# Mobile Robot Localization by RFID Method

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*Abstract*—**This paper explores the merits of the indoor positioning system using Radio-frequency identification (RFID) technology for mobile robots. The indoor positioning function by the Received Signal Strength Indicator (RSSI) and the Link Quality Indicator (LQI) method is developed first to determine the location of the robot. The RSSI and the LQI based indoor positioning system employs wireless signal intensities to build the intensity distribution map and compares the signal intensity of the transmitters obtained by the receivers to determine the location of the robot. In the end, the implementation is to use a predetermined indoor environment, which is set up beforehand to validate the RFID based indoor positioning system developed by a mobile robot. Validation results show that the precision of the positioning system in one-dimensional is 10 cm and the average accuracy rate is 97.23%. The precision of the positioning system in two-dimensional is 10cm x 10cm and the average accuracy rate is 79.73%. Finally, the average error of the robot tracking in two-dimensional is 14.16cm.**

*Keywords-RFID technology; RSSI; LQI; indoor positioning; mobile robot*

## I. INTRODUCTION

Currently, various kinds of robots are used to make work efficiently and avoid the dangerous situations for human beings. In order to make the robot perform the designated activities like human beings in an unknown environment, the robot must be able to perceive its own locations. By being able to perceive its position in the environment, the robot can then move autonomously to achieve its tasks.

For the purpose of knowing the location of the robot, different methods have been developed, including multiple sensors for obstacle detection in the environment such as infrared sensor [1]-[5], ultrasonic sensor [6]-[7], image methods [8]-[14], lasers [15]-[17], color belt method [13], landmark [18]-[22] and RFID [20]-[31], etc. The RFID tag includes a small RF transmitter and receiver. An RFID reader transmits an encoded radio signal to interrogate the tag. The tag receives the message and responds with its identification information. This study adopts the RFID method for robot localization for its simplicity and wireless features.

In this paper, Section I introduces the structure of the paper. Section II introduces the information about the RFID system. Section III and Section IV introduce the basic principles of positioning and the positioning techniques. Section V introduces the system design and the implementation. In the end, Section VI shows the results and the discussion and Section VII is to sum up the paper.

## II. RFID SYSTEM

RFID is a technology that transfers data between a reader and an electronic tag attached to an object for the purpose of identification and tracking via wireless signals and has attracted great attentions recently for its tracking capability. It was originally intended in industry as an alternative to the bar code and logistic applications. Its advantage includes no requirement of direct contact or line-of-sight scanning.

The purpose of an RFID system is to enable data to be transmitted to and from the tag. The data may provide identification or location information, or specifics about the product being tagged, such as price, color, date of purchasing, etc. A basic RFID system consists of three components, namely an antenna, a transceiver (with a decoder often combined into the reader) and a transporter (an RF tag, electrically programmed with unique information). The antenna transmits radio signals to activate the transponder.

Three types of RFID tags are commonly used, including active, passive and semi-passive ones. Active RFID tags broadcast their signal to the reader, and are typically more reliable and accurate than passive ones. They send stronger signals and thus are more adaptable to environments that are hard to transmit other types of tags, such as under water situations or those requiring a longer distance of communications. However, their required power source makes them larger and more expensive. Passive RFID tags, on the other hand, do not need internal power supplies and rely on the RFID reader to transmit data so that they are smaller and cheaper. A small electrical current is received through radio waves by the RFID antenna which has enough power to transmit a response. They are more suited for warehousing environments where the interference is not severe and the distances are relatively short. Semi-passive RFID tags are similar to the active ones with an internal power supply, but it does not broadcast any signal until the reader initiates it.

## III. THE BASIC PRINCIPLES OF POSITIONING

### A. RSSI (Received Signal Strength Indicator)

RSSI [32]-[33] uses a channel path loss propagation model to describe the signal decay with distance. RSSI represents the signal strength. When the transmitter is near to the receiver, the RSSI value is larger and vice versa. For localization, three receivers are required at least. In the free space propagation model, the transmitted and received signal power ratio is as follows:

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2}$$

where $P_r$ (dB), $P_t$ (dB), $G_r$, $G_t$, $\lambda$ (m) and $d$ (m) denote the received signal power, the transmitted signal power, the receiver antenna gain, the transmitter antenna gain, the signal wavelength and the distance between the transmitter and the receiver, respectively

In an indoor environment, the received and transmitted power ratio is susceptible to both multi-path interference and shadowing effects. Therefore, the signal strength will be different from that in free space. In addition, the resulted distance will have errors due to refractions at edges and from the media, different propagation speeds, polarization and scatterings, etc. That is, the deduced location will not be at one point but will fall into an area. Therefore, the total received power from the tag has to take into account the effects of multi-reflections and other error factors which may cause the power loss. Thus, the total received power previously given is modified as follows:

$$P_r \approx P_{ref} + P_{err} + \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2}$$

where $P_{ref}$ (dB) and $P_{err}$ (dB) represent the power due to reflections and other error factors, respectively.

### B. LQI (Link Quality Indicator)

In practical applications, the total received power can not be used directly due to affecting factors mentioned above. Hence, in this study we use the link quality indicator (LQI) method for our distance reduction to avoid the problems.

LQI [34] is determined by two characteristic of the receiving packets, namely, signal strength and quality. It is specified by IEEE802.15.4 to assess the quality of the communication link between a receiver and transmitter. LQI is based on signal to-noise ratio or energy density of the signal in the frequency band used and provides average correlation values for each incoming packet. As with RSSI, LQI allows users to assess the communication link considering the environmental effects on a single transmitter/receiver pair. However, LQI provides a more thorough estimate of the quality of the link than RSSI since it assesses all possible frequencies in the physical layer of the transmission.

The basic idea of using LQI for distance determination is that the transmission quality is better when the distance is smaller and vice versa. In general, the values of LQI are expressed in binary digits of a byte from 0 to 255 with 255 indicating the highest link quality. That is, the received signal is divided into 256 parts equally from the weakest to strongest by the manufacturer.

## IV. POSITIONING TECHNIQUES

The positioning technique adopted in this study includes pattern matching and related algorithms as follows.

### A. Pattern matching location technology

The pattern matching between the received signal and the database of the training samples for positioning is known as the fingerprint matching method. The matching process is divided into two phases as shown in Figure 1; namely off line (off stage) and on line (real time) as follows.
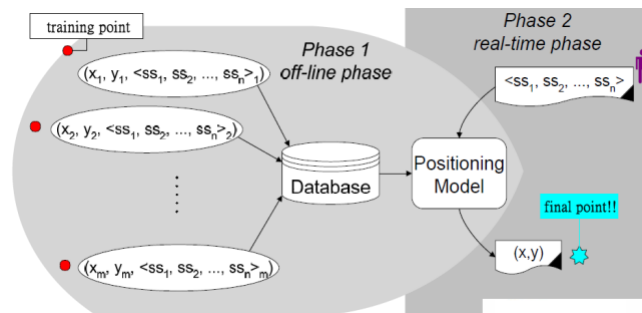


Figure 1: Pattern matching for location

· Off line (Off stage): establishing the feature database.

This is the training phase in which the signal strengths at a number of locations are measured and recorded to the database first. The format of the received signal strength of each record is denoted by $(x, y, \langle ss_1, ss_2, \ldots, ss_n \rangle)$, where $(x, y)$ is the coordinate of the training location and $ss_i (i = 1, 2, \ldots, n)$ is the received signal strength at the training point from the ith transmitter. Once the database is established, positioning can be accomplished by pattern matching between the received signal strength and that in the database.

· On line (Real time)

After establishing the database, real time position localization is performed. In this situation, a number of training locations is selected at which the received signal strength from every sender is recorded and the received signal pattern is then compared with the training pattern in the database for positioning. In general, positioning model will give several possible estimated locations combined with their probabilities. In the present method, only the highest likelihood location is selected.

### B. Probability-based method

Probability method is the use of conditional probability statistics. Under current conditions, use the current location of the user to find the most likely location of the user. Firstly, establish the characteristic vector for every training location to form the database of the characteristic vectors. The characteristic vector is denoted by $C_i = \langle C_1^i, C_2^i, \ldots, C_n^i \rangle$, where the $C_j^i$ is the $i^{th}$ training location receiving the distributed signal strength from the $j^{th}$ transmitter. Using statistical methods to collect all possible distributed signal patterns from every transmitter of the training location, and then to set the threshold value of the number of the correct matching data. When the number of the correct matching data is greater than the threshold value, the training location is used to estimate the position.

## V. SYSTEM DESIGN AND IMPLEMENTATION

The procedure of location planning is set in two steps; first, one-dimensional line planning; then two-dimensional

positioning planning. By varying the distance between the robot and the signal transmitter, the law of the received signal by LQI is established to determine the positioning relationship.
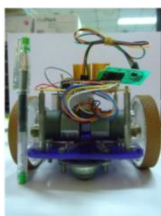


Figure 2: RFID module     Figure 3: the mobile robot

In Figure 2 is RFID module, which is operated at the frequency of 315M Hz. The effective radius of RFID module is 15 meters with an antenna. In Figure 3, the mobile robot uses a micro-processor AT89S52 to control the motors for movements and uses the Bluetooth for remote control via a personal computer. The robot size is145mm long by 115mm wide by 120 mm high and weighs 1kgw.

Table I. The specifications of RF8315RT

| Specifications | Description |
|---|---|
| Receiver Supply Voltage : | 9VDC via wall adaptor if necessary |
| Receiver Supply Current : | 4mA Typical |
| Receiver Output : | RS232, 9600 Baud, 8 bit words,1 stop bit,1 start bit, no parity |
| Transmitter Power Supply : | CR2032 (7,000 hours) |
| Operating Frequency : | 315 Mhz |
| Data Format : | 4 characters |
| Effective Radius : | 15 meters by using antenna |

Table I is the specifications of the RFID module. As shown in Figure 4, the positioning system consists of the mobile robot, RFID modules and the personal computer. It has four active RFID tags with an RFID receiver for its position module. The RFID receiver is responsible for transmitting the received signal strength of the RFID tags via RS232 to the personal computer for data processing. The personal computer processes the received signal strength of each RFID tag and displays the positioning results.
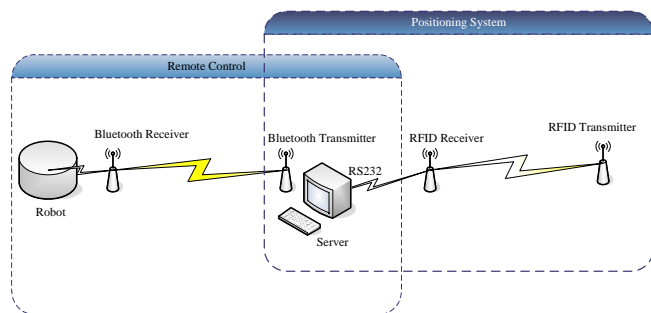


Figure 4: System configuration

## VI.   RESULT AND DISCUSSION

### A.  LQI statistics and the deduced distance database table

For real time positioning, we need to establish the reference database of LQI versus known distance first. This is accomplished by fixing the transmitter location, varying the receiver distance step by step from the transmitter and measuring the corresponding LQI value at each location. In In Figure 5, it shows that how is the LQI reference table being established. It shows that at distance $d_1$, the corresponding $LQI_1$ is measured. Then, the receiver is moved to location 2 where the distance is $d_2 = 2d_1$ to measure $LQI_2$, and so on. The LQI values are measured a total of 30 data at each location so that data variance can be reduced to obtain an interval of the average value and thus to strengthen the reliability of the received signal.
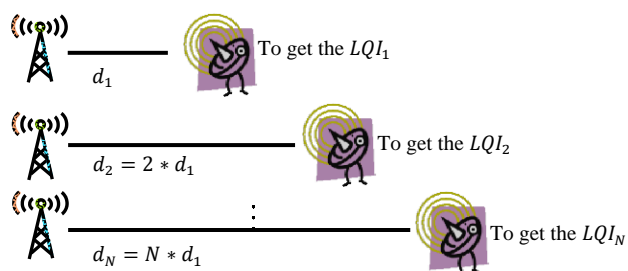


| Distance | $d_1$ | $d_2$ | … | $d_N$ |
|---|---|---|---|---|
| LQI | $LQI_1$ | $LQI_2$ | … | $LQI_N$ |

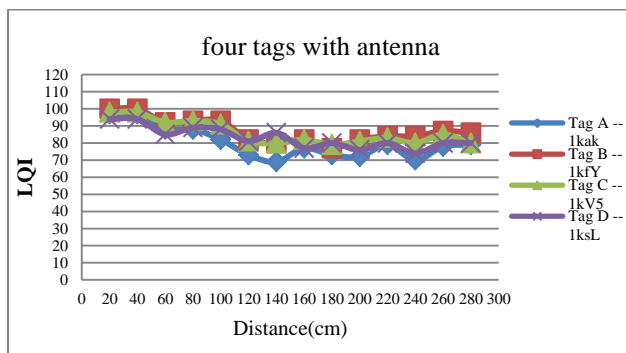Figure 5: Establishing the LOI reference table with known distance.



Figure 6: LQI distributions versus distance for four RFIDs, each with an antenna.

Typical signal strength variations versus distance are shown in Figure 6 for four RFID tags. It can be observed that the signal strength decreases with some oscillation as the distance increases from 0 cm to 140 cm. For distances greater than 140 cm, the LQI value levels off to about a fixed range. The signal can be received to a distance as far as 1500 cm. It is clear that the gain of each RFID is not the same because the curves shown in Figure 6 do not coincide to each other. To unveil the reason of this inconsistency among the RFIDs, the antenna of the RFID is removed and the measurements are taken again with the same conditions as that of Figure 6. The results are shown in Figure 7. It can

be seen that data variation among the RFIDs is reduced considerably. That is, the variation in antennas of the RFIDs is the main reason causing the data spreading shown in Figure 6.

The results depicted in Figure 7 indicate that the signal strength decreases as the distance increases from 0 cm to 80 cm. The oscillatory variation shown in Figure 6 is greatly reduced. Furthermore, the decreasing rate of the LQI value is larger than that with antennas. For the distance greater than 80 cm, the LQI value is reasonably constant. The signal can be received as far as 8 m, shorter than that with the antenna of 15 m. That is, the antenna gain factor is about 1.75. Because a constant LQI value is not suitable for distance determination, the LQI in the range from 0 to 80 cm illustrated in Figure 7 is used for distance determination in this study due to the larger negative slope.
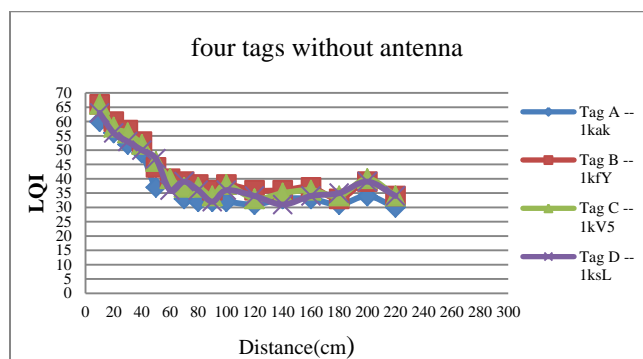


Figure 7: LQI distributions versus distance for the RFIDs without any antenna.

## B. Experimental one-dimensional positioning for mobile robot

Table II. The table of one-dimensional position and the actual distance prediction (measuring a total of 30 data)

| Location | 10 cm | 20 cm | 30 cm | 40 cm | 50 cm | 60 cm |
|---|---|---|---|---|---|---|
| the numbers of true positioning | 30 | 30 | 30 | 29 | 26 | 30 |
| the numbers of false positioning | 0 | 0 | 0 | 1 | 4 | 0 |
| accuracy | 100 % | 100 % | 100 % | 96.67 % | 86.67 % | 100 % |

➢     The average accuracy:97.23%

For the one dimensional positioning experiments, at each distance, the measurements are conducted a total of 30 data for each location and the distance is changed with an interval of 10 cm. The results are shown in Table II. The number of false positing given in the table means the number of incorrect measurement among the 30 measurements at each location. The accuracy is deduced by dividing the number of accurate positing to the total measurement number 30. It can be observed that within the distance of 30 cm and at the distance of 60 cm, no error

occurs. However, at the distances of 40 cm and 50 cm, the errors are 10 cm and ±10 cm, respectively. That is, at these two locations, an error of one measurement interval (10 cm) is observed due to the oscillatory behavior of LQI shown in Figure 7 at these distances.

## C. Pattern matching location technology to establish the signal strength database

In the off-line stage, we establish the characteristics of the positioning database. The environment is divided into 36 cells by an area of 10 cm x 10 cm each first. Then we measure the signal strength LQI of each position to establish the location reference database. In real-time applications, we use the positioning module and positioning rules described above to estimate the receiver position. Figure 8 shows the experimental environment for real time testing. It can be seen that a tag was installed at each corner of the four corners of the environment while a robot moves inside the area enclosed by the tags.
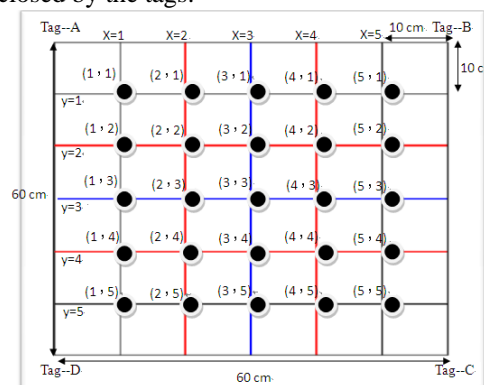


Figure 8: The testing environment.

Figures 9(a)-(d) illustrate the variation of the signal strength for each RFID tag. The result shows that the signal strength of the tag varies from the distance in the indoor environment. That is, the received signal strength is smaller when the distance is farther. This is true for all of the four tags investigated. However, it is also evident that at the same distance, the received signal strength from each tag. That is, when using the received signal strength of the tags to determine a specific location in the environment, the deduced coordinate is not a single value but during an interval.
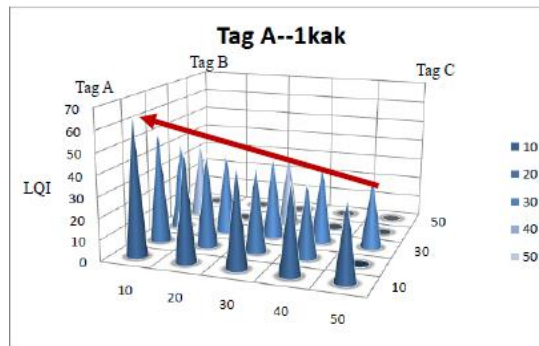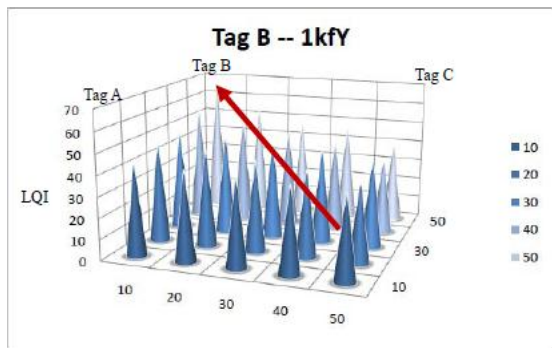


Figure 9(a) Signal strengths from Tag A
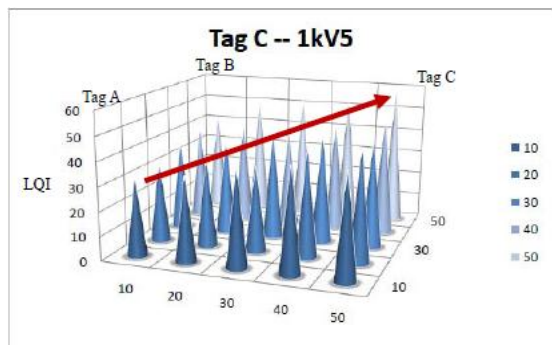
Figure 9(b) Signal strengths from Tag B
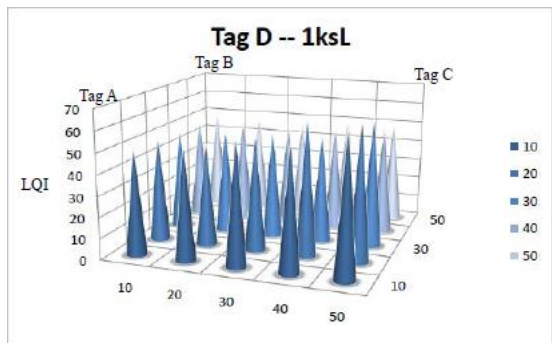


Figure 9(c) Signal strengths from Tag C



Figure 9(d) Signal strengths from Tag D

*D.  E Two-dimensional localization for tracking the mobile robot*

This experiment is adding the mobile robot for tracking observation. Place the receiver in the mobile robot and observe the localization results. In Figure 10, this is the result of two-dimensional localization for mobile tracking and the tracking path is (5 , 5)→(5 , 4)→(5 , 3)→(4 , 3)→(3 , 3)→(3 , 2)→(3 , 1).

The wireless location signal strength is affected by fluctuations, so real-time tracking is a great challenge. According to experimental the results, it could be observed that the accuracy rate is low at the coordinate of (1 , 2), (1 , 3), and(1 , 4). It is clear that when the robot makes a turn, the receiver will follow the turning action and causes a positioning error. Therefore, the robot must wait for a while for the signal to be steady so that the positioning results can be more accurate.
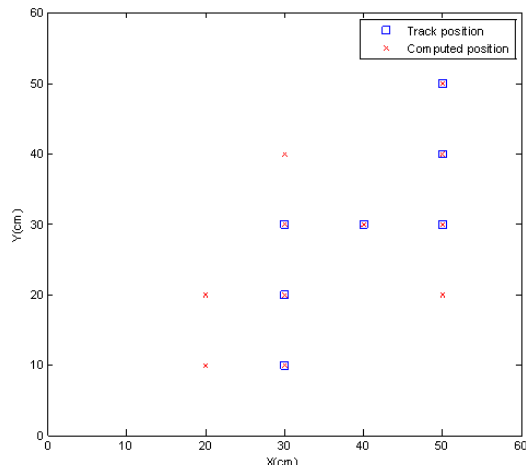


Figure 10: Two-dimensional localization for tracking mobile

In Figure 11, it shows the estimated localization average error of walking path for mobile robot. The average localization error is 14.16 cm.
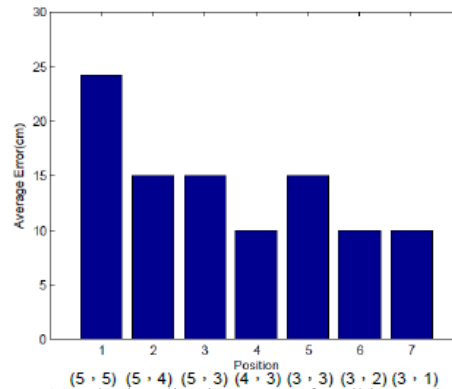


Figure 11: The localization error of walking path for robot

## VII.   CONCLUSION

This study uses the property of the signal strength for positioning. The accuracy of one-dimensional localization without antennas is 10 cm and the average accuracy rate is about 97%. Therefore, in one-dimensional positioning by using the robot for adaptive positioning control is good.

For two-dimensional positioning in the area of 60 cm x 60 cm, the location average accuracy is about 79.7%, not as good as the one dimensional case due to errors generated by the wireless signal interference from the surrounding objects.

To expand the scope of the present localization method, in addition to increasing the number of RFID tags, the other approach is to unify the antenna specifications with high-gains.

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