A Location System with RFID Technology in Building Construction Site

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***Abstract*- In this paper, the authors explained the overview of data sampling method for development of a location system for workers using RFID technology. Data is the RSSI (Receive Signal Strength Indication) from RFID tag attached to the worker installing a rolling shutter, and was obtained from antennas and RFID readers set around the construction site. Discriminant analysis was done using RSSI collected and the area where worker is performing a task, and a estimation model of the working area was prepared. The model had a range of the percentage of correctly classified from 3% to 30%. The authors suggested the method to make estimate by using integrated models prepared in respect of RFID readers, and showed the percentage of correctly classified of 43.2%. According to the result, the authors confirmed the possibility of the location system with RFID technology, and mentioned the factors necessary to develop for further practical use.**

***Index Terms*—Location system, RFID Technology, Building construction site, Discriminant analysis model**

I. INTRODUCTION

IN recent years, because of high demand of the improvement of the work productivity in the construction, the simplification of the working process at site and the modularization of material are developing. In such atmosphere, evaluation of works have been able to only be made by supervisors' physical observation, and it is impossible to understand concurrent performance all over the construction site at once. Site management in the construction process becomes more efficient by gathering and evaluating the location data of the workers and materials obtained.

In this paper, the authors aim to confirm the suitability of RFID Technology, with analyzing workers ID and RSSI, for developing location system inside ongoing building construction site.

In this study area and RSSI data is collected from worker installing a rolling shutter, then the Discriminant analysis classified the area and examine the possibility of the system. Moreover, the authors analyzed the result and determined the factors necessary for RFID in the site management.

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II. LOCATION SYSTEM IN COSTRUCTION SITE

We can collect the worker's performance data progressively if we can monitor how and where workers are working. Also, it would be easier to make analysis for site management, such as safety, productivity and quality control.

The authors have suggested the method to measure the movement of a worker using 6DOF data and estimate the type of performance being done, and examined the effectiveness of the system[1].

A number of indoor location systems with wireless sensors have been used. Active Badge [2] is used diffuse infra-red technology to realize indoor location positioning. RADAR[3] and MoteTrack[4] are RF based systems for location and tracking users inside building, Cricket [5] and Active Bat [6] are two primary examples that uses the ultrasonic technology. SpotON[7] and LANDMARC[8] are location sensing systems using the RFID technology.

But these systems are operated under much favorable atmosphere for measurement where constant data reception is expected. On the other hand, in construction site, where full of radio wave interruption by temporary facilities such as scaffoldings, noise from electrical tools, reduction of waves by metal obstacles and other hazards exist, receiving constant and reliable data from sensors is more difficult so the examination of effectiveness is required.

Further more, for the site under the construction of walls and ceilings, the location of sensors are not fixed and moved because of working progress, unlike finished building, therefore, selecting sensors with less calibration adjustments for relocation is necessary for this system.

In this method, the authors examined the factors relating to the location systems and adopted RFID Technology.

RFID(Radio frequency identification) is a technology that involves tags that emit radio signals and devices called readers that pick up the signal[9]. The method of identification is to store a serial number that identifies a worker, on a microchip that is attached to an RFID tag. The reader converts the radio waves reflected back from the RFID tag into identification and RSSI information that can then be passed on to computers.

In this paper, the authors confirm the possibility of location system with RSSI, and develop the estimating model with discriminant analysis using actual data obtained through the rolling shutter installation.

III. EXPERIMENT FOR RFID DATA COLLECTION

A. Experiment Overview

The authors performed the RSSI data collection in order to develop the estimation model of the location system. The data was obtained from two workers installing a rolling shutter.

The RFID equipment used was composed of readers receiving signals from the tag and active tag with a battery embedded. (Table.1)

The operating frequency of the readers and tags is 315.5MHz and detection range of seven meters. The tag has power level of 500 μ V/m and signals with an interval of 0.5 second.

Readers are set at four places around the rolling shutter.(Fig.1)

At first a reader (Reader_1) is placed at the top of assemble scaffoldings located in front of the rolling shutter to monitor the movement of the worker on the scaffoldings. Then the second and third readers (Reader_2, Reader_3) are set at the level of 1,800, 2,400mm apart of each other to monitor the movement of the worker at the floor. The last reader (Reader_4)is set beside the material storage area by the scaffoldings to monitor the movement around the storage area.

Relationship of the readers and floor plan are displayed in Fig-3.

Readers directly attached to the scaffoldings are fixed with the plastic band. (Fig.2)The tag ID and RSSI data which readers obtained are sent to the data server through the wireless LAN converter.

Table.1 RFID specification

Reader	Size	152mm by 117mm by 30mm
	Weight	620g
	Frequency	315.1MHz
	Power	DC6v
Tag	Size	45mm by 38mm by 10mm
	Weight	10.3g
	Frequency	315.1MHz
	Power	CR2032

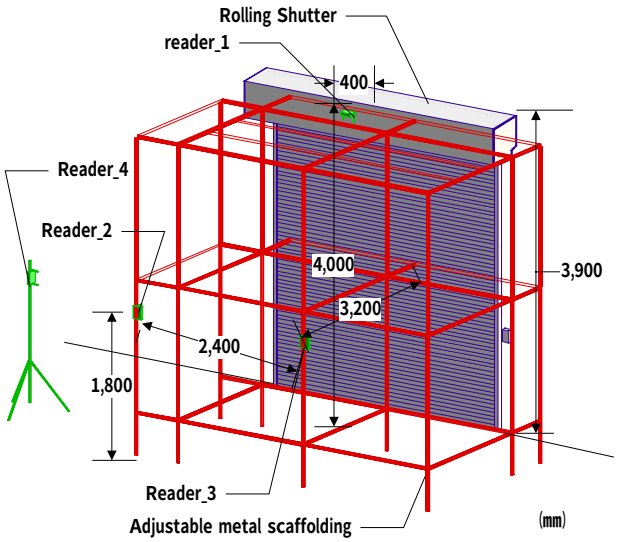

Fig.1 Location of readers

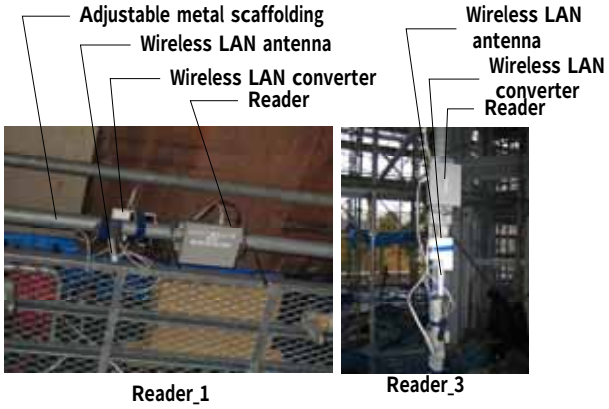

Fig.2 Pictures of readers

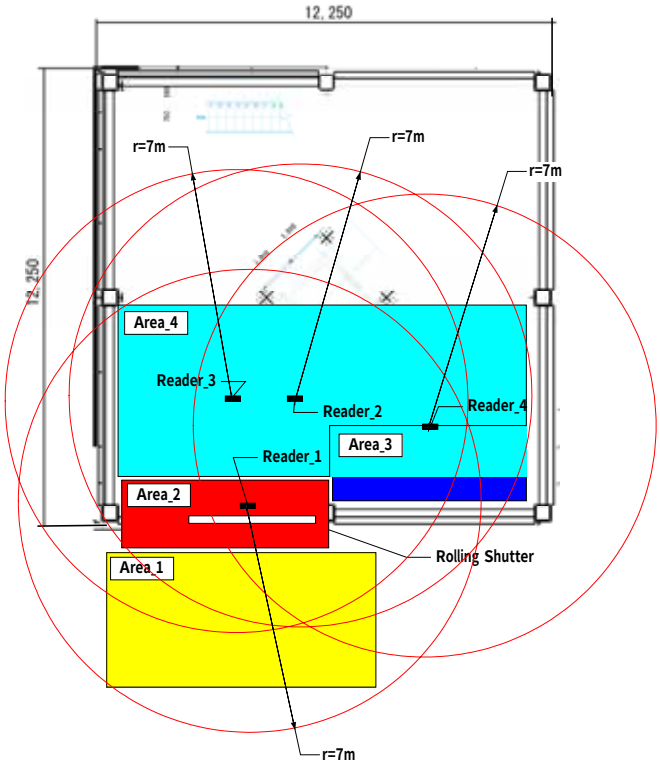

Fig.3 Detecting area of readers

B. Collecting data

Data collected for the research is working time, location of the worker, and tag RSSI data from readers.

Referring to the video tape, the site area is divided into four parts according to the task.

The classification of the area and the type of task is described below.

Area_1：Worker picks up the material from the truck and move with material. Then he cut the material with an power saw .

Area_2 ： Attaching rolling shutter parts and take measurement.

Area_3：Carrying material to the storage area .

Area_4：moving for adjusting scaffoldings, and preparing power supply.

Next the area and type of task is videotaped each second.

RSSI from tag are collected as integer values between the range of 0 and 256, with minimum value and maximum of 0 and 256, respectively. When RSSI value is 0, it shows the situation either tag is out of readers' detection range or detection is not possible even if the tag is in the range. Tag is located nearest to the reader when RSSI value is 255.

Two tags are attached to each worker. In order not to interrupt the movement of worker nor disrupt detection, tags are attached in form of safety belt. Also, the possible RSSI change occurring at the change of direction, tags are attached at the both sides of the body as in fig-4.

Fig.4 Tags attached to the worker

Fig.5 Installation works

C. Analyzing task

Installation procedure (fig.5) is divided into task breakdowns and measured time for each part, and then analysis is prepared for it.

At first, installation procedure is broken into 7 parts: Attachment, Processing, Measurement, Handling, Movement, Removal, Preparation, and amount of time required is measured for each breakdown of tasks. (Table.2) Time needed for two workers was 678.6 minutes. Attachment, removal, and measurement are mainly performed in the Area_2, and took total of 204.5 minutes (29.9%). Processing was done in the Area_1, and because the material are precut, time needed was just 21.3 minutes (3.1%). Handling and Movement are extended across the areas, and spent 192.3 minutes (28.3%)

Moreover, because it was the first day of the installation, extra 260.5 minutes was required for preparation activities, such as setting scaffoldings, calibrating tools, and pre-work meeting.

Attachment is performed in the following order: Plain-side bracket、Gear-side bracket , Drum、Gear、Guides、Slats、Bottom rail, Finish.

With worker-based breakdown, worker-A mainly performed attachment and measurement, while worker-B mainly performed processing, handling, movement, and preparation.

Table.2 Time required for each task

Work	Activity	time (min.)	total (min.)	rate (%)
Attachment	position adjustment	28.8	162.1	23.8%
	preparation for welding	2.9		
	welding	69.0		
	centering control	0.7		
	change shape	1.3		
	roll up the slats	6.0		
	bolt up	0.3		
	screw up	30.5		
	compress slat's hook	1.4		
	confirmation	2.3		
	supporting	18.7		
	roll down the slats	0.2		
Processing	surface treatment	9.8	21.3	3.1%
	cutting	11.5		
Measurement	use a carpenter' square	9.0	33.9	4.9%
	use a tape	11.0		
	use a plum	13.1		
	comparison	0.7		
Handling	materials	25.4	32.6	4.8%
	scaffolds	7.2		
Movement	walking	159.7	159.7	23.5%
Remove	hit a hammer	6.1	8.6	1.2%
	pulling	1.2		
	control	1.3		
Preparation	setting scaffoldings, calibration tolls, etc.	260.5	260.5	38.3%
total(min.)			678.6	100.0%

D. Analyzing RSSI

The authors analyzed the relationship between tasks using RSSI statistics analysis.

The average of tag RSSI was within the range of 160 to 180. (Table 3) By comparing worker-A and worker-B in the result, each tag RSSI average differs by about 10. The reason for the difference is due to the RSSI change in difference of position taken by the worker.

Then the authors analyzed the amount of time when RSSI was zero during the tasks, and checked how well tags were recognized while the work was done. (Fig.6) For tags attached to the same worker, there are about 30% difference between two tags. In addition to that, Reader_1 set above the Area_2, where attachment was performed, the reader could not recognize 18-52% of the time spent, and for readers set above 1.8m from the floor of Area 3 and Area 4 had 50-98% of the time which RSSI was zero.

From the result, adjustment for the detection range among the reader is necessary in order to avoid detection rate decrease due to the relationship among the workers and readers, and to select

the location where readers' waves spread evenly. Also, tags attached to the body should be increased and the locations must be selected to avoid them to be hidden for typical body position.

In addition to the relationship among readers and tags, use of power tools and welding machine, which may intervene operation frequency of RFID system, is the other factor effecting the detection ratio.

Table.3 Mean value for RSSI in each area.

Tag		Area_1	Area_2	Area_3	Area_4
WorkerA_ Tag_1	Mean value	171.2	161.7	158.5	165.9
	Standard deviation	12.6	15.2	17.9	17.7
	Coeffient of variation(%)	7.3%	9.4%	11.3%	10.7%
	Sample of size	14090	12577	92	165
WorkerA_ Tag_2	Mean value	169.2	167.7	174.1	162.8
	Standard deviation	19.9	16.5	14.7	19.6
	Coeffient of variation(%)	11.8%	9.9%	8.4%	12.0%
	Sample of size	1801	30595	312	398
WorkerB_ Tag_1	Mean value	179.0	174.9	179.4	171.3
	Standard deviation	27.0	17.2	16.7	19.2
	Coeffient of variation(%)	15.1%	9.8%	9.3%	11.2%
	Sample of size	4534	26253	5063	5454
WorkerB_ Tag_2	Mean value	183.8	163.8	173.8	160.5
	Standard deviation	15.6	16.3	19.4	18.3
	Coeffient of variation(%)	8.5%	10.0%	11.1%	11.4%
	Sample of size	2338	9969	2764	1435

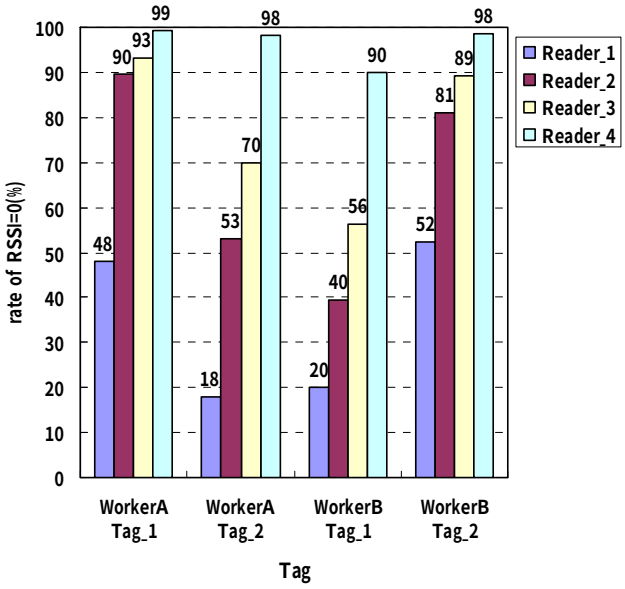

Fig.6 Rate of RSSI = 0

IV. Development and Confirmation of Discriminant Analysis Model

The authors examined the effectiveness of the classification of the area performed, using RSSI obtained from readers set at the site.

Areas 1 to 4, categorized by the tasks, are set as groups to distinguish the area. Then the RSSI data from readers are taken as input data and discrimination function was calculated by the discriminant analysis.

The authors used the maximum value of RSSI of the two tags attached to the worker as input data, and eliminated value of zero for RSSI as irregular value.

Then the randomly adopted 70% of the all data obtained from readers (29,264 / 41,808) was used for the model.

Discrimination functions calculated from RSSI from Reader_1 were the following (1) to (4). Table 4 displays the result for the classification by area, using the model developed from the the functions. Overall classification result excluding when RSSI is zero was 27.2%, and 22.7% when included. (Table.4)

For Area_1, the classification result was just for 0.6%, and 27.9% was classified as Area_3, whose detection area overlaps that of Area_1. In addition to that, the radio waves are often interrupted by the walls as obstacles, 53.4% of RSSI values is zero, determined as detection was incomplete.

Classification result for the Area 2 was 23.5%, while Area_3 and Area_4 were higher than 46%, approximately twice the result of Area_2. Area_4 has more tasks which are performed around the border of Area_2 so that 40.4% of the result was classified as in Area_4.

$$Y_{Area\_1} = 0.658 \times x_{Rssi\_1} - 58.980 \qquad (1)$$

$$Y_{Area\_2} = 0.606 \times x_{Rssi\_1} - 50.212 \qquad (2)$$

$$Y_{Area\_3} = 0.652 \times x_{Rssi\_1} - 57.867 \qquad (3)$$

$$Y_{Area\_4} = 0.599 \times x_{Rssi\_1} - 49.056 \qquad (4)$$

Table.4 Classification Results on the Reader_1 model

Area		Original Membership				Total
		Area_1	Area_2	Area_3	Area_4	
Predicted Group Membership	Area_1	29	425	22	45	521
		0.6%	2.0%	1.1%	3.3%	1.8%
	Area_2	95	5029	58	228	5410
		2.1%	23.5%	3.0%	16.7%	18.5%
	Area_3	1274	5543	901	404	8122
		27.9%	25.9%	46.0%	29.6%	27.8%
	Area_4	731	8637	324	672	10364
		16.0%	40.4%	16.6%	49.2%	35.4%
	Outside of Area	2437	1742	652	16	4847
		53.4%	8.1%	33.3%	1.2%	16.6%
Total		4566	21376	1957	1365	29264
		100.0%	100.0%	100.0%	100.0%	100.0%

Percentage of correctly classified: 22.7%

Classification functions 5 to 8 were derived from the date of Reader 2, and result was 31.1%. (Table 5)

$$Y_{Area\_1} = 0.730 \times x_{Rssi\_2} - 59.485 \qquad (5)$$

$$Y_{Area\_2} = 0.848 \times x_{Rssi\_2} - 79.711 \qquad (6)$$

$$Y_{Area\_3} = 0.808 \times x_{Rssi\_2} - 72.453 \qquad (7)$$

$$Y_{Area\_4} = 0.768 \times x_{Rssi\_2} - 65.649 \qquad (8)$$

Table.5 Classification Results on the Reader_2 model

Area		Original Membership				Total
		Area_1	Area_2	Area_3	Area_4	
Predicted Group Membership	Area_1	546	539	303	477	1865
		12.0%	2.5%	15.2%	34.7%	6.4%
	Area_2	225	7945	726	285	9181
		4.9%	37.2%	36.4%	20.8%	31.4%
	Area_3	46	2587	380	288	3301
		1.0%	12.1%	19.0%	21.0%	11.3%
	Area_4	443	1402	275	229	2349
		9.7%	6.6%	13.8%	16.7%	8.0%
	Outside of Area	3298	8864	312	94	12568
		72.4%	41.5%	15.6%	6.8%	42.9%
Total		4558	21337	1996	1373	29264
		100.0%	100.0%	100.0%	100.0%	100.0%

Percentage of correctly classified: 31.1%

Classification functions 9 to 12 were derived from the date of Reader 3, and result was 13.8%. (Table 6)

$$Y_{Area\_1} = 0.751 \times x_{Rssi\_3} - 69.184 \qquad (9)$$

$$Y_{Area\_2} = 0.822 \times x_{Rssi\_3} - 82.675 \qquad (10)$$

$$Y_{Area\_3} = 0.810 \times x_{Rssi\_3} - 80.242 \qquad (11)$$

$$Y_{Area\_4} = 0.734 \times x_{Rssi\_3} - 66.148 \qquad (12)$$

Table.6 Classification Results on the Reader_3 model

Area		Original Membership				Total
		Area_1	Area_2	Area_3	Area_4	
Predicted Group Membership	Area_1	558	529	45	345	1477
		11.9%	2.5%	2.3%	25.5%	5.0%
	Area_2	38	2609	102	206	2955
		0.8%	12.3%	5.1%	15.2%	10.1%
	Area_3	108	3644	298	113	4163
		2.3%	17.2%	15.0%	8.3%	14.2%
	Area_4	453	2381	109	566	3509
		9.7%	11.2%	5.5%	41.8%	12.0%
	Outside of Area	3537	12060	1438	125	17160
		75.4%	56.8%	72.2%	9.2%	58.6%
Total		4694	21223	1992	1355	29264
		100.0%	100.0%	100.0%	100.0%	100.0%

Percentage of correctly classified: 13.8%

Classification functions 13 to 16 were derived from the date of Reader 4, and result was 3.7%. (Table 7)

$$Y_{Area\_1} = 0.650 \times x_{Rssi\_4} - 55.311 \qquad (13)$$

$$Y_{Area\_2} = 0.652 \times x_{Rssi\_4} - 55.703 \qquad (14)$$

$$Y_{Area\_3} = 0.657 \times x_{Rssi\_4} - 56.545 \qquad (15)$$

$$Y_{Area\_4} = 0.746 \times x_{Rssi\_4} - 72.420 \qquad (16)$$

Table.7 Classification Results on the Reader_4 model

Area		Original Membership				Total
		Area_1	Area_2	Area_3	Area_4	
Predicted Group Membership	Area_1	0	0	0	0	0
		0.0%	0.0%	0.0%	0.0%	0.0%
	Area_2	151	395	160	82	788
		3.2%	1.9%	7.9%	6.2%	2.7%
	Area_3	5	179	668	32	884
		0.1%	0.8%	33.1%	2.4%	3.0%
	Area_4	4	14	26	9	53
		0.1%	0.1%	1.3%	0.7%	0.2%
	Outside of Area	4568	20612	1164	1195	27539
		96.6%	97.2%	57.7%	90.7%	94.1%
Total		4728	21200	2018	1318	29264
		100.0%	100.0%	100.0%	100.0%	100.0%

Percentage of correctly classified: 3.7%

Examination of the model effectiveness using 30% of test data was performed. Comparison between the data was made and the difference of the result was within 2%, confirming the effectiveness of the model. (Fig 7)

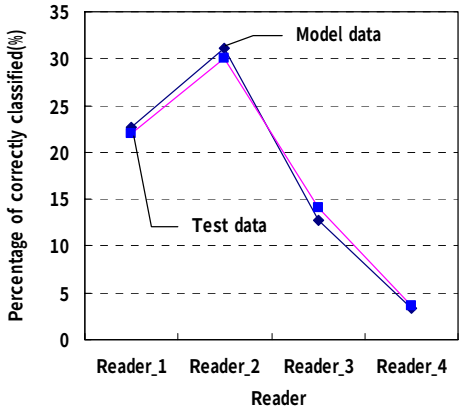

fig.7 Comparison of the classification result between the model data and test data

Classification of areas using each reader resulted less than 30%, and then result for four readers combined were obtained.

The authors considered the effect of more than 80% of undetectable values in the data to the classification function, and suggested the method using Mahalanobis Generalized Distance (MGD), calculated with mean value and valiance of RSSI obtained from each reader, to classify the area.

The method of classification takes following steps. First, the number of RSSI data (n) from readers are sorted to each area (m), and calculate the mean (17) and valiance (18). Then MGD (19) is calculated using the mean and valiance derived. At the same time MGD of each area are compared, and minimum value of MGD (20) is selected. At last minimum MGD of each readers are also compared to identify the least value among them (21), which determines the area which the worker is performing his task.

$$\bar{x}_j = \frac{1}{n}\sum_{i=1}^{n} x_{ij} \qquad (17)$$

$$s_j^{\,2} = \frac{1}{n-1}\sum_{i=1}^{n}\left(x_{ij} - \bar{x}_j\right)^2 \qquad (18)$$

$$D_j^i = \frac{\left|x_{ij} - \bar{x}_j\right|}{\sqrt{s_j^{\,2}}} \qquad (19)$$

$$T_j^i = \min\left(D_1^i, D_2^i, \cdots, D_{m-1}^i, D_m^i\right) \qquad (20)$$

$$S_j^i = \min\left(T_1^i, T_2^i, \cdots, T_{m-1}^i, T_m^i\right) \qquad (21)$$

Table.8 Mean and variance of RSSI

Reader	Area	Mean	variance
Reader_1	Area_1	$\bar{x}_1 = 174.98$	$s_1^2 = 16.40$
	Area_2	$\bar{x}_2 = 161.11$	$s_2^2 = 18.23$
	Area_3	$\bar{x}_3 = 173.28$	$s_3^2 = 13.11$
	Area_4	$\bar{x}_4 = 159.19$	$s_4^2 = 14.41$
Reader_2	Area_1	$\bar{x}_5 = 159.09$	$s_5^2 = 12.95$
	Area_2	$\bar{x}_6 = 184.72$	$s_6^2 = 25.79$
	Area_3	$\bar{x}_7 = 175.95$	$s_7^2 = 15.55$
	Area_4	$\bar{x}_8 = 167.32$	$s_8^2 = 15.35$
Reader_3	Area_1	$\bar{x}_9 = 180.59$	$s_9^2 = 15.47$
	Area_2	$\bar{x}_{10} = 197.74$	$s_{10}^2 = 16.98$
	Area_3	$\bar{x}_{11} = 194.76$	$s_{11}^2 = 12.43$
	Area_4	$\bar{x}_{12} = 176.50$	$s_{12}^2 = 18.75$
Reader_4	Area_1	$\bar{x}_{13} = 165.95$	$s_{13}^2 = 17.82$
	Area_2	$\bar{x}_{14} = 166.55$	$s_{14}^2 = 9.58$
	Area_3	$\bar{x}_{15} = 167.84$	$s_{15}^2 = 15.48$
	Area_4	$\bar{x}_{16} = 190.46$	$s_{16}^2 = 15.67$

The authors calculated the mean and valiance of RSSI with collected data, and then determined the area that the worker is in, using the MGD, the classification result was 43.2%. (Table. 9)

In result, adjustment among four readers are made, so that the classification result was more than 10% better than the result obtained from single reader, however, still the result suggesting neighboring area is more than 10 % as well. Because of the result, interpolation of readers must be considered to select the location.

Table.9 Classification Results using MGD data

Area		Origina Membership				Total
		Area_1	Area_2	Area_3	Area_4	
Predicted Group Membership	Area_1	352	1648	242	237	2479
		5.3%	5.4%	8.5%	12.4%	5.9%
	Area_2	289	15121	451	328	16189
		4.3%	49.8%	15.9%	17.1%	38.7%
	Area_3	1568	6881	1582	358	10389
		23.5%	22.6%	55.7%	18.7%	24.8%
	Area_4	1431	4930	392	990	7743
		21.5%	16.2%	13.8%	51.7%	18.5%
	Outside of Area	3029	1803	174	2	5008
		45.4%	5.9%	6.1%	0.1%	12.0%
Total		6669	30383	2841	1915	41808
		100.0%	100.0%	100.0%	100.0%	100.0%

Percentage of correctly classified: 43.2%

IV. CONCLUSION

The authors examined the effectiveness of the RFID Technology for determining the location of workers in the construction site. In the paper, the authors performed the experiment in the rolling shutter installation, classification result of 3% to 30% was obtained from collecting and analyzing RSSI and areas data, and 43.2% by using four RFID readers' data altogether.

After the research, the authors found that decrease in detection rate due to site atmosphere, change of RSSI from worker at the same location but different body posture, difficulties in classifying area for readers' overlapping detection area may result lower rate of classification.

In order to apply RFID Technology into the location system in the construction site management, improvement on detection rate, development of noise reduction process for obstacles, and using multiple readers to divide data recording function are necessary.

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