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Indoor Robot Localisation with Active RFID

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ABSTRACT

Radio Frequency Identification (RFID) is a technology of location determination and data capture. An RFID based system relies on the interaction between readers (also known as interrogator) and tags (transponders). Active RFID technology is suitable for tracking costly assets or moving objects such as mobile robots. Once affixed with RFID tags, a robot can be localised. However, there is a tendency for accuracy to vary greatly as well as delay in readings. Those problems may be enlarged in real time applications. This paper provides an overview of implementing RFID in precision tracking of mobile robots. We tested a mobile robot in a variety of situations in order to ascertain the effeciveness and accuracy of an RFID indoor tracking solution. We found that the system plots the robot accurately as expected in some cases. However, we also found that the average accuracy is quite low and the best area for deploying tags is limited.

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1. INTRODUCTION

RFID technology is commonly used in many sectors in recent years. A typical RFID system consists of a number of readers and tags. Stored with unique information or description of one object, a tag is allowed to be embedded in almost everything, varying from a car key to a living animal. Tags transmit data to nearby readers via radio waves actively or passively activated by the readers, which gather and deal with the information accordingly. RFID technology has a wide range of overwhelming superiority. RFID technology is good at document authentication, access control, people or livestock monitoring, environment detection, industrial automation, supply chain integration [1]. Moreover, it offers better solution for monitoring moving objects such as people or living animals as well as mobile robots. In fact, RFID system deployment has soared in almost all domains over the last decade [2]. For instance, the advent of modern RFID technology makes automotive manufacturing systems been more simply traceable and manageable (e.g., mixed-product assembly line). Active RFID technology is suitable for tracking costly assets or moving objects, mobile robots for example. Once affixed with RFID tags, a robot can be localised. Moreover, the robot is able to automatically read the instruments (tag code) and its state can be estimated.

RFID systems can provide reliable traceability to moving items or objects. Outdoors of course we know that the Global Positioning System (GPS) can locate objects equipped with GPS receivers to <2m. GPS however does not work well indoors. In contrast, a real-time indoor localisation systems (RTLS) offers a solution for indoor tracking. Another popular outdoor approach is to use Mobile Cellular Systems (MCS) technology, via mobile phones/devices to estimate the location through comparing the time signal consumes for arrival and the relative signal force from other towers in the immediate vicinity. According to characteristics of this approach, the precision which is within about 50m x 50m is not usable for indoor determination activity [3]. In addition, the main advantage of RFID compared with the MCS is that a large amount of transponders can be deployed and read in a RFID network. Therefore, RFID technology is believed to be an appropriate approach for indoor tracking of people or assets.

However, there are limitations for RFID technology. For instance, the read rate accuracy of RFID is affected by tag collisions or reader collisions or these two conditions happen simultaneously. It is widely known that accuracy is a high priority in real-time location systems (RTLS) [4]. Though some existing protocols and anti-collision algorithms offer the possibility of avoiding collision, the problem is triggered if unique identification (UID) is given to each of the RFID tag [5]. There are alternatives such as Virtual Route Tracking (VRT) which can be used for tracking moving objects and people. However, that approach requires fixed RFID reader, which is less practical in real applications [6]. Therefore, inaccuracy and too much delay are intolerable for applications that require exact data input and real-time position. The overall goal of the project is to explore the use of RFID radar in real-time localisation of mobile robots indoors.

2. INDOOR LOCATION DETERMINATION FOR ROBOTS

The ability to know the real time location of a robot itself is the pre-condition for other tasks that are commanded such as navigation [7]. Not every localisation problem has the same difficulty. Problems are characterized by different factors. The main factor is the type of knowledge that is given at the beginning and during the operating procedure [8]. The initial robot pose is supposed to be known in *position tracking*, and approaches for it are always connected with presumption of small error exists. This type of problem is a local problem because of the locality of uncertainty. In contrast, the initial robot pose is unknown in *global localisation*. The robot has little or no information concerning its primary environment. Position tracking is included in global localisation. The global localisation problem has a variant, *kidnapped robot problem*. It is more difficult than the former. The kidnapped robot is a place recognition problem triggered when robots are in an unknown environment [9]. Static environments are environments where the only variable quantity (state) is the robot's pose. In other words, except for the position of mobile robot, all objects keep fixed in such an environment. Location estimation can be effective.

Single-robot localisation deals with only one robot. It is the most widely applied method to robot localisation. All data is gathered together in a single robot platform and interaction event is not required. It is more of convenience than multi-robot localisation [8]. A multi-robot localisation problem can be tackled by localising each robot independently. However, there is an opportunity to obtain better results if robots have the ability to detect each other. Once a robot identifies the relative position of another one, internal beliefs of both of them can be refined based on the estimation of the other one. As a result, both of the robots harvest improvement of precision. This approach is especially attractive for global localisation so as to diminish the uncertainty [9]. Those dimensions represent the four most essential traits of the robot localisation problem. Also there are many representatives that have the effect on the hardness of the problem such as data lost during motion.

Monte Carlo Localization (MCL) is one of the most widely used algorithms in robot localization [7]. MCL has been utilized to target-tracking, statistical and computer vision literature as well as dynamic probabilistic networks. MCL identify robots' belief based on fast sampling technology. Importance re-sampling is used to estimate the distribution behind when robots move or sense. Another scheme belonged to the adaptive sampling is applied to balance the computation and precision. Consequently, in case of global localisation MCL uses many samples, while the number of sample reduces if the position of robot is nearly recognized. The advantages of MCL compared with previous techniques, such as Kalman filter-based techniques, Topological Markov localization, Grid-based Markov localization [10] is that MCL is able to express multi-modal distributions and as a result, robots can be localized globally. In addition, memory requirements are low, there is higher accuracy as the condition is continuous and implementation is relatively simple. However, MCL has some constraints. It may get stuck in an indoor environment as well as the kidnapped robot problem. Simultaneously Localization and Mapping (SLAM) is widely used for creating a map and localizing itself using the map. A variety of methods are available for this goal such as RFID technology. It performs well in a high-dimensional estimation problems [11].

3. RFID ROBOT LOCALIZATION SETUP

The Intelligent Systems Research Centre at the University of Ulster has a superbly equipped robotics lab with powered floor, Vicon tracking system, computer subnet of 8 PC's. It also has a PR2 (Personal Robot 2), a robust and one of the worlds most advanced robotic platforms from willow garage; a shadow hand (one of the worlds most advanced robotic hands with 21DoF), mounted on one of our SCHUNK arms and Scitos Bases; 4 Scitos G5 Mobile robot bases (one with a head and vision system, two with 7DOF SCHUNK arms mounted and one standard); 2 SCHUNK 7DOF manipulator arms; 10 Pioneer

Mobile Robots with camera, microphone and sick laser and a state of the art cluster and GPU processing units. The pioneer robots were used in the location tests. The indoor environment consisted of two regions. One was the User Interest Region (UIR) and the other was the obstacle region (robotic lab). The RFID reader developed by Trolley Scan is shown in Figure 2. It serves as a bridge connecting the laptop and the tags (see Figure 1). The mobile robots were driven by lab staff. A variety of active tags were used. Their power grades varied as well.

Figure 1. Stick tag & card sized transponders

Figure 2. Front panel of RFID-radar

The experimental position was located in the laboratory inside the MS building. The internal environment is shown in Figure 3. The experimental region was 3x10 meters. The devices are a desktop, an RFID-radar, some RFID active tags and a number of pioneer robots. The movement of tags are displayed in the application. Once running, the RFID-radar can track all the tags simultaneously. While the robot, controlled by a person, moves within the experimental region, we recorded location positions for each robot.

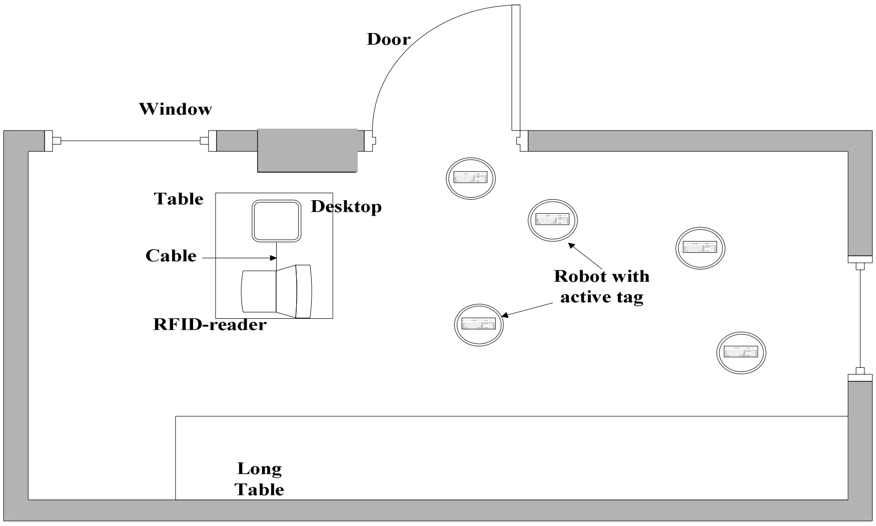
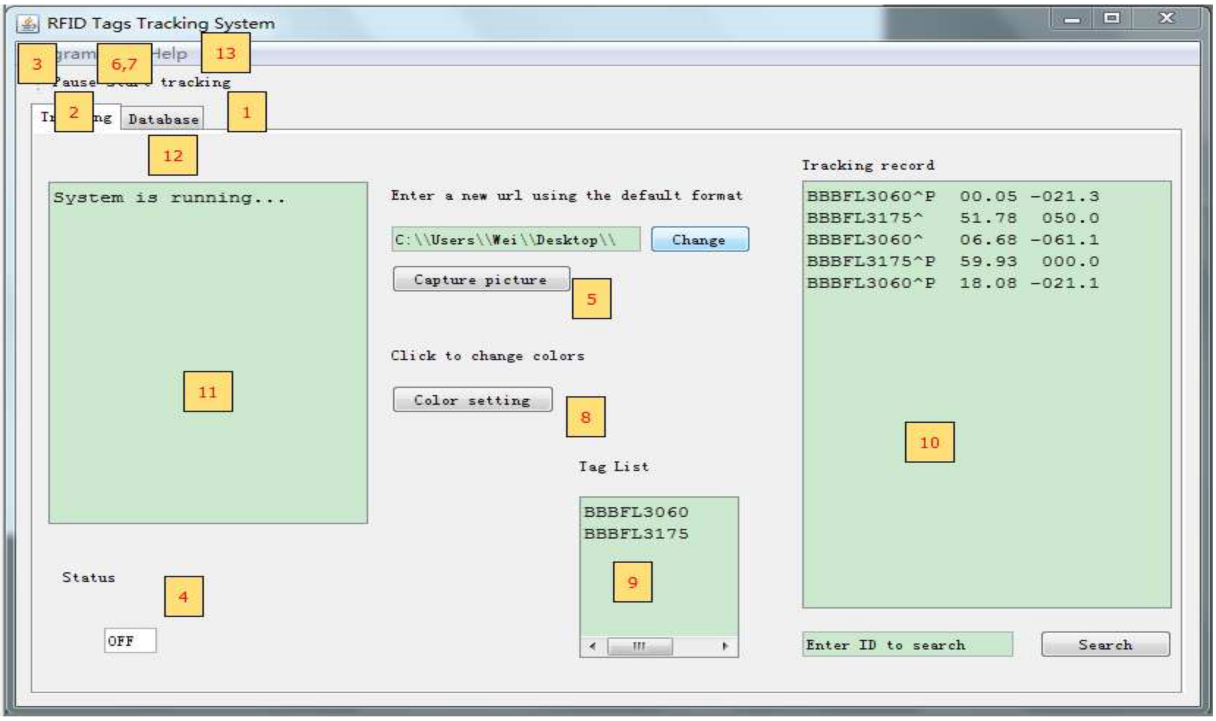


Figure 3. Physical deployment overview

Tags were attached to robots at different heights. The speed with which the robot is moving can affect tag readability because a tag requires certain time to energise itself or emit its signal before any movement. The position a tag is in relative to the reader antenna depends on whether or not this tag can be read accurately. Antenna type and orientation are two elements that result in tag orientation. For example, with a linear polarized antenna, the tag has to be oriented to the antenna so that it can properly align itself with the electromagnetic field of the antenna.



```
System is running...
```

C:\\Users\\Wei\\Desktop\\

```
BBBFL3060^P  00.05 -021.3
BBBFL3175^   51.78  050.0
BBBFL3060^   06.68 -061.1
BBBFL3175^P  59.93  000.0
BBBFL3060^P  18.08 -021.1
```

```
BBBFL3060
BBBFL3175
```

Figure 4. Initial interface (Tracking sub-system and other sub-system)

The main interface (

Figure 4) can also switch to the database sub-system window (Figure 6). The window will not be closed by clicking the “close” button in the Northeast part of the frame. The only way to close the main window is to select the “file” option on the menu, followed by clicking “Exit Application” option. In order to ensure the size of each component consisting this window and relative position, this main window is not allowed to change the size after its initialization. However, this interface is able to move anywhere if necessary. After clicking the “Program” menu button on the top-left side of the initial window, the popup menu appears as illustrated in

Figure 5, including three functions: starting the program, pause the system and exiting the program. While in the “File” menu, the importing or exporting file function occurs when the “Import records” or the “Export records” menu item is pressed.

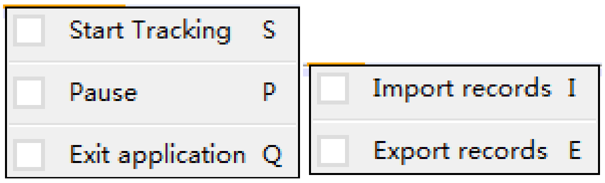
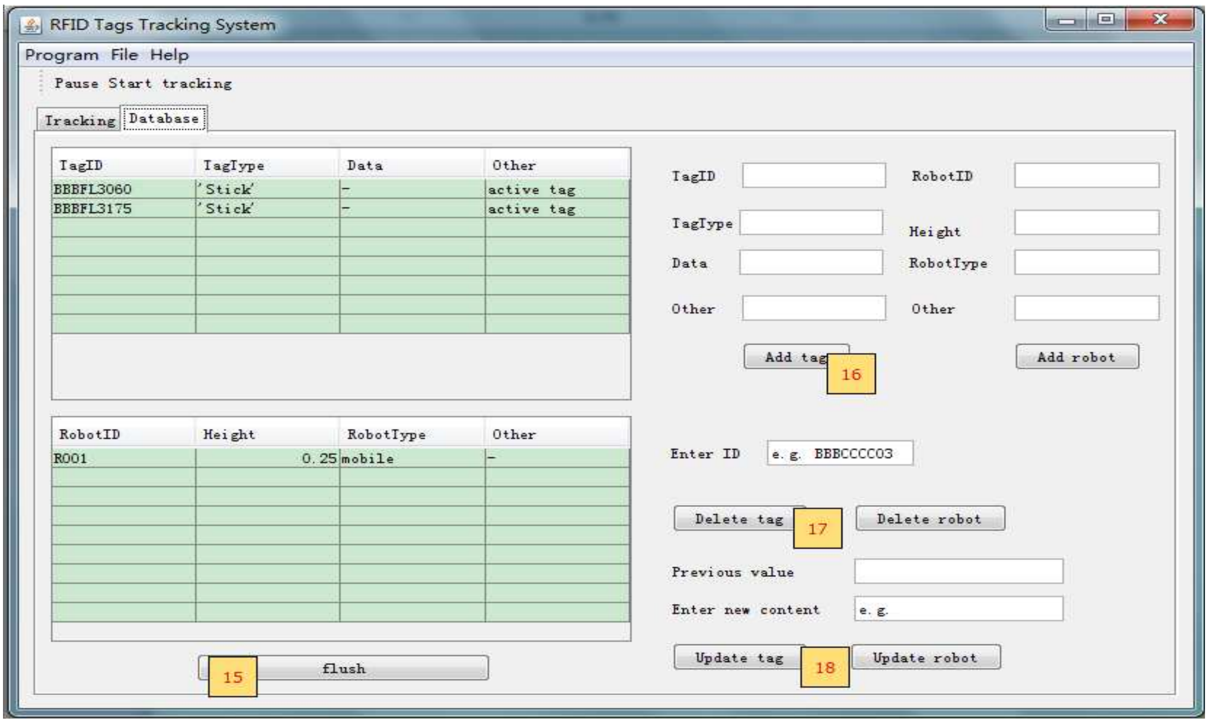


Figure 5. Program menu items

Figure 7 shows a file which stores a tag’s identifier as well as distance and angle value. As shown, there are some strings for tags’ identification and regarding distance and angle. “ON” command is the starting tag of the system. More explanation of each line of command that involves in this system will be specifically introduced afterwards. Once the switch is on, a transponder automatically emits signal which is received by reader inside of the RFID radar. Through the special port written in Java, the reader transmits received identification of tag to the main application in the form of string, as well as other tag information such as the angle, distance. Given the id number of a tag, the main system then is able to require more details about the monitored tag from database. MySQL was used to support database operations.



TagID	TagType	Data	Other
BBBFL3060	'Stick'	–	active tag
BBBFL3175	'Stick'	–	active tag

RobotID	Height	RobotType	Other
R001	0. 25	mobile	–

Enter ID: e. g. BBBCCCC03

Enter new content: e. g.

Figure 6. Database management sub-system

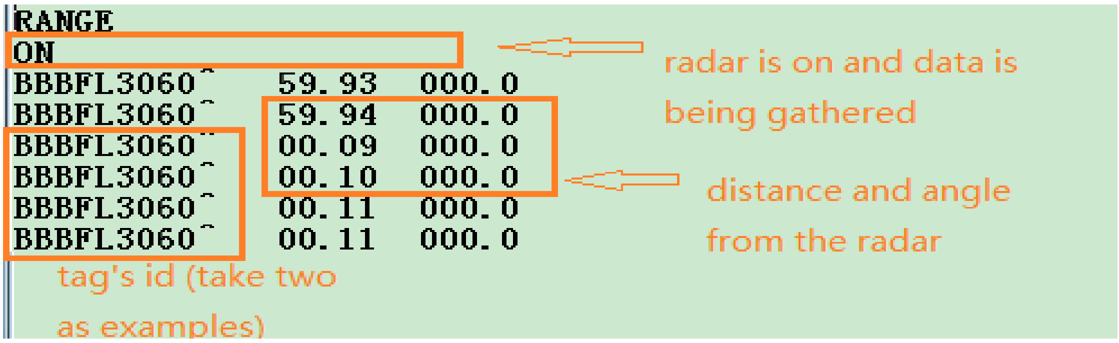

```
RANGE
ON
BBBFL3060^    59.93   000.0
BBBFL3060^    59.94   000.0
BBBFL3060^    00.09   000.0
BBBFL3060^    00.10   000.0
BBBFL3060^    00.11   000.0
BBBFL3060^    00.11   000.0
```

Figure 7. Data on record.txt file

5. EVALUATION

In order to calibrate system and determine real world accuracies, we conducted prior to the active mapping tests, a series of static tag detection experiments. A tag was placed (id number BBBFL3060) in front of the radar, about 3 meters away with a little angle. The machine was switched on and printed out the tag's id number, the distance and angle of the tag. The number in distance column kept staying at approximately 3.32 while the angle was just above 0.10°.

Figure 8 illustrates the image result of BBBFL3060 tag after dealing with 60 lines of the message read from the RFID radar. Though there are only few points on the map, actually many points are in the same place and are covered by the final points. The errors on the map are obvious as they are a small distance to the north of the real location. Sometimes if the distance of a tag from the radar is just larger than 2 meters, the amount of space reported fluctuates between 23 m to 25 m which is incorrect (see

Figure 9). Tags ideally should keep a distance from the radar, which is better if it is greater than 2 meters; otherwise the relevant tags' identification can deviate from true position.

After the analysis of the experimental data, the success percentage has been counted as shown in Formula A:

$$\text{Success percentage} = \frac{\text{successful experiment count}}{\text{Total experiment count}} \qquad \text{(Formula A)}$$

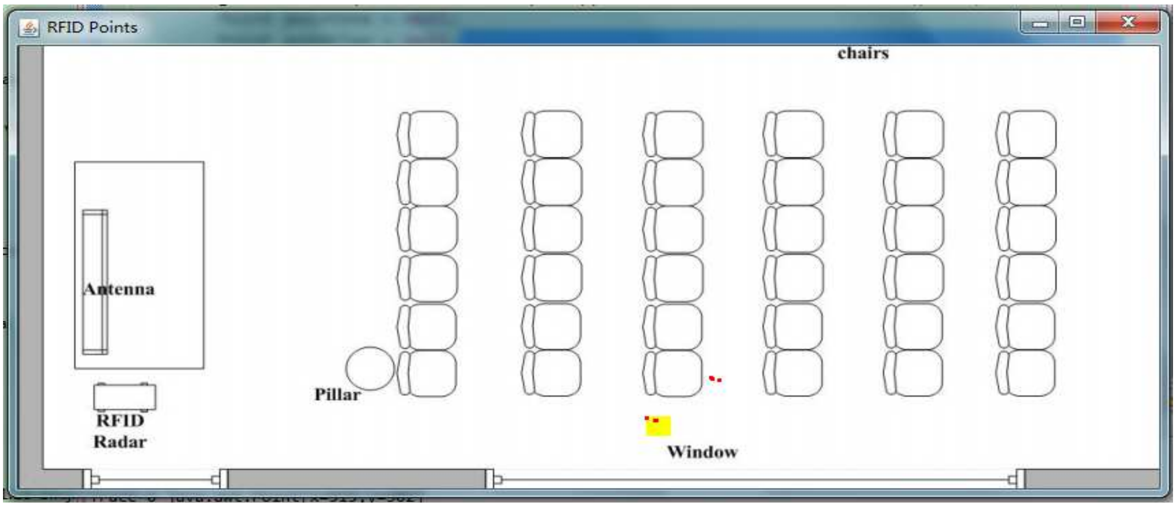
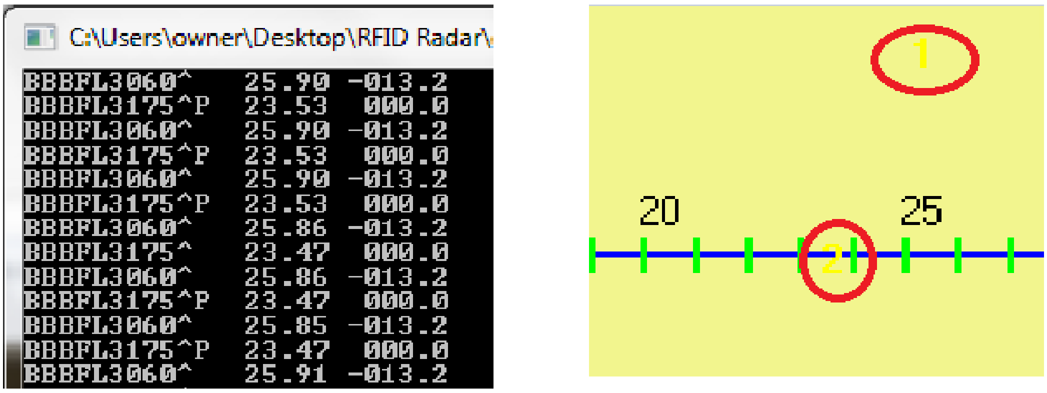


Figure 8. Results on application map (60 lines from radar)
(Note: Red points: experimental result; Yellow area: real tag's position)



```
BBBFL3060^    25.90 -013.2
BBBFL3175^P   23.53  000.0
BBBFL3060^    25.90 -013.2
BBBFL3175^P   23.53  000.0
BBBFL3060^    25.90 -013.2
BBBFL3175^P   23.53  000.0
BBBFL3060^    25.86 -013.2
BBBFL3175^    23.47  000.0
BBBFL3060^    25.86 -013.2
BBBFL3175^P   23.47  000.0
BBBFL3060^    25.85 -013.2
BBBFL3175^P   23.47  000.0
BBBFL3060^    25.91 -013.2
```

Figure 9. Inaccuracy example

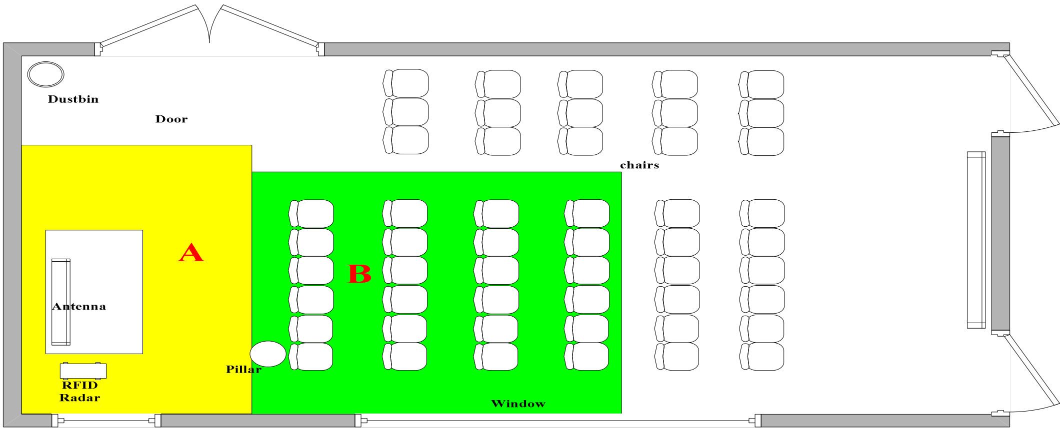


Figure 10. Accuracy rate map

Where the total experiment count is estimated by just simply pressing the start button on the radar, and the successful experiment count can be calculated based on the number of testing with an expected result, no

matter how long it was. In general, the start button is frequently pressed, about 2 to 3 times per minute, if a tag is near the radar (the area A in yellow, see
Figure 10), however this condition always results in unexpected data output from the machine as the distance is too small to compute.

In contrast, if a tag is located in the green area in
Figure 10 it will be recognized slower than that in the area A so that the observation lasts longer, with a higher accuracy ratio. Thus the system runs 2 minutes a time in average if a tag is placed in this area while the percentage of successful times is larger. Overall the success percentage in the area A can be as low as 1/10 to 1/15 or even 0 when in extreme situations, depending on the distance of a tag from the radar. This figure in the area B stables at 1/4 to 1/6. However, the success percentage seems quite unreliable as this value partly relies on the recall of number; therefore it is not precise enough. Consequently the concept of valuable time ratio is introduced to deal with the accuracy issue.

$$\text{Valuable time ratio} = \frac{\text{real time spent in expected output}}{\text{total time spent}} \qquad \text{(Formula B)}$$

This is a simple formula with only two parameters; the term real time spent in expected output here means the sum of the period of each successful testing while the total time spent represents the time the author spent in the laboratory, generally 2 hours or more at one time. This formula can be used to compute and evaluate the figure or success ratio that each area produces. The value in the area B is approximately five times as many as that in area A, 0.8/6 (hours) and less 0.1/4 (hours) respectively. The figure from the other area group is medium which is about 0.04 (0.4/10 hours). The reason is other area inside the laboratory has a longer distance from the radar, which takes more time to wait for the establishment of interaction. The conclusions of the average accuracy of tag are given in Table 1 after comprehensively consideration of the values of formula A and B. The approach is to take the weighted average number of them with the weight ratio 4:1.

Average accuracy (area A) = (1/12.5 * 4 + 0.1/4) / (4+1) = 0.069
Average accuracy (area B) = (1/5 * 4 + 0.8/6) / (4+1) = 0.177
Average accuracy (other area) = (1/7 * 4 + 0.4/10) / (4+1) = 0.122

Table 1.Analysis of accuracy ratio map

Area name	Being recognized	Error occurrence	Average accuracy
Area A (Yellow)	Very easy	high	0.069
Area B (Green)	Medium	Low	0.177
Other Area (no colour)	Different	Medium	0.122

In addition, the working distance of the radar is able to cover every corner of the room. The greatest linear distance is estimated around 8 meters. The ability of being recognized decreases as the distance becomes smaller. But since no work has been done outdoor, any prediction or guess about how far the radar can work is unreliable, but which can be part of the future work. To summarize, area B is the best location for tracking tags not only because of its suitable distance for the radar, but also attributes to a lower error rate and the highest average accuracy. The way to place a tag is also important. It would be better to let a tag stand in vertical direction to ensure the achievement of the greatest interaction area.

Next we tested the performance of the application in terms of instant response and the quality of tag motion observation when the tag is moving. Figure 11 shows the comparison between positions of a tag after handling the data from the radar and the real motion trace of the robot with the attached tag. The location of the tag kept updating while the robot was moving. However, the result was that only in some areas the tag could be recognized. The reason is that once the tag is required to change the location using “RANGE” command, a delay occurs lasting for about 45 seconds. After this delay, the robot may arrive in a different place. Through many times’ test, the fact can be concluded that the RFID radar cannot track a continuously moving object. In order to get a trace like the real one, the moving item must move slowly. Figure 12 shows the environment of the laboratory and the initial position of the robot with *MobileEYEs* software.

In conclusion, the system can simultaneously track the locations of tags. However, due to the limitations of the radar itself, it cannot make instant response to the movement of any tag. The application can be indoors.in any location. Only one change needs be made is to update a proper background picture which reflects the physical environment of a specific area with the maximum range at 50 meters. We are currently working on the creation of a higher quality map. The monitored area on the map should therefore be distinguished using two boundaries and other areas should be marked in a different colour.

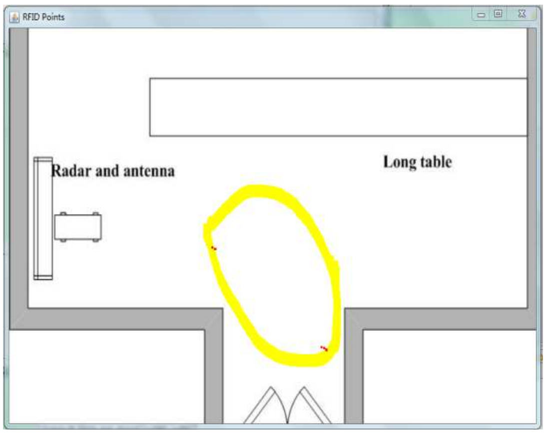


Figure 11: Moving tag (robot move 4 cycles) Red points: gathered data; Yellow cycle: robot's real trace

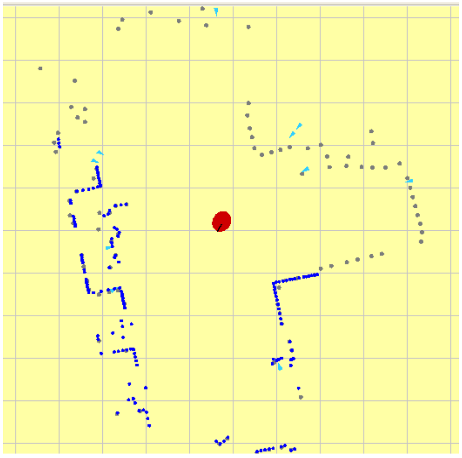


Figure 12: 'MobileEYEs' screen (Red point represents robot, blue and grey points show the profile of the lab)

6. CONCLUSION

The aim of this research was to test the use of RFID in tracking robots. The system plots the robot accurately as expected in most cases. However, it is also noticeable that the average accuracy is quite low and the best area for deploying tags is quite small. Moreover, the shortage of tracking moving tags in real time is due to the inherent disadvantage of the radar as the delay encounters in the initial period of each testing and the moment when trying to update the positions of robots after sending the "RANGE" command. In addition, a minor angle error slightly affects the location in a small-scale area, but once in a vast indoor area or in an open area, even a tiny angle mistake can lead to a huge difference. Moreover when the machines are used in an outdoor environment, irregular strong wind, flying birds or other geographic barriers would reduce tag's locating precision. This finding also proved by the fact that frequent movement of people between tags and radar significantly influences positioning performance in terms of both distance and angle statistics. It is however suitable for use in small open environments where there is not too much interference from moving objects such as in a meadow for livestock monitoring, in a large car park for property security purposes or in a manufacturing industry for supply chain management.

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