A Qualitative Approach to Mobile Robot Navigation Using RFID

Mahbuba Hossain1*, Dr. Muhammad Mahbub Rashid2, Sayem Ahmed3, and Md. Akhtaruzzaman4
Department of Mechatronics Engineering
International Islamic University Malaysia, 53100 Kuala Lumpur, Malaysia.

mahbuba.hsn@gmail.com, mahbub@iium.edu.my, sayem7746@gmail.com, and akhter900@yahoo.com

Abstract. Radio Frequency Identification (RFID) system allows automatic identification of items with RFID tags using radio-waves. As the RFID tag has its unique identification number, it is also possible to detect a specific region where the RFID tag lies in. Recently it is widely been used in mobile robot navigation, localization, and mapping both in indoor and outdoor environment. This paper represents a navigation strategy for autonomous mobile robot using passive RFID system. Conventional approaches, such as landmark or dead-reckoning with excessive number of sensors, have complexities in establishing the navigation and localization process. The proposed method satisfies less complexity in navigation strategy as well as estimation of not only the position but also the orientation of the autonomous robot. In this research, polar coordinate system is adopted on the navigation surface where RFID tags are places in a grid with constant displacements. This paper also presents the performance comparisons among various grid architectures through simulation to establish a better solution of the navigation system. In addition, some stationary obstacles are introduced in the navigation environment to satisfy the viability of the navigation process of the autonomous mobile robot.

Keywords- Radio Frequency Identification, RFID, Navigation, Mobile robot, Passive RFID, RFID reader, RFID tags.

1. Introduction

Navigation and localisation of mobile robot both in indoor and outdoor environment is an important and challenging issue to accomplish. Basically mobile robot navigation requires a few abilities; localization, orientation, ability to move, and a means to determine whether the goal is achieved or not. The objective is to find the most efficient way to reach a destination. Many approaches on mobile robot navigation are aforementioned and can be categorized in two ways, Relative Localization (RL) and Absolute Localization (AL). The RL includes dead reckoning and inertial navigation strategies where the AL includes passive/active RFID, landmarks, map-based, and vision-based localization process [1].

Dead reckoning is one of the conventional approaches where the main strategy is to measure the number of wheel revolution and use relative motion [2][3]. Grid based line following mobile robot combining with dead-reckoning strategy is represented in a research where the robot’s task was to perform in a soccer game competition [4]. The problems of dead-reckoning process are uncertainty
caused by the wheel slip and error accumulation. The problem can be solved by using external sensor to revise the accumulated errors by estimating the pose and location through observing the existing landmarks in its environment [5][6][7]. Again problem occurs because of ambient lights and shielding obstacles which cause the landmarks not to be observable. So, instead of using landmarks, many researchers tried to use active RFID tags but some problems still remain in terms of maintenance and battery replacement issues. Not only that, using active RFID tags increase the system complexity because of the determination of its path depending on the signal strength of two or more antennas [8].

A recent research [9] represents Received Signal Strength Indicator (RSSI) measurements and comparison technique between two RFID sensors and Back-propagation Artificial Neural Network (BPANN) for robot localization. Such classification system grows complexity and the learning procedure needs huge datasets. The system also increases power consumption.

Navigation routes can be observed through Global Positioning System (GPS) and using active RFID. But GPS cannot be used in indoor environment because it loses range and strength of signals. In outdoor environment, GPS system is used successfully for mobile robots navigation [10] [11]. Park S. et al. (2010) presented intelligent localization system for mobile robot using Passive RFID by calculating the read-time of RFID system but the study does not introduce any obstacle avoidance mechanism [12]. Some researchers describe the estimation of mobile robot orientation in unknown environment by using 2D range scans [13].

Passive RFID can provide a non-vision based navigation system where the small detecting range could be considered. In this research, a passive RFID reader is mounted on the robot and a number of tags are placed on the navigation surface based on specific grid architecture. There are two main objectives of the research. Firstly, provide a suitable navigation technique for the robot to reach its target location avoiding the obstacles. Secondly, verify the performance of navigation based on various grid architectures. Different grid architectures will provide different resolutions for path planning during navigation. The position and orientation of the robot will be identified based on the information detected from the placed tags on the grid points and the compass. The proposed strategy will also minimize the power consumption of the entire system.

The rest of the paper is organized as follows: RFID system, system design, and grid architecture are presented in Section 2. Section 3 represents the Navigation Algorithm. Section 4 presents simulation and results analysis. Concluding remarks are presented in section 5.

2. System description

2.1. RFID system

RFID system has three basic components, RFID reader (interrogators), RFID tags (transponders), and Firmware. The firmware establishes a communication between the reader and tag to retrieve the tag serial (ID) number. The firmware also maintains the communication with main controller to send the tag ID so that the controller can perform its necessary task using that information. The RFID reader can detect a RFID tag in its wireless range. Depending on the operating principles, a tag can be characterized as active, semi-passive, and passive [15]. A passive RFID tag is least complex and cheapest among the all three types. Passive tag does not have its own power source. It uses the Electromagnetic (EM) field from the reader to power up its internal circuit.

2.2. System architecture and design

For this project, the task of the main controller (PIC) is to accumulate and process necessary information obtained from sensors, such as Compass, RFID tags, Infra Red (IR) sensor, Ultrasonic sensor, etc. to drive the mobile robot navigating in the indoor environment. The RFID system used in this research is passive RFID type. The coil antenna of the reader is mounted under the robot base so that the robot can detect the tag underneath while traveling on the navigation surface. Based on the ID number of a tag as detected on the navigation surface, the robot calculates its location respect to that tag information. As the tag detection range is about 7 cm, the signal does not overlap with other tags. Figure 1 represents the physical system architecture with sensors and actuators distribution around the controller of the mobile robot.
Based on the above architecture, the controller unit receives the necessary information about the environment from Distance sensor, Digital compass, and RFID reader. The controller sends the current status and other information to LCD display. Most importantly, controller generates output signals to drive the motors so that the robot can move to its goal following the selected route. The compass helps to identify its orientation and the direction of the target destination based on the angular displacement, $\theta$, from the reference $y$-axis. The distance sensor helps the robot to detect any obstacle on its navigation route. Furthermore, the RFID reader has the key responsibility which helps the robot to identify its current position, direction and the distance of the goal location. During the navigation task, the RFID reader sense the tags located on the grid points of the navigation surface. If the robot is diverted from its targeted direction line, new direction route is recalculated based on the information taken from RFID and also from compass. The mobile robot controller also has connection with wireless communication device such as Bluetooth to communicate with external device like PC through which several commands could be send to the robot and also the new goals could be assigned.

2.3. Grid architecture and RFID tag displacement

The displacements of the tags on the floor are regular and in square grid patterns as presented in figure 2. This type of structure is considered to have a simplified navigation strategy. In this research, two types of displacement patterns are used, smaller (20cm) and larger (25cm) displacement, between two corresponding tags. Each tag has its own ID so its location in the grid is fixed from other tags. The $(x, y)$ coordinate of each tag is changed to the polar coordinate system represented as $(r, \theta)$ where ‘$r$’ is the displacement between the goal and the present tag and ‘$\theta$’ is the angle between the $y$-axis and the target line. Objective is to reach the target using the shortest possible route.
3. Navigation algorithm

As the purpose of this navigation is to reach the goal, the basic algorithm can be presented with a flow diagram as shown in figure 3. For this algorithm all the ID of RFID tags are predefined and stored in the MCU with the corresponding coordinate locations. As a result, robot knows all the positions of the tags in its environment as well as the position of the assigned goal position. For the initial condition, the robot is placed on a particular tag. As the process begins, the robot considers the tag as the source position and information are used to calculate \((r, \theta)\) and determines the direct distance ‘\(r\)’ which has to travel and the angle ‘\(\theta\)’ to fix its orientation by rotational turning. As it detects any new tag on its way, the robot directs itself to the location of the new tag and performs calculations to determine the new \((r, \theta)\). Every time the robot detects a new tag, it updates its position and continues to reach the goal.

During the navigation process, if any obstacle is detected in its way, the robot tries to avoid it by turning counterclockwise or clockwise direction until the obstacle goes out off range. If the obstacle is on the right the robot turns counterclockwise and if the obstacle is on the left, robot turns clockwise. If the obstacle is detected in front, the robot turns clockwise or counterclockwise depending on the direction of the goal. The tags are placed on the navigation surface at a significant distance so that only one tag can be detected in a particular time. If tag detection range is large enough and more than one tag is detected at the same time, the nearest one has to be identified using RSSI technique.

The equations to calculate the distance and the angle can be presented as,

\[
\begin{align*}
r &= \sqrt{\Delta x^2 + \Delta y^2} \\
\theta &= \tan^{-1}\left(\frac{\Delta x}{\Delta y}\right) \\
\Delta x &= x_{tag} - x_{current} \\
\Delta y &= y_{tag} - y_{current}
\end{align*}
\]
\( r = \text{Displacement between target tag and present tag} \)
\( \theta = \text{Angle between reference (y-axis) and target tag} \)
\( \Delta x = \text{Displacement in x-axis between target tag and present tag} \)
\( \Delta y = \text{Displacement in y-axis between target tag and present tag} \)

4. Simulation and result analysis
Using the algorithm, some simulations are conducted to validate the performance of the navigation procedure. Two different grid environments are used. Both include square grid structures as described in section 2.3. One environment has spacing (20cm × 20cm) and the other with spacing (25cm × 25cm). The navigation strategy also tested through simulation both for with and without obstacles.

![Simulation Diagram](image)

**Figure 4.** Robot navigation with tag spacing (a) 25cm × 25cm and (b) 20cm × 20cm (No obstacles).

The above two navigation environment is considered as without obstacles. Simulation results present the smooth navigation of the robot with some small deflections in terms of orientations. For both of the cases robot reaches to its destination. In figure 4 (a), where (25cm×25cm) displacement is used, the robot updates its position for four times during the movement while figure 4 (b), where (20cm×20cm) grid displacement is used, presents 6 updates points while navigating from source to destination. So, first grid environment allows the robot to reach its destination faster than the second environment. Table 1 and figure 5 present the errors in angular displacement of the robot from the desired angle during navigation.

| Analysis with Tag Spacing 25cm×25cm | Analysis with Tag Spacing 20cm×20cm |
|-------------------------------------|-------------------------------------|
| **Update from nearby tag** | **Measured angle, \( \theta \) (°)** | **Angle error from Desired Angle (%)** | **Update from nearby tag** | **Measured angle, \( \theta \) (°)** | **Angle error from Desired Angle (%)** |
| 0 | 39.2 | 0 | 0 | 39.3 | 0 |
| 1 | 38.3 | 2.295918367 | 1 | 38.7 | 1.526717557 |
| 2 | 37 | 5.612244898 | 2 | 37.9 | 3.562340967 |
| 3 | 37.2 | 5.102040816 | 3 | 36.9 | 6.106870229 |
| 4 | 27.5 | 29.84693878 | 4 | 35.5 | 9.669211196 |
| 5 | Goal | 0 | 5 | 36.9 | 6.106870229 |
| - | - | - | 6 | 45 | -14.50381679 |
| - | - | - | 7 | Goal | 0 |
Figure 5. Orientation error during navigation process, (a) with tag spacing 25cm×25cm and (b) tag spacing 20cm×20cm (with no obstacles, test 1).

Figure 6. Test case 2; Simulation of the robot navigation (a) with Tags spacing 25cm×25cm and (b) with Tags spacing 20cm×20cm (With obstacles).

Figure 6 shows the result of another simulation test where some obstacles are placed. For both of the conditions, the source, destination, and obstacle placements are same so that the performance of the robot navigation for the two different environments can be compared. The result presents that for both of the situations, the numbers of update points are same but for first environment, the robot
travels longer distance than the second one. First environment, where (25cm x 25cm) tag displacements are used, also shows that a large angle error occurs at the point when robot meets an obstacle on its way. Table 2 presents the list of angle errors occurred during the navigation process for both of the cases. Figure 7 shows the graphical representation of the angle errors.

The error of the navigation process can be analysed using the position error, orientation error, and time taken to reach the goal. Here only one aspect is considered for the navigation algorithm and that is orientation or angular deflection. Results have shown that the algorithm used is quite simple and straightforward. It also can be observed that without obstacles, the navigation route is smooth having less orientation error. With obstacles, the orientation error increases but it still reaches the goal with less complicity.

Table 2. Errors in angular displacement of the robot with obstacles (test 2).

| Update from nearby tag | Analysis with Tag Spacing 25cm×25cm | Analysis with Tag Spacing 20cm×20cm |
|------------------------|-------------------------------------|-------------------------------------|
|                        | Measured angle, θ (°) | Angle error from Desired Angle (%) | Measured angle, θ (°) | Angle error from Desired Angle (%) |
| 0                      | 36.9                  | 0                                   | 0                      | 36                                   | 0                                   |
| 1                      | 35.5                  | 3.79403794                          | 1                      | 35                                   | 2.777777778                         |
| 2                      | 33.7                  | 8.672086721                         | 2                      | 33.7                                 | 6.388888889                         |
| 3 (Obstacle)           | 90                    | -143.902439                         | 4 (Obstacle)           | 29.7                                 | 17.5                               |
| 4                      | 21.8                  | 40.92140921                         | 5                      | 31                                   | 13.88888889                         |
| 5                      | 26.6                  | 27.91327913                         | 6                      | 26.6                                 | 26.11111111                         |
| 7                      | Goal                  | 0                                   | 7                      | Goal                                 | 0                                   |

Figure 7. Graphs showing the orientation error during navigation process with (a) tag spacing 25cm×25cm and (b) tag spacing 20cm×20cm (with obstacles, test 2).
Figure 8 presents another simulation result with different arrangement of obstacles. The result shows that the first environment (25cm x 25cm spacing of tags) causes large angular deflection at the meeting point with obstacle. But both of the cases, robot finds its possible shortest path to reach the goal. Basically, environment with different tag spacing shows different results. Smaller spacing provides more update of its position in the environment compared to larger spacing and therefore better resolution in navigation. But, as there is a better resolution for small spacing environment, there exists frequent updates of positions which increase time in travelling from source to destination. On the other hand, larger tag spacing provides less update points as the gaps among tags are large and the travelling time decreases. For obstacles, smaller tag spacing shows less deviation than the bigger tag spacing environment. Table 3 shows the errors in angular displacement of the robot while travelling from source to destination. Figure 9 represents the graphical view of the errors.

Table 3. Errors in angular displacement of the robot with obstacles (test 3).

| Analysis with Tag Spacing 25cm×25cm | Analysis with Tag Spacing 20cm×20cm |
|-----------------------------------|-----------------------------------|
| Update from nearby tag | Measured angle, θ (°) | Angle error from Desired Angle (%) | Update from nearby tag | Measured angle, θ (°) | Angle error from Desired Angle (%) |
| 0 | 45 | 0 | 0 | 45 | 0 |
| 1 | 45 | 0 | 1 | 45 | 0 |
| 2 | 45 | 0 | 2 | 45 | 0 |
| 3 | 45 | 0 | 3 | 45 | 0 |
| 4 (Obstacle) | 0 | 100 | 4 | 45 | 0 |
| 5 | 53.1 | -18 | 5 | 45 | 0 |
| 6 | 56.3 | -25.11111111 | 6 (Obstacle) | 51.3 | -14 |
| 7 | 63.4 | -40.88888889 | 7 | 53.1 | -18 |
| 8 | Goal | - | 8 | 56.3 | -25.11111111 |
| - | - | - | 9 | 63.4 | -40.88888889 |
| - | - | - | 10 | Goal | 0 |

Figure 8. Test case 3; Simulation of the navigation procedure (a) with tag spacing 25cm×25cm and (b) with tag spacing 20cm×20cm (With obstacles).
Figure 9. Graphs showing the orientation error during navigation process with (a) tag spacing 25cm×25cm and (b) tag spacing 20cm×20cm (With obstacles, test 3).

For both of the environment shown in this paper, path is easily observed and goal successfully reached. But it is important to keep in mind that the displacement of the tags should not be too small or too large because the smallest displacement will increase frequent and unnecessary updates and largest displacement will increase the possibility of dead-reckoning or sometimes the goal cannot be achieved at all.

5. Conclusion
Based on the simulation and analysis, this method shows effective results in providing good navigation system for mobile robot in indoor environment. The system provides the information for both position and orientation of the robot. No matter what the initial orientation of the robot is, it can orient itself successfully to face to the goal location. As the tags positions are known to the robot and the tag spacing is regular, the robot can perform its navigation tasks only in the same environment. This could be a drawback of the system because the robot will not be able to navigate in unknown environment. Future work will include the experimental investigation of this navigation algorithm to analyze its effectiveness in real environment. With the angle error, the analysis of position error and the travelling time should be taken into consideration to represent a good analytical report of the system. A good hardware with robust controller could lead the system to its level of perfection in the fields of mobile robot navigation.

References

[1] Park S Hashimoto S 2009 An approach for mobile robot navigation under randomly distributed passive RFID environment Proc. of Int. Con. On Mechatronics (ICM 2009) vol. 1 no. 6 pp. 14-17

[2] Park S Saegusa R Hashimoto S 2007 Autonomous navigation of a mobile robot based on passive RFID Int. Symp. On Robot and Human interactive Communication (RO-MAN 2007) vol. 218 no. 223, pp. 26-29

[3] Crowley J L 1989 Control of Displacements and Rotation in a Robot Vehicle Proc. of Int. Con.
on Robotics and Automation.

[4] Akhtaruzzaman M Hasan S K Shafie A A 2009 Design and Development of an Intelligent Autonomous Mobile Robot for a Soccer Game Competition Proc. of Int. Con. On Mechanical and Electronics Engineering (ICMEE 2009, World Scientific) pp. 167-171

[5] Tsuji Y Yagi Y Yachida M 2001 Robust Alternative Estimation of an Environment Map and Robot Egomotion Using an Omni-directional Vision sensor Journal of the Robotics Society of Japan vol. 9 no. 1 pp. 59-67

[6] Drocourt C. Delahoche L Pegard C and Clerentin A 1999 Mobile Robot Localization Based on and Omni-directional Stereoscopic Vision Perception System Proc. of Int. Con. on Rob. Auto. pp.1329-1334

[7] Betke M Gurvits K 1997 Mobile Robot Localization Using Landmarks IEEE Trans. on Rob. And Auto. vol. 13 no. 2 pp. 251-263

[8] Gueaieb W Miah M S 2009 A modular cost-effective mobile robot navigation system using RFID technology Journal of Communications, USA, 4 (2) pp. 89-95

[9] Nosaiba A S Khalid A M 2012 Autonomous mobile robot localization based on RSSI measurements using an RFID sensor and neural network BPANN Journal of King Saud University - Computer and Information Sciences, Available online 23 October 2012, ISSN 1319-1578, 10.1016/j.jksuci.2012.10.001.

[10] Se-gon R Hyouk R C 2009 3-D Tag-Based RFID System for Recognition of Object IEEE Trans. on Automation Science and Engineering Vol. 6 Iss. 1 pp. 55-65

[11] Shair S Chandler J H Gonzalez-Villela V J Parkin R M Jackson M R 2008 The Use of Aerial Images and GPS for Mobile Robot Waypoint Navigation IEEE/ASME Trans. on Mechatronics vol.13 no.6 pp. 692-699

[12] Park S Saegusa R Hashimoto S 2010 An intelligent localization algorithm using read time of RFID system Journal of Advanced Engineering Informatics Vol. 24 Iss. 4 pp. 490-497

[13] Lu F Milios E 1997 Robot Pose Estimation in Unknown Environments by Matching 2D Range Scans Journal of Intelligent and Robotic Systems Vol. 18 Iss. 3 pp 249-275

[14] Akhtaruzzaman M Shafie A A Rashid M 2012 Designing an Algorithm for Bioloid Humanoid Navigating in its Indoor Environment Journal of Mechanical Engineering and Automation Vol. 2(3) pp. 36-44

[15] Chawal V Ha D S 2007 An overview of passive RFID IEEE Applications & Practice pp. 11-17.