which have space constraints due to a lot of people and equipment moving within the site everyday. During the process of construction finishing, in particular, when most of the required resources need to be inputted, the timely conveyance of required materials in and out of the site should be monitored in order to ensure the smooth accomplishment of the construction. The higher the building being built, the more different the work processes that need to be simultaneously done, so it is essential that timely conveyance and stacking of the various materials are done to ensure smooth construction. Therefore, creating a material tracking system has become a critical factor in ensuring that various materials are delivered when needed and that the entire processing of materials are continuously monitored.

Given this situation, a material tracking system using the existing barcode was developed in Korea, and a new material tracking system using Radio Frequency Identification (hereinafter referred to as RFID), which has recently attracted interest from different industries, has been undertaken.

The purpose of this study is to determine RFID readability using ceiling panels as the subject, as a prior process in developing a RFID-based material tracking system for finishing materials. This study aims to provide basic data in determining the main specifications (sort and position of tags, number and range of antennas) for the development of a RFID-based material tracking system in the future.

1.2 Purposes and contents of research and development

The study was conducted as follows:

First, we selected the representative finishing material for the test on RFID readability, which are related to domestic and overseas trends in RFID development.

Second, on the subject of the selected finishing material, we embodied the main tests and conducted the tests.

Third, after the tests were finished, we compiled the experimental results and considerations for the introduction of a new RFID-based material tracking system in the future.

2. TRENDS IN DOMESTIC AND OVERSEAS RFID TECHNOLOGY

2.1 RFID technology

RFID is a chip that stores the overall information such as purchase requirement, manufacture, delivery, procurement, stacking and loading on the tag. The chip can be linked to a portable communications network and integrated into an information system so that the stored information can be read by a reader with its own antenna. As shown in Fig. 1, the RFID system consists of a reader with its own antenna, an antenna that can transmit and receive the information, a tag where the information can be stored and exchanged through a protocol, a server and a network. The individual function of each part is as follows: the reader can read and write information on the RFID tag, the antenna can exchange the stored data on the tag with the defined frequency and protocol, and the tag is the storage, which is the core function of RFID.

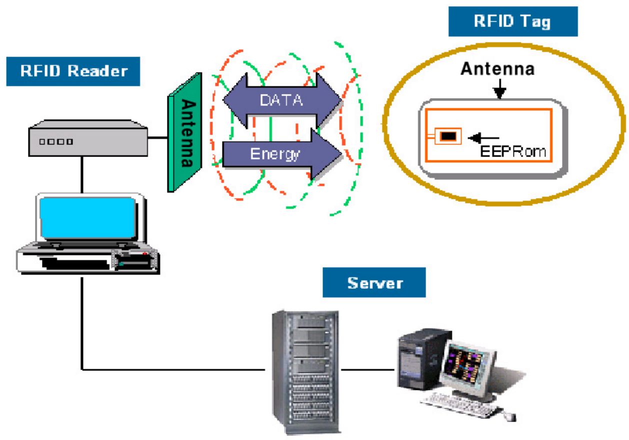

Figure 1. RFID system composition

The RFID tag can be categorized into Active and Passive, depending on the necessity of power supply. The active-type needs power supply but the passive-type can be operated with the electromagnetic field of the reader without requiring a direct power supply from inside or outside the tag. The active-type reduces the power supply needed by the reader and recognizes the data even at a long distance from the reader, but its working time can be limited and it has a higher price than the passive-type because it needs a power supply device. On the other hand, the passive-type has a lighter weight, its price is cheaper and it can be semi-permanently used, but its readability range is shorter and it consumes more power than the active-type. In addition, the frequency for the RFID is varied and the frequency bands mainly used are below 153 KHz, 13.56 MHz, 433 MHz, 860~960MHz and 2.45 GHz.

2.2 Selection of representative finishing material

A super high-rise building (more than 45 stories) can require around 1,000 materials, although this may vary a little depending on the kind of building. Of these materials, around 100 are used for frame construction and 900 are used for construction finishing. In addition, sort, shape and size of the materials are different and the method of purchase, transportation, loading, hoisting and installation of each material are also different. Therefore, it is impossible in reality to establish a material-tracking plan that takes all the numerous materials into consideration. Because of this, we selected the representative materials on which the material tracking system with RFID will be applied based on literature considerations, convergence of expert opinions (construction site, RFID-related companies, material production specialists), and the requirements for application to the current RFID technology (electronic wave interference, package, size).

Before the selection was started, we set a pool of 10 kinds of representative finishing materials based on existing literature considerations. It is more effective to select materials with a high possibility of RFID application from all the materials that had already been proven through existing results of previous studies. In terms of the pool of 10 kinds of representative materials, we interviewed and consulted with experts on the property (wave interference), package, size and requirements in the construction site. As a result, it was concluded thatmaterials packed and forwarded from a manufacturer as a box or pallet unit, which do not need additional assembly at the site,would be good for the test. Therefore, we selected ceiling panels as the subject of the study among complete products that are packed as a box, such as ceramic products, tiles and ceiling panels.

3. TEST ON RFID READABILITY

3.1 First test on RFID readability

3.1.1 Summary of the test and specifications

We conducted the first test by changing the experimental conditions, such as the distance between the tag and the antenna, the number and position of the antennas, and the boxes with ceiling panels, several times. The purpose of the test was to determine the readability of the selected RFID equipment, which would be utilized as the basic data for the main considerations in the future, such as the position of the tag, the direction and number of antennas considering the readability distance, and the place of attachment.

Table 1. Specification of the RFID Readability in the first test

Division	Item	Contents
Reader	Frequency	UHF 902-928 MHz
	Power supplied	100V-240VAC
	Power consumed	25 Watts
	Port	RS232 interface, LAN TCP/IP interface
	Size and weight	(cm) 19 x 26 x 5 / (kg) 2.1
	Operation and proper temperature	(℃) 0 to +50 / (℃) -20 to +70
Antenna	size and weight	(cm) 22 x 27 x 4 / (kg) 0.57
	Cable	RG 58, 1.8 m
Tag	Frequency	UHF 902-928 MHz
	Memory	64-bit user-programmable memory factory or field
	Collision prevention	Data rate up to 200 tag reads per second.
	Power	Incident reader signal, passive tag
	Readability range	Up to 4 meters in free space.
Ceiling pane	Thickness: 12mm, Size: 300×600mm, Number per pack : 18pieces	

We executed the test within a 3.6m x 3.6m rectangular space with grids at the cross and down intervals of 0.6m. In the grids, we installed one or two antennas that could connect to the reader and attached a tag on each box. We conducted the test on readability by changing the box's flight into one, two or three on the basis of 1 box, 4 boxes and 6 boxes and moving the boxes in accordance with the 0.6 grid interval. The specification of the ceiling panels and the RFID equipment used in this test is shown in <Table 1>.

3.1.2 Main test results

The main test results of the first test on RFID readability are as follows:

· Readability according to the tag's direction

From the result, it is analyzed that the tag in the right front of the antenna is recognized best. Since the tags were not recognized when they were overlapped, it is recommended that overlapping of the tags should be prevented when the RFID equipment is actually applied to ceiling plates in the future.

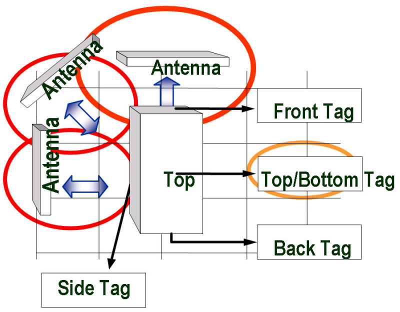

Figure 2. Directions of Antenna and a Tag

· Readability according to change in the number of antennas

When one antenna was used, it was best recognized within a 0.6m area around the antenna. When two antennas were used, it was best recognized within a 1.2m area around the antennas, which means that if the number of antennas increases, the readability range is also expanded according to the increase in the number.

· Change in readability rate according to the increase in the number of boxes (number of tags)

Without changing any of the other conditions such as the number, direction and height of antennas, if the number of boxes (number of tag changes from 16 to 50) is increased, the readability rate tended to decrease by 12~13% on the average. This indicates that the increase in the number of tags enhanced mutual interference owing to the overlapping of the tags, and thus, the number of antennas and readers should also be increased.

3.2 Second test on RFID readability

3.2.1 Summary of the test and specifications

The second test on RFID readability was a follow-up study of the first test where one and two antennas were used. We conducted the second test to verify changes in readability by using three and four antennas, changing the antennas' disposition in various ways, and using different kinds of antennas(circular-type, linear-type). In addition, we made an order for the manufacture of a gate with a width of 3m and a height of 3m. We installed the RFID reader and the antenna on the gate in order to measure the readability when a box with a tag goes through. It is expected that such a gate will be used for carrying in material and invoice inspection on a site experiment in the future. We conducted the test within a 3.6m x 3.6m rectangular space with grids at the cross and down intervals of 0.6m, similar to the first test. Also, 18 boxes of ceiling plates (6 boxes, 3 flights) were used, the same as in the first test. A total of 76 RFID tags were used in the test (each tag was attached to the front, back, right and left of a box, which accounted for 72 tags, and on two tags were attached to top and bottom of each box from the first flight and the third flight respectively, which accounted for 4 tags). The main specifications are shown in <Table 2>.

Table 2. Specification of the RFID Readability in the second test

Division	Item	Contents
Reader	Frequency	UHF 902-928 MHz
	Power supplied	12VDC, 2A(unregulated), 100V-240VAC
	Power consumed	25 Watts
	Port	RS232 interface, LAN TCP/IP interface
	Size and weight	(cm) 19 x 26 x 5 / (kg) 2.1
	Operation and proper temperature	(℃) 0 to +50 / (℃) - 20 to +70
Antenna	Size and weight	(cm) 22 x 27 x 4 / (kg) 0.57
	Cable	RG 58, 1.8 m
	Radiative pattern	Linear, Circular
Tag	Frequency	UHF 902-928 MHz
	Memory	64-bit user-programmable memory factory or field
	Collision prevention	Data rate up to 200 tag reads per second.
	Power	Incident reader signal (passive backscatter)
	Readability range	Up to 4 meters in free space.
Ceiling panel	Thickness : 12mm, Size: 300×600mm, Number per pack : 18 pieces	

Reader		Antenna	
Tag		Ceiling Panel	

We used the linear antenna and circular antenna in accordance with the radiative property of electronic wave. The circular antenna is not sensitive to a specific direction and the readability rate is low due to its wide beam-width.

On the contrary, the linear antenna is highly sensitive to specific direction so that the readability rate is very high due to its small beam-width. If the two antennas' properties are combined properly, it is believed that the performance will be improved from the aspect of readability rate.

Therefore, considering the properties of the two antennas, we used various combinations in the test and we also used the average value of the experimental result.

3.2.2 Main test results

The main test results of the second test on RFID readability are as follows:

·Average readability rate according to the increase in the number of antenna (three antennas)

First of all, we increased the number of antennas to two, three and four, as shown in <Fig. 3>, and then experimental the results shown in <Fig. 4>. When four antennas were installed, the average readability rate was the highest at 96%, and when two circular antennas and two linear antennas were installed on the top and the sides, respectively, the readability rate reached 100%. From the result, we can verify that the readability rate was improved as the number of antennas increased.

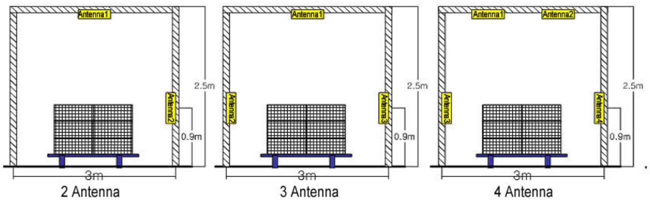

Figure 3. Increment in the number of antenna

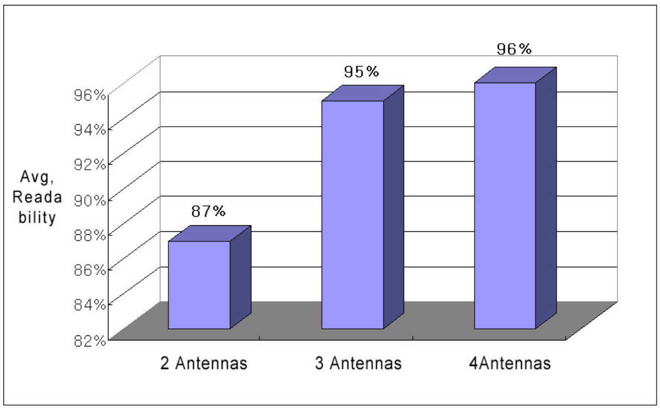

Figure 4. Experimental results of increase in number of antenna

Average readability rate according to the change in the antennas' disposition (three antennas)

As shown in <Fig. 5>, we conducted the test on readability by disposing three antennas in various positions and then measured the readability of each. From the experimental result shown in <Fig. 6>, A-3, C, E and F showed over a 95% readability rate, which was excellent overall. Among these, the 3-C, where two circular antennas and one linear antenna were installed on the top and the side, respectively, showed a 99% readability rate, which was the best result.

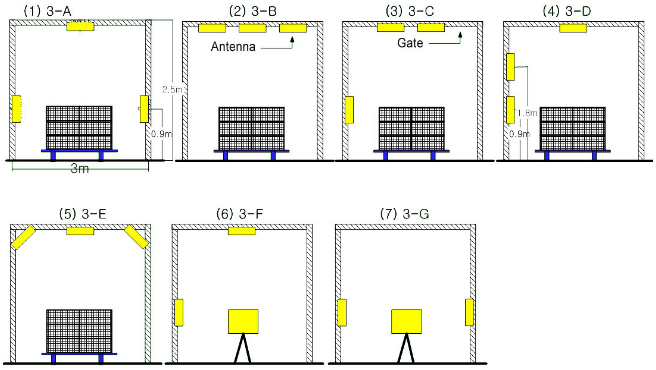

Figure 5. Different dispositions of the three antennas

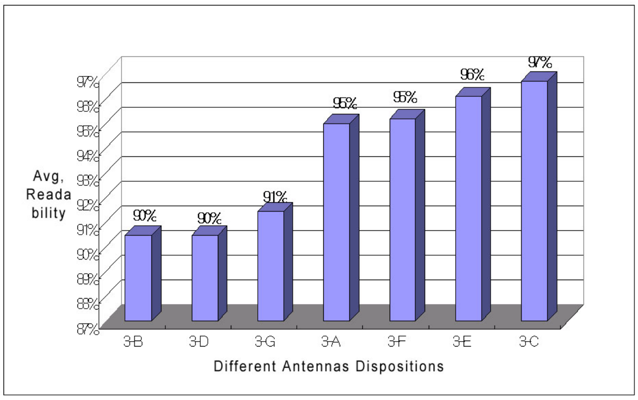

Figure 6. Experimental result of different dispositions of the three antennas

Average readability rate according to the increase in the number of antennas (four antennas)

We conducted the test on readability by disposing four antennas in various ways as shown in <Fig. 7>. From the experimental result shown in <Fig. 8>, 4-A and B showed over a 96% readability rate, which was excellent overall. Similar to the result of the abovementioned experiment ①, in the case of 4-A, where two circular antennas and two linear antennas were installed on the top and the sides, respectively, the highest readability rate was shown to be 100%. The highest readability rate was shown when two circular antennas and one linear antenna were installed on the top and the sides, respectively, which is similar to using four antennas.

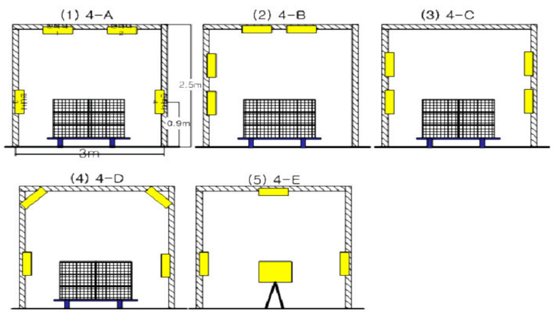

Figure 7. Different dispositions of four antennas

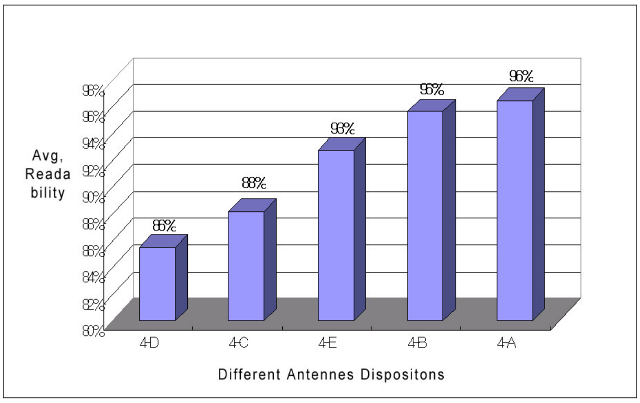

Figure 8. Experimental result of different dispositions of the four antennas

The situation is closely related to the characteristics of the antenna. For example, when linear antennas are installed on the sides, the direction of the tag on the box is more effective to be read by the antenna so that the readability rate becomes higher. It is believed that the experimental results can be used as basic information when monitoring finishing materials on the site and when determining the location of the RFID antenna on the site entry and within the hoist in the future. In addition, it will be helpful in terms of determining the direction of the tag on the box.

Figure 9. Second test on RFID readability

4. CONCLUSION

In this study, as the previous stage of developing a RFID-based system possible to apply to and monitor the finishing materials, we conducted tests on RFID readability using ceiling panels, rather than other finishing materials, as the subject. "

We can verify that there were differences in the readability rate in accordance with the direction and installation place of the tag, the direction and number of antennas, and changes in the disposition. When a tag is on a horizontal direction to an antenna or when a tag is in the right front of an antenna, the readability rate is very high. In addition, the more antennas that are installed, the higher the readability rate becomes. In addition, when the distance between the tag and the antenna is shorter, the readability rate becomes higher. If the same number of antennas are disposed in the same position, there is a decline of 12~13 % in the average readability rate as the number of boxes increases. From the result, it can be concluded that to improve the readability rate, the number of antennas should be increased as the number of tags increases.

From the second test, we can confirm that the readability rate becomes higher as the number of antennas increases. From the results of the experiment on different dispositions of three or four antennas and from the antenna's property, it is analyzed that the highest readability rate was shown when two circular antenna and two linear antenna were installed on the top and on the side, respectively (in the case of three antennas, two on the top and one on the side). It is considered that the test result can be highly helpful in determining the disposition of antennas and the attachment location place of tags on the box when the material tracking system is installed on the site in the future.

The final purpose of this study was to develop an RFID-based material tracking system. To design and apply a material tracking system for a site, we are planning to conduct a test in the future. In addition, we will additionally test readability in a variety of ways to finally build a system that satisfies practical use and economic efficiency.

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