On Using Passive RFID Tags to Control Robots for Path Following

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Abstract: Although very few robots actually go to Mars, we continue to design these machines as if they were organisms operating in a totally unknown and hostile environment. In fact, in most situations, the environment is not only predictable, but it can also be manipulated so that the missions of the autonomous robot may be supported, by including sensors, actuators, computing and communication equipment. One of the most convenient ways to manipulate the environment is to deploy a number of RFID devices, capable of storing a variety of digital data, aimed to provide autonomous robots with valuable navigation information. As a result, the on-board equipment can be significantly reduced, along with the power requirements, and the overall cost of the robots. While the vast majority of the applications of the RFID technology for robot control are related to robot localization and mapping, this paper presents an experiment aimed to demonstrate the possibility of using RFID tags for path following.

Keywords: RFID, real time robot control, path following, embedded devices.

1. Introduction

RFID and Robot Control

A RFID (Radio Frequency Identification) system ([1]) typically consists in a reader, equipped with an antenna, and at least one "RFID tag", which is a small ROM/EEPROM memory, and additional circuits for providing power and access to the digital data stored in the tag (see Figure 1).

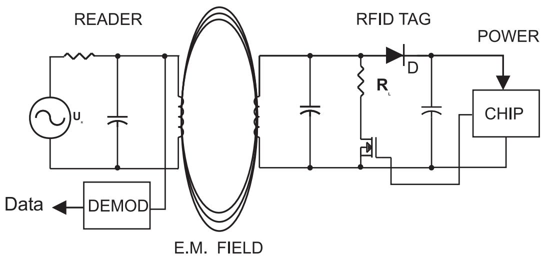

Figure 1. A typycal, passive RFID system

Most RFID tags are passive, i.e. they draw power from the electromagnetic field generated by the reader's antenna.

This is one of their major advantages- the other is the very low cost.

The actual data transfer between the reader and the tag is based on "load modulation", obtained by connecting a variable load to the resonant circuit of the receiver's antenna. The resulting amplitude modulation (A.S.K. – Amplitude Shift Key) can be sensed and decoded by the reader.

Depending on the maximum range where data transfer between reader and tags is possible, RFID devices are called:

- proximity tags (operating range between 0 and 100mm)
- vicinity tags (operating range between 100 mm and 1000 mm)
- long range tags (operating range between 1 m and 15 m. These are usually active – they have their own power supply, and are much more expensive).

Typical data storage capacity of the low cost tags range from a few bytes of ROM, to a few kilobytes of EEPROM.

The A.S.K data transfer is collision prone, i.e. if more than one tag is in the recognition area of the reader, as shown in Figure 2, a data collision will occur, and none of the tags will be read.

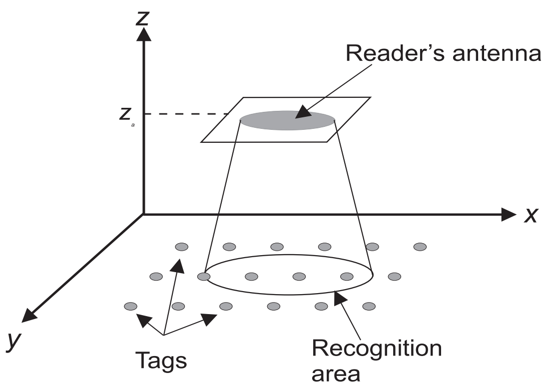

Figure 2. A placement of tags with more than one tag in the recognition area of the reader may lead to data collision.

The solution is to adjust the tag density and the distance between the reader's antenna and the tags, so that only one tag is in the recognition area, like in Figure 3, or to use a modern reader, having collision avoidance capabilities. Even in this last case, tags are read one by one, in sequence.

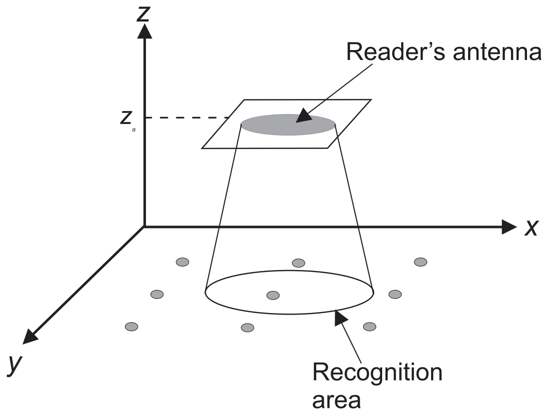

Figure 3. Placement of tags for collision-free data transfer

This aspect is essential for understanding the applicability and the limitations of using RFID tags in robot navigation. If, for example, a tag distribution as depicted in figure 3 is used for robot localization, with the reader carried by the mobile robot, and the tags embedded in the floor, store the absolute coordinates *(x,y)* of their location, the positionning error will be comparable to the radius of the recognition area, and there is no direct means to determine the robot orientation, based on the information stored by the tags.

On the other hand, since the robot can access only one tag at a time, the possibility to define paths, as sequences of points, defined by information stored in different tags, seems, at a first glance, very limited.

This is the reason why the majority of the literature on this topic focuses on the problem of using RFID for robot localization.

This paper presents two possible solutions to the problem of defining and following paths for real time control of mobile robots, by means of passive RFID tags deployed in the environment.

Besides this introduction this work is structured as follows:

Section 2 is a brief overview of the RFID based solutions for robot control.

Section 3 presents the general issues related to defining and following paths by means of RFID tags, and suggests one possible solution.

Section 4 presents a new method for defining paths in a RFID augmented environment, and the experimental results obtained. We called this method "the riverbed model".

Finally, section 5 is reserved for discussion and conclusions.

2. Related Work

Although the principles of the RFID are known since 1973 ([2]), recent advances in this technology led to a significant drop of the tag prices, along with an increase of their performances.

After 2004, a great number of research articles address the problem of using RFID technology for robot control. Most of them ([3], [4],…, [10]) propose various solutions for robot self-localization and mapping.

Haehnel et al. in ([3]) use a reduced set of wall mounted vicinity tags, and a probabilistic method to determine the robot's position.

Kulyukin et al. ([4]) also propose wall mounted vicinity tags as landmarks in a system aimed to guide visually impaired persons. Later, they propose an improved solution ([5]), based on proximity tags embedded in a "smart floor".

Park and Hashimoto ([6]) also use a network of floor mounted proximity tags, and propose a method to determine the robot orientation by measuring the response time of the tags.

In ([7]) and ([8]), the authors determine the position of the robot with respect to the RFID tags, based on considerations about the propagation of the electromagnetic waves.

The solutions proposed in ([9]) and ([10]) rely on fusing the the RFID and odometry information to obtain more accurate position estimations.

An important step towards using RFID in path following was made by Mamei and Zambonelli ([11]) by defining a model for "digital pheromones", stored in read/write RFID tags embedded in a smart floor.

Susnea et al. also use a smart floor, and propose in ([12]) a solution based on two lateral RFID readers for sensing spatial gradients of the digital pheromone distribution, and use this information as positionning error, relative to the pheromone trail. A fuzzy logic controller is used for the actual task of path following.

3. Defining Robot Paths Using Multiple RFID Tags

Since the memory capacity of the commonly used RFID tags is not enough to store the whole map of the environment, and only one tag can be read at any given time, one possible way to define path is to store in each tag only information about the next "lookahead point" ([13]), located on the trajectory, at a constant distance L, relative to the current position.

Assuming that the robot has a means to estimate its own current orientation θ (e.g. a magnetic, or giroscopic compass), and that each tag stores its own absolute coordinates (x,y), and the coordinates of the lookahead point G, (x_G,y_G), with the notations in figure 4, one possible way to define the positionning error is:

$$\phi_E = \psi - \theta \tag{1}$$

where θ is the current orientation of the robot, as reported by the compass, and ψ is computed with (2).

$$\psi = arctg(\frac{y_G - y}{x_G - x}) \tag{2}$$

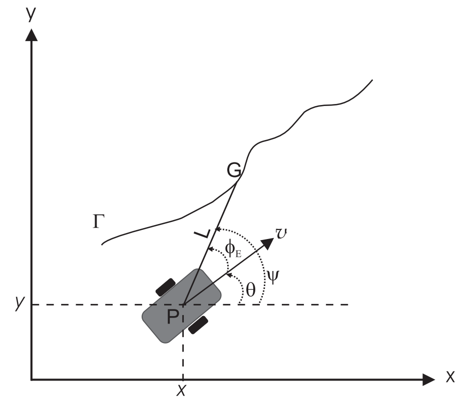

Figure 4. Defining lookahead points

Furthermore, any control algorithm capable to minimize this error (PID, fuzzy logic, sliding mode) is suitable for solving the problem of the actual path following.

The "pure pursuit" algorithm ([13], [14]), wherein the positionning error is defined by the curvature of an arc, tangent to the current orientation and passing through the lookahead point is also applicable.

4. A New Method to Define Robot Paths Using Passive RFID Proximity Tags

The Idea

Consider a smart floor, as shown in Figure 3.

This structures the space into a 2D grid, where each cell has a RFID tag in the center, and a size (a) comparable with the diameter of the recognition area of the RFID readers (see Figure 5).

For the usual proximity tags, the recognition area can be considered circular, with a diameter of 15-20cm. Commonly used research robots, like Pioneer3-DX and PeopleBot *(www.mobilerobots.com)* have a bias (b) of 38-45cm. If the robots are equipped with two readers, placed laterally on the left and right sides of the robot, these will read tags located 3-4 cells apart from each other.

Now, let's assume that each tag contains a one byte unsigned integer, which is interpreted as the "virtual altitude" of the corresponding cell.

Figure 6 shows an example of representing the map of the RFID augmented environment, including virtual altitude information. In this representation, darker shades of gray indicate cells with higher altitude, while zero altitude cells are depicted in white.

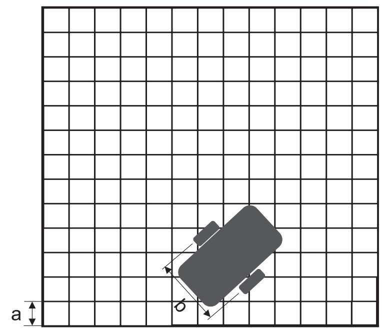

Figure 5. An example of grid map associated with the RFID smart floor

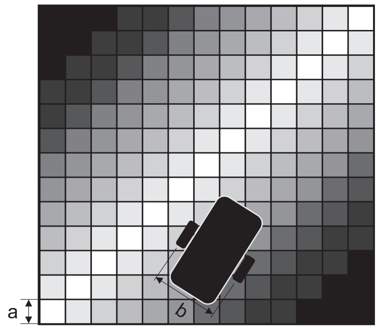

Figure 6. Defining a path by means of virtual altitude information stored in RFID tags

By sensing the altitude of the cells with two readers, the robot can be easily controlled to follow the path defined as adjacent cells with the lowest altitude.

The positionning error in this case is simply:

$$e = A_L - A_R \tag{3}$$

Where A_L and A_R are the altitudes of the cells corresponding to the left and right drive wheel of the robot. If (x_0, y_0, θ_0) is the current position of the robot, and b is the distance between the planes of the drive wheels, it is assumed that the coordinates of the two readers that read the altitude are:

$$x_R = x_0 - \frac{b}{2}\sin\theta_0 \tag{4}$$

$$y_R = y_0 - \frac{b}{2}\cos\theta_0 \tag{5}$$

$$x_L = x_0 + \frac{b}{2}\sin\theta_0 \tag{6}$$

$$y_L = y_0 + \frac{b}{2}\cos\theta_0 \tag{7}$$

The whole process is entirely similar to the flow of a river. That's why we called this method of defining paths "the riverbed model".

Experimental Setup

In the first stage of the experiment, both the smart floor and the robot were simulated by software applications running on two computers (Figure 7).

We have used MobileSim, provided by MobileRobots, (www.mobilerobots.com) as the robot simulator. This offers a pretty good simulation of the kinematic behaviour of the robots Pioneer3-DX and PeopleBot, used in the second stage of the experiment.

According to the experimental protocol, the robot/simulated robot periodically sends to the control application data packets containing the current position of the robot (x_0, y_0, θ_0). The software computes the positions of the readers with (4),..(7) and extracts the altitudes A_L, A_R, then computes the positionning error with (3).

The actual control application, running on a second computer, was a simple fuzzy logic controller (FLC), described in ([15]).

The FLC receives as input the difference of altitude sensed by the two RFID readers/extracted from the map simulating the smart floor, computed with (3), and generates references for the speeds of the drive wheels (v_R, v_L).

The smart floor, was represented as a 100x100 matrix, stored in a separate text file.

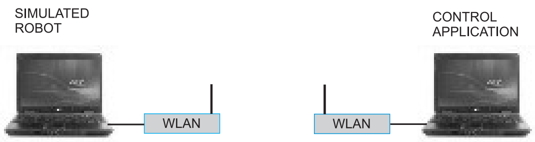

Figure 7. Simulation setup for stage 1

In the second stage of the experiment, we have used off the shelf Pioneer3-DX and PeopleBot robots, with no modifications to the control application (Figure 8). The smart floor was still simulated.

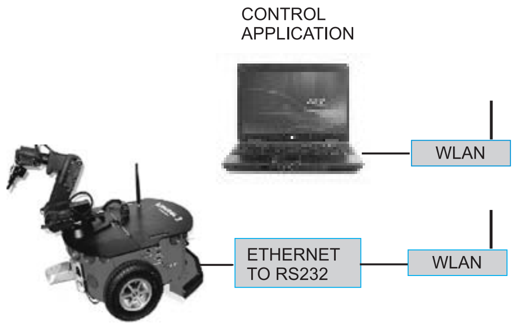

Figure 8. Simulation setup for stage 2

Figure 9 and figure 10 present the path of the simulated robot, recorded with MobileSim, in two typical control situations.

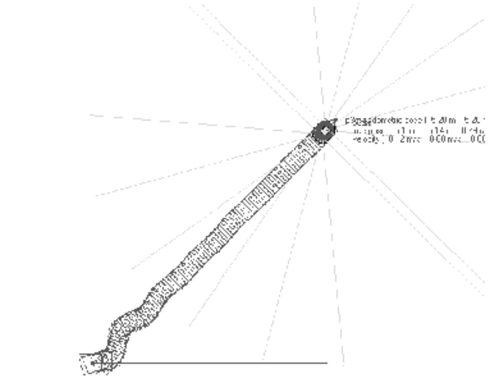

Figure 9. Recorded simulation result for a 45 degrees turn of the target path

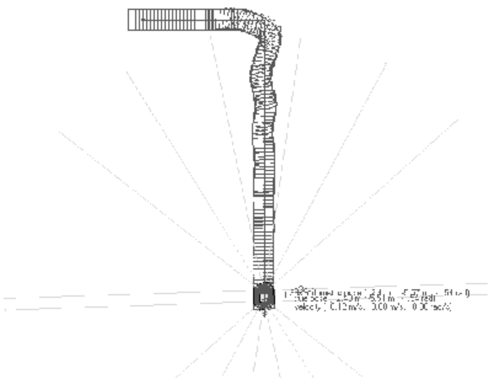

Figure 10. Recorded simulation result for a 90 degrees turn of the target path

Experiments with real robots showed no significant differences.

5. Discussion and Conclusions

This very simple method for defining and following paths in a RFID augmented environment has several important advantages:

- It requires very low storage memory for each tag. Even with the cheapest tags, hundreds of distinct paths can be defined this way.
- The computational load for the computer responsible with the path following task is also very low. As a result, this can be implemented using low cost, low power microcontrollers.
- It doesn't even require a localization system for the robots.
- It is compatible with some simple, reactive, obstacle avoidance algorithms, like the one described in ([16]).
- It is also compatible with several localization systems.
- The operations required to prepare the smart floor are relatively simple and can be automated. Some "smart carpets" are already commercially available.
- It can contribute to a drastic cost reduction of some service robots, like intelligent wheelchairs, or intelligent walkers to carry or guide patients in hospitals, nursing homes, etc. or even for designing intelligent shopping carts able to guide persons with various disabilities in supermarkets.

The only problem is that the accuracy of defining paths is limited by the size of the recognition area of the RFID readers (15-20cm). Some oscillations are unavoidable, but they can be reduced through a proper design of the controller.

Even the much discussed problem of the security of data stored in RFID tags is not a real issue in this case. If a hacker manages to alter the data stored in some RFID tags, given the inherent distributed nature of the system, the overall effect on the operation of the system would be barely perceptible.

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