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A DEVELOPMENT OF INTELLIGENT CONSTRUCTION LIFT-CAR TOOLKIT DEVICE FOR CONSTRUCTION VERTICAL LOGISTICS MANAGEMENT

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ABSTRACT: High-rise construction sites, especially those situated in spatially constrained urban areas, have difficulties in timely delivery of materials. Modern techniques such as Just-in-time delivery, and use of information technology such as Project Management Information System (PMIS), are targeted to improve the efficiency of the logistics. Such IT-driven management techniques can be further benefited from state-of-the-art devices such as Radio Frequency Identification (RFID) tags and Ubiquitous Sensor Networks (USN), which has resulted in notable achievements in automated logistics management at the construction sites. Based on those achievements, this research develops USN hardware toolkits for construction lifts, which aims to be automated the vertical material delivery by sensing the material information and routing it automatically to the right place. The gathered information from the sensors can also be used for monitoring the overall status. The developed system will be tested in the actual high-rise construction sites to assess the system's feasibility. The proposed system is being implemented using Zigbee communication modules and RFID sensor networks which will communicate with the intelligent palette system (previously developed by the authors). To support the system, a lift-mountable intelligent toolkit is under development. Its feasibility test will be conducted by applying the implemented system to a test bed and then analyzing efficiency of the system and the toolkit. The collected test data will be provided as a basis of autonomous vertical transport equipment development. From this research, efficient management of the material lift is expected with increased accuracy, as well as better management of overall construction schedule benefited from the system. Further research will be expected to develop a smart construction lift, which will eliminate the need for human supervision, thus enabling a real 'autonomous' operation of the system.

Keywords: Vertical Logistics Management, Construction-Lift, Intelligent Toolkit Device, USN, RFID

1. Introduction and Motivation

Comparing to other industries, logistics process in the construction industry is relatively ill-defined and flexible [1]. For high-rise building project in a dense urban area, various resources have to be transported vertically under varying, often adverse, situations using limited number of available lifts. In such situations, effective management of the vertical transportation is a necessity for a successful project [2]. The higher a building grows, the more management issues its builder has to face in terms of scheduling, cost, etc., besides increased materials to be managed on-site. Efficient planning of resource transportation and proper management of it would benefit the scheduling and cost reduction of such spatially restricted high-rise construction projects; on the other hand, problems in resource transportation in the construction sites would negatively impact their schedule, resulting in delayed schedule, cost overrun, and other bad issues. While sophisticated managerial techniques such as Six Sigma, JIT (Just-in-time) Production and Lean Production has been adopted to the construction industry for improved logistics, systematic implementation such as intelligent management system with automated features are yet to be prevalent, and more researches are still demanded for such systems.

This research is a part of bigger research framework for automated logistics management for construction sites, utilizing state-of-the-art technologies such as Radio Frequency Identification (RFID) and Ubiquitous Sensors Network (USN). It aims to develop a USN-based mechanical toolkit for building intelligent construction lift system, which will enable better transportation capability, enhanced management efficiency, and real-time monitoring capability. A prototype system will be developed using the toolkit to be tested in a real world high-rise building construction for assessment of the system's performance and real-world feasibility. The main purpose of this research is to present a new alternative for managing vertical transportation of spatially constrained construction projects, such as urban high-rise buildings.

Figure 1 describes the scope and methodology of our research.

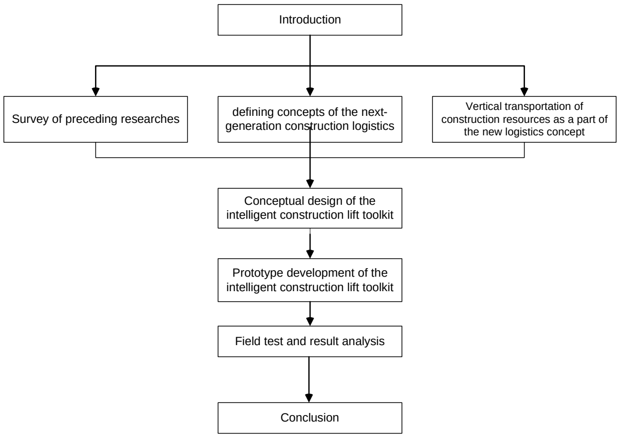


Figure 1. Overall structure of this paper, which also illustrates the scope and methodology of the research

2. As-is Construction Logistics Management

2.1 Precedent researches in construction logistics

We surveyed related researches preceding ours, mostly done in South Korea, and then we could identify three research categories from them: *Management theory (including enhancement of existing practices) and its application* ([1], [3] ~ [18]), *Procurement improvement* ([19] ~ [23]), and *Adoption of state-of-the-art technology* ([24-31]). It seems that researches on RFID/USN based logistics support systems and decision support models for such systems began to appear since 2003. Kwon's research on inter-equipment information acquisition mechanism for construction logistics [1] is a basis of this research; based upon it, the authors have designed a universal mechanical toolkit for building a vertical transportation management system for construction sites. The system considers construction lift cars as primary means of such transportation system.

2.2 Precedent researches in vertical transportation management in construction projects

Table 2 summarizes the known researches of vertical transportation, logistics management of it, and other related topics.

As shown in Table 2, existing researches on vertical transportation management can be categorized into : (1) *layout planning of tower cranes* ([29] and [32]), (2) *load balancing of tower cranes and construction lifts* ([33] and [34]) and (3) *supply systems for supporting such plans* ([2] and [35]). None of the surveyed researches utilized RFID/USN systems for monitoring vertical resource movement; also, No automated systems seem to have been researched for those topics.

Table 1. Precedent researches in vertical transportation management in construction projects

Notable researches	Topics
Evaluating the Feasibility of a Lift Plan for Finish Materials in High-Rise Building Construction [36]	Feasibility study on lifting plans for finish materials in high-rise construction
Genetic Algorithm for Optimizing Supply Locations around Tower Crane [32]	Genetic Algorithm for Optimizing Supply Locations around Tower Crane
A Study on directions of Developing a Transportation and Procurement System for JIT Management of Curtain Walls in High-Rise Building Construction [35]	Supply system of curtain walls for just-in-time fabrication
Development of the lift-up and procurement system for Just-in-time in the Building Construction [29]	Lifting system for Just-in-time production of construction
Condition and Problem of Lift-up Plan for Finishing Material in High-Rise Building Construction [2]	Current practices and problems in lifting plans for finish works of high-rise construction
A Study of the High-rise building`s Lift-up Management-through Division of Loading Factors of Equipment materials [33]	Proposals for improved load balancing of lifting for high-rise construction projects
Hoist Scheduling Chart and Lifting Load Leveling Method for Applying JIT(Just-In-Time) in Construction [34]	Techniques for lift scheduling and load leveling for just-in-time construction

2.3 Concept of next-generation vertical transportation (and logistics) management

A next-generation construction logistics management system is envisioned by the authors as a logistics management environment, especially suited for large-scale high-rise construction projects. It comprises a logistics process model (with support system) and intelligent logistics equipments such as a mover, a trailer, a construction lift, a gate sensor, etc., with various electronic systems which make them 'intelligent'; RFID and USN technologies are featured in the system as a foundation of data communication and management related to the logistics process (Kwon, S. H. 2008). Figure 2 depicts the overall organization of the system.

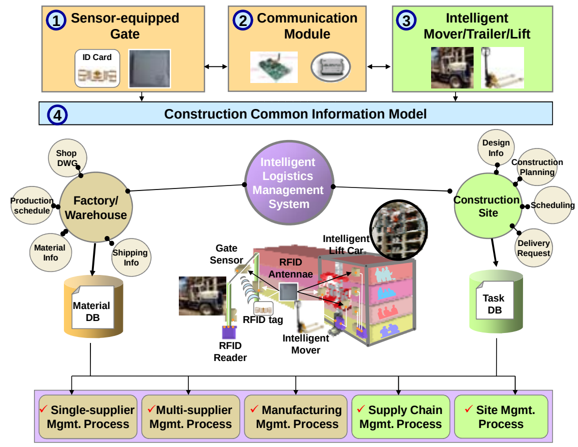


Figure 2. Next-generation intelligent construction logistics management system overview

As shown in the figure, the intelligent system monitors various kinds of construction materials in various stages from their production to on-site installation. For vertical transportation management, which is the main subject of this research, a similar diagram is shown in Figure 3.

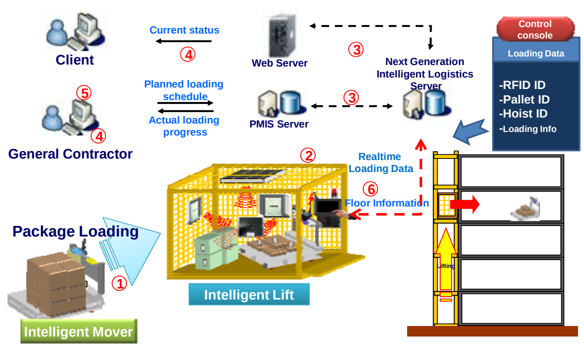


Figure 3. Next-generation construction vertical transportation control and management system

The proposed vertical transportation management scheme illustrated in Figure 3 monitors incoming materials via RFID tags attached to them. Intelligent Movers (IM) have sensors to read the tag signal, while those signals can also be captured by handheld RFID reader at any point. When the materials are loaded to the intelligent lift car, they are checked for target location and quantities against the information given from a central logistics management computer server. The transported material's final states (whether they are dispatched to the right places at the right time) are also monitored. A project management information system (PMIS) receives the monitoring information and compares the current state with a planned schedule to catch any anomalies. Such intelligent features will let a project manager confident about what is going on and ensure her that everything is under control. In the following sections, the detailed description of the proposed system, especially the add-on toolkit for a construction lift car, is presented.

3. Design of the construction lift toolkit

3.1 Performance requirements for the toolkit

The proposed toolkit mentioned in previous sections must be capable of the following tasks: First, it must be capable of reading RFID tags and identify what the tagged materials are when they are loaded to the refitted lift. Second, the toolkit must be capable of short-range data communication so that it can share information with other intelligent equipments such as IM. Third, it must be able to send the recognized tag data to the logistic server and/or the PMIS. Forth, from those servers it must be able to receive the destination to which loaded materials to be sent. Fifth, when the material arrives its destination floor, the toolkit must verify whether current floor is the correct destination and information about the floor must be given to it.

In addition to these functional requirements, the toolkit must satisfy the following standard work cases:
Case 1: It communicates with other intelligent equipments such as IM.
Case 2: It lifts individual materials each of which is equipped with an RFID tag.
Case 3: With previously loaded materials, it loads extra materials with RFID tags

These cases are reflected in a workflow model of intelligent construction lift operations (with the toolkit), one of which is shown in Figure 4. Functional requirements of the toolkit have been derived from the model, which is also shown in Table 3

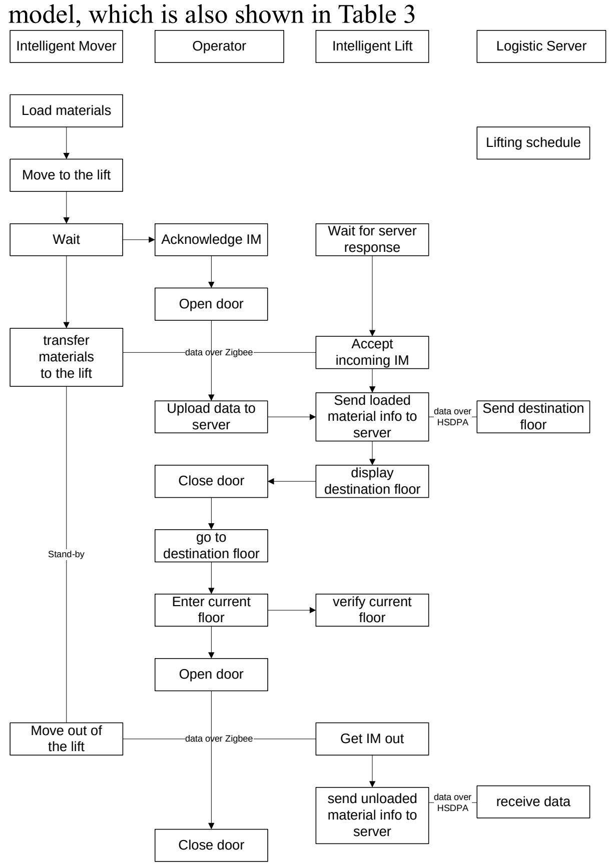


Figure 4. Standard workflow of the intelligent construction lift. In this diagram, the lift interoperates

with the intelligent movers (IM).

Table 2. Functional requirements of the intelligent construction lift toolkit

Functional requirements	*Available technological alternatives*
Short-range data communication between intelligent equipments	Zigbee
Automatic identification of RFID tags	RFID Reader
Emergency power supply (in case main power fails)	Battery Pack
User interfaces	Touch Screen Monitor

3.2. Design of the toolkit with construction logistics management in mind

Figure 5 illustrates the concept and functional parts of the intelligent construction lift toolkit, which reflects the requirements discussed in previous sections. These concepts, shown in Figure 5, were implemented in the prototype system, whose design is partially seen in Figure 6.

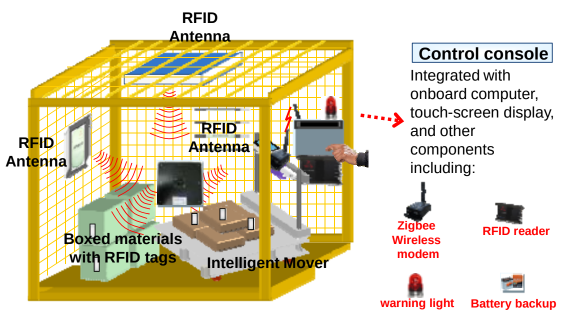


Figure 5. Illustration of the intelligent construction lift toolkit concept for next-generation construction logistics.

Its design highlights can be briefly described as follows:

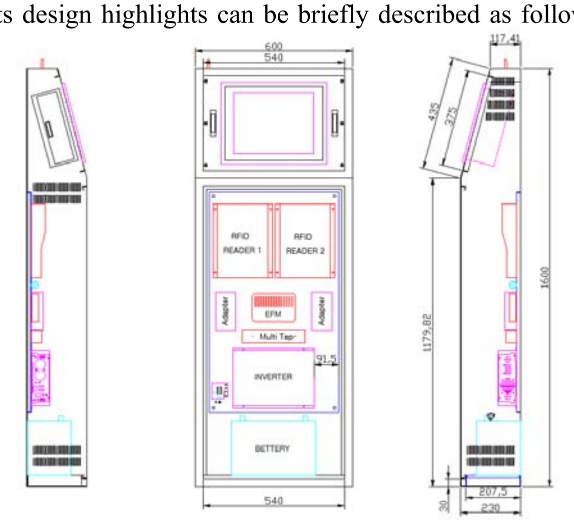


Figure 6. Design of the intelligent construction lift toolkit - console-section.

First, the entry-area RFID readers are separated from the exit-area readers, as the entry and the exit gates are often separated in most construction lifts. And a touch-screen display integrated with an industry-grade personal computer is used, providing better user ergonomics at 120 centimeters of its height. An auxiliary battery pack and an accompanying DC-to-AC converter are equipped to prevent the system black out should main power fail.

3.3 Selection of a suitable lift car type

There are several different types of lift cars available with variable capacity and speed. In Table 4, Comparisons between these lift car types are made[2]. From the table, it is shown that their performance differences seem to be come largely from different inverter types they use and different locations of the drive motors.

Table 3. Performances of different lift types

types	Nominal loads (ton)	Lifting speed (m/min)	dimension of the loading room (m)	Max. size of the door opening(m)	Frequency of power alternation (Hz)	Nominal power consumption (KVA)	Location of the drive motors	Use of inverters
Low speed	1.0-1.2	38	1.27x2.9x2.5	1.27x2.4	50/60	2x 27KVA	internal	no
Med speed	1.2-1.5	70	1.5x4.0x2.65	1.5x2.6	50/60	2x 47KVA	rooftop	yes
High capacity	1.2-2.0	38	1.5x4.0x2.65	1.5x2.6	50/60	2x 75KVA	rooftop	yes
High speed	2.0-3.0	100	1.5x4.5x2.65	1.5x2.6	50/60	2x 64KVA	rooftop	yes

This research assumes that the fourth type (high speed type) will be most common in future high-rise projects, therefore the toolkit test was planned to be conducted with this lift type.

4. Comparison of different construction lift vehicle types

4.1 Test plan

Table 5 reiterates the functional requirements identified in previous sections and then states the performance items of the prototype implementation that needs to be evaluated through the tests.

Table 4. Functional requirements of the intelligent construction toolkit and their corresponding performance items

Required functionality	Performance items n
Auto identification of RFID tags	Range of tag Identification with successful re
Undisrupted power supply	Time of continuous supply above certain volta
Intelligent short-range data communication	Zigbee applicability
Communication with PMIS	Availability of various wireless communicatio

Total of two tests have been conducted overall, each test was conducted with following procedure:

First, tests measuring radio-based communication performances of the prototype toolkit were made. These tests include range measurement of RFID devices, communication tests of Zigbee modules, and data communication tests using cellular telephony network

2 Please note: same table appears in the author's other paper [37].

(HSDPA).

Second, tests measuring various performance aspects of Intelligent Movers (IM) prototype were made. They include communication tests with the toolkit using eight RFID antennae, public network-based wireless communication availability tests using HSDPA/Mobile WiMax technologies with evaluating battery performance as well.

4.2 Pilot tests of constituent modules

Prior to testing the fully-blown prototype, some modules that comprise our prototype were individually tested against their performance requirement. These tests were divided into three categories:

First, performance evaluation of the RFID antennae deployed to the field

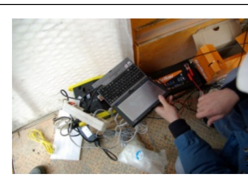
Second, performance of short-range communication using Zigbee

Third, operations of wireless communication modules

For these tests, RFID tags of 900Mhz frequency band were used. This frequency band is susceptible to reflection against material surfaces, affecting the performance of the receivers. Furthermore, complex shape of the construction lift system, which is made of steel cause a complex signal dispersion pattern, which was poorly understood at the time of the test. The researchers had to derive empirical figures on this issue.

(a) A lift car used in the test.

(b) Installation of the RFID modules



(c) Communication test of the sensors

(d) Test of the signal recognition ration with varying door aperture of the lift

Figure 7. Pilot test of the toolkit components

The results from the component tests can be summarized as follows:

First, Zigbee modules performed well without significant noise issues up to 5 meters, a range within which the intelligent construction lift and the intelligent mover would communicate.

Second, performance of the RFID modules were observed, which is summarized in Table 6.

Table 5. RFID recognition performances with varying door apertures

Test condition		RFID Receiver performance (readable range)
Door aperture	Closed	Unreadable
	Halfway open	Within 5 meters
	Fully open	Within 8 meters

Third, cellular telephony-based data communication was tested on the test field. It was confirmed that the communication was stable enough to be used for our system

4.3 Tests of the whole prototype system

The entire prototype was developed, with feedback from the earlier component tests, to be tested for RFID recognition performances under varying conditions which might affect signal attenuation. Figure 7 shows the photos taken from actual test scenes, showing the appearance of the installed toolkit (a) and the RFID antennae installed (b).

(a) Prototype of the intelligent construction lift toolkit

(b) RFID antennae installed

Figure 8. Prototype of the intelligent construction lift toolkit, installed to a lift for testing

The prototype test was done as follows:

First, RFID signal recognition tests with varying antenna types
Second, RFID signal recognition tests with varying antenna positions
Third, RFID signal recognition tests with varying antenna gains

Passive tags were used for the RFID tags, which were attached to two distinct positions in a test box – top face of the box and side face of it. Each box simulates a material transported using the lift.

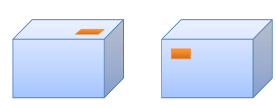


Figure 9. Different tag locations attached to test boxes.

Left: top-attached, right: side-attached

The test was conducted in a test facility of a South Korean construction lift manufacturer.

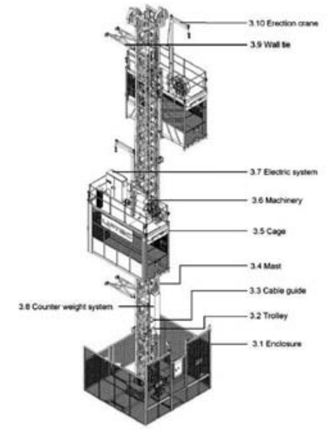
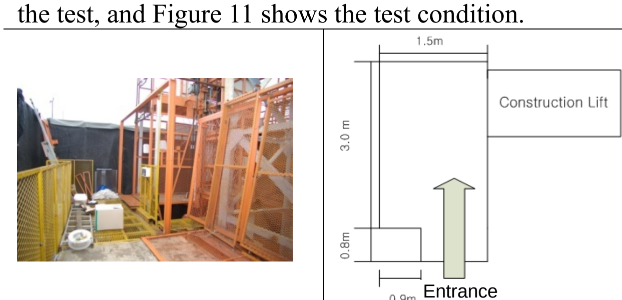


Figure 10 A picture of a construction lift car same as the one used in the test

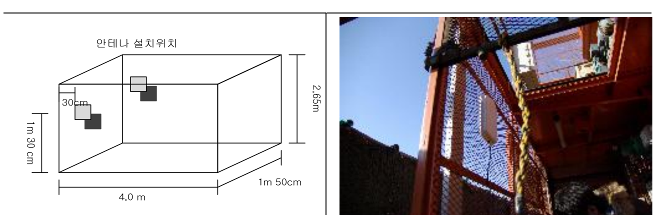
Figure 10 shows the model of the construction lift used in the test, and Figure 11 shows the test condition.



(a) Actual photo of the test facility | (b) test condition

Figure 11. Test condition

The first test, recognition performance under varying antenna types, was done using two antenna types: a linear type and a circular type. As shown in Figure 12, both antennae were installed at 30 centimeters from the car's entrance with 130 centimeters above its floor. An RX antenna and a TX antenna pair were symmetrically mounted[3]. Results from the first test are summarized in Table 7.



(a) Installation condition | (b) actual photo of the installation

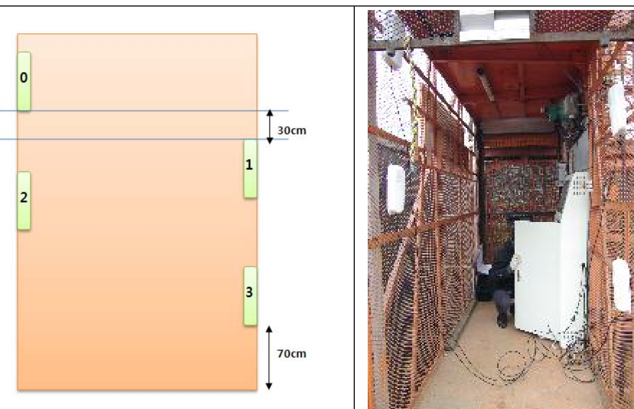
Figure 12. Locations of the Antennae

[3] A typical RFID antenna consists of a pair of two modules: an TX, which sends radio waves to a tag to be activated, a RX receives back the signal from the activated tag.

Table 6. Antenna Type Test Result

Antenna Type	Box Type	Range 0m	1m	2m	3m	4m
Linear Type	Front Tag	5	3	0	0	0
	Left Side Tag	5	4	1	0	0
	Right Side Tag	5	4	1	0	0
Circular Type	Front Tag	5	5	4	4	0
	Left Side Tag	5	5	5	4	1
	Right Side Tag	5	5	3	2	0

The second test evaluated the recognition performance with varying antenna locations. The circular type antennae were used as it performed better than the linear ones in the previous test. At first trial, two RX-TX pairs[4] of the antennae were installed at 2.6 meters above the floor, as test continues, the antennae were descended at pre-determined interval, intended to test both symmetrical antennae positions and non-symmetrical positions. Figure 13 illustrates the conditions of this test.



(a) test conditions | (b) photo of the actual test scene

Figure 1. Test of antenna performance under varying installation heights.

As shown in Table 8, differences of recognition performances under varying antennae heights turned out to be negligible.

Table 7. Recognition performances under varying antenna heights

RX-TX Position	Box Type	Antenna Hight	Range 0m	1m	2m	3m	4m
RX=TX	Front Tag	2.65m	5	5	3	0	0
		2.35m	5	5	4	1	0
		2.05m	5	5	4	2	0
		1.75m	5	5	4	2	0
		1.45m	5	5	4	2	0
	Left Side Tag	2.65m	5	5	4	3	1
		2.35m	5	5	4	3	1
		2.05m	5	5	5	3	1

[4] From Figure 13, when the left-side antennae performed as TX, the right-side ones then would perform as RX. The reader itself would set which one should be TX (and vice-versa).

		1.75m	5	5	5	5	1
		1.45m	5	5	5	5	1
	Right Side Tag	2.65m	5	5	3	0	0
		2.35m	5	5	3	0	0
		2.05m	5	5	3	1	0
		1.75m	5	5	4	2	0
		1.45m	5	5	4	2	0
RX≠TX	Front Tag	2.65m	5	5	3	0	0
		2.35m	5	5	4	1	0
		2.05m	5	5	4	2	0
		1.75m	5	5	4	2	0
		1.45m	5	5	4	2	0
	Left Side Tag	2.65m	5	5	4	3	1
		2.35m	5	5	4	3	1
		2.05m	5	5	5	3	1
		1.75m	5	5	5	5	1
		1.45m	5	5	5	5	1
	Right Side Tag	2.65m	5	5	3	0	0
		2.35m	5	5	3	0	0
		2.05m	5	5	3	1	0
		1.75m	5	5	4	2	0
		1.45m	5	5	4	2	0

As shown in Table 8, differences of recognition performances under varying antennae heights turned out to be negligible. However, the tag location on the boxes did show significant difference in recognition performance. Also, tags attached to left-side of the boxes performed well than right-sided ones.

The last test, recognition performance under varying reader sensitivities, were conducted, using minimum sensitivity setting of 0 to the maximum setting of 255 with interval of 30.

(a) adjusting reader sensitivity | (b) test result

Figure 14. RFID recognition performance test under varying reader sensitivities

Figure 13 shows how sensitivities of the readers were adjusted and the results. It was revealed that sensitivity of the reader would affect little to the recognition performance.

5. Conclusion

In this research the authors developed a toolkit for refitting construction lifts as a part of intelligent construction logistics management system. A prototype of such toolkit has developed and tested to evaluate its performance. The test results can be summarized as follows:

First, RFID antenna types affected the recognition performance of the readers used in our prototype under our test settings. Test results shows that a circular-type antenna would be a better choice for use in the lift cars.

Second, location of the sensors in the lift car affected little to the recognition performance. The best height for the antennae mounts was between 1.45 meters and 1.75 meters.

Third, when the tags were side-mounted on the transported materials, their recognition ratio varied. It was believed to happen because the radio waves reflected on the left-side wall of the test area, which was made of steel. Generally left-mounted tags performed worse than right-mounted tags, as reflection didn't occur at right-side of the area.

Fourth, sensitivity of the reader virtually didn't affect the recognition performance.

Overall, the test results proved that our prototype would work as planned in a real-world construction sites. Besides, standard processes of vertical resource transport are also proposed so the intelligent lifts can be operated efficiently when deployed.

Future research will include following activities: development of support software for the toolkit, connectivity with PMIS and logistics servers, and a study on efficient communication algorithms between the intelligent equipments. By doing this research, the authors would like to contribute the future of the construction industry: its logistics will become more efficient and systematic- such improvements will transform the industry from labor-intensive low-tech into more high-tech prone innovative industry.

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