Indoor Positioning System Based on the RSSI using Passive Tags

R. H. Murofushi, R. F. Gonçalves, A. R. Sousa, J. J. P. Z. S. Tavares

Abstract — **Radio Frequency Identification (RFID) technology having been realized of its potential usages only in recent years and nowadays it is widely used in multidisciplinary industries and applications. Indoor positioning systems (IPSs) locate objects in closed structures such as office buildings, hospitals, stores, factories, and warehouses, where Global Positioning System devices generally do not work. This paper introduces a unidimensional IPS using the RFID technology using the Received Signal Strength Indication (RSSI) to estimate the position of a reduced scale mobile vehicle and compare with the distance measured by an ultrasonic sensor. Results show a root mean square error of 5.7 cm.**

Keywords-RFID; Indoor Positioning; RSSI

I. Introduction

Generally, Location Based Services (LBS) system consists of five basic components: mobile device, communication network, positioning component, which is responsible for determining the mobile device position, service and application provider which processes user's requests and offers the required services and data and content provider which stores all information that can be requested by the user [1]

An important problem in robotics is the positioning of mobile vehicles. It is usually desired know the position be relative to a global frame of reference. In many situations, this is accomplished with GPS data. Unfortunately, there are many situations where there is no GPS reception (its accuracy is very limited when operating indoors due to limited satellite reception) and other methods must be used. GPS reception is not possible in underground mines, tunnels, or within buildings [2]. Indoor object localization and navigation would be of immense help for several applications such as navigational assistance for the blind, tour guide robots, inventory and asset tracking, healthcare, and defense [3].

A number of alternative technologies have been proposed for indoor positioning systems over the years. The most commons include vision, infrared, ultrasound, Wireless Local Area Network (WLAN), Radio Frequency Identification (RFID), and Bluetooth [3]. And one possible technology useful in this task is the radio frequency identification (RFID) that is an automatic data collection technology mainly used for object identification and tracking [1, 3, 4]. A typical RFID system comprises a reader module, which modulates data and commands into an RF signal, along with an antenna for the signal transmission. Passive RFID tags when located inside the reader's electromagnetic field acquire energy with the aid of their built-in antenna by means of inductive or radiative coupling. The acquired energy is consequently used to power up an IC chip with integrated memory attached to the tag antenna [5].

Olszewski et al. in [3] the RFID technology is used to improve the indoor navigation system of a mobile robot for navigation and a combination of ultrasonic and IR sensors are used for obstacle detection and avoidance during navigation. The RFID reader and antennae are embedded into the mobile robot. To increase accuracy of an indoor guidance system, a triangulation method was proposed to accurately detect the location. The method of interest is a combination of Time of Arrival (TOA) and a variation Received Signal Strength Indication (RSSI). Using TOA, the present location will be able to be determined through data collected from the antennas. In addition, by varying transmission power levels of the antennas, a distance can be obtained from the correlation of readings found in each power level. The concept of utilizing RFID for indoor localization has been shown to be both technically and economically feasible.

Errington et al. in [2] investigates the concept of using an array of RFID tags placed at fixed known positions to provide the initial position to the Simultaneous Localization and Mapping (SLAM) algorithm. The mobile vehicle is mounted with an RFID tag reader and antenna used to detect the tags. The application of interest here involves determining the initial position of a stationary vehicle in an underground mine using an array of RFID tags placed at known positions to provide the initial position of the stationary vehicle. The results suggest that RFID-based positioning, using the Least Square approach, has the potential to provide relatively accurate and low-cost initial position estimation.

Saab and Nakad in [6] presents a standalone Indoor Positioning System (IPS) using radio frequency identification (RFID) technology. The concept is based on a vehicle carrying an RFID reader module, which reads low-cost passive tags installed next to the object path. A positioning system using a Kalman filter is proposed. The inputs of the proposed algorithm are the measurements of the backscattered signal power propagated from nearby RFID tags and a tag–path position database. Experimental results are presented, illustrating the high performance of the proposed positioning system.

DiGiampaolo and Martinelli in [7-8] proposes a global localization system combining odometry data with RFID readings. The RFID tags are placed at the ceiling of the environment and can be detected by a mobile robot unit traveling below them. The detection of the tags is the only information used in the proposed approach (no distance or bearing to the tag is considered available), but only a small

R. H Murofushi is with the Mechanical Engineering Department, Federal University of Uberlândia (e-mail: hiroshi.murofushi@ufu.br).
R. F. Gonçalves is with the Mechanical Engineering Department, Federal University of Uberlândia (e-mail: rafael_froede11@yahoo.com.br).
A. R. Sousa is with the Mechanical Engineering Department, Federal University of Uberlândia (e-mail: alexandre.sousa@ufu.br).
J. J. P. Z. S. Tavares is with the Mechanical Engineering Department, Federal University of Uberlândia (e-mail: jean.tavares@ufu.br).

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number (about one each square meter or less) of tags are used. This is possible using a suitable tag's antenna in ultrahigh frequency band, expressly designed to obtain regular and stable RFID detection regions. A satisfactory performance is achieved, with an average position error of about 0.1 m.

Differently from the previous literature, this work introduces an unidimensional IPS based on the RSSI of the backscattered signal power propagated by the RFID tag coupled to the mobile vehicle. The antenna is located at a fixed and known position, as similar to RFID implementation site. This setup shows more flexibility of the system because there may be several tagged objects in the same environment and only a couple of antennae so that the IPS is cheaper than have one antennae for each tracked object. In addition, the antennae is incompatible to put it on the used prototype due to its size.

II. PROBLEM STATEMENT AND HARDWARE DEFINITION

The problem consist on designing an unidimensional IPS based on the RSSI of the backscattered signal power propagated by the RFID tag coupled to the mobile vehicle. The antenna is located at a fixed and known position and the Fig. 1 shows a picture of the prototype used in the experimental tests with a passive UHF tag coupled.

This vehicle has approximately 10 cm (width) x 10 cm (depth) x 25 cm (high) and is equipped with an Arduino Uno R3, two stepper motors and drivers, three ultrasonic sensors, though only one is used for the experiments, battery, inertial navigation sensor and a passive tag.

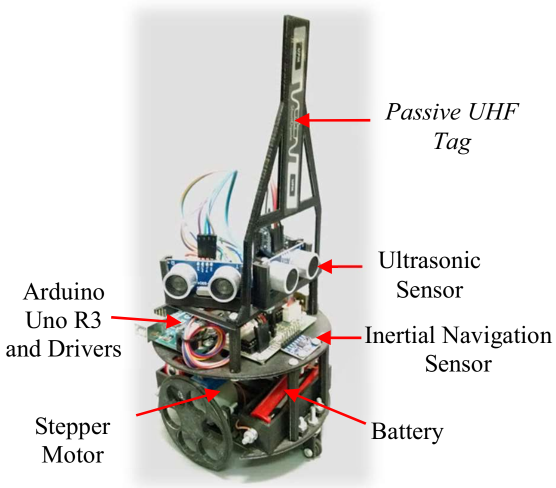

Figure 1. Vehicle description

The RFID reader used is a M6e-micro from ThingMagic coupled to a 32 dB antenna (902-928 MHz frequency working range). This reader has a resolution of 1 dBm and can be programmed using Java, C++ and C# languages. A short dipole passive tag is used with dimensions of 92 mm (width) x 11 mm (depth).

III. METHODOLOGY

According to Al-Ahmmar [1] in his literature review there are four basic indoor positioning algorithms; TOA, Time Difference of Arrival (TDOA), Angle of Arrival (AOA), and RSSI.

The RSSI estimates the distance of unknown node to reference node from some sets of measuring units using the attenuation of emitted signal strength. This method can only be possible with radio signals [9]. RSSI localization method could be using either a propagation model algorithm or a fingerprinting algorithm. Propagation model algorithm (PMA) establishes the relationship between RSSI and the distance. Generally, the larger the RSSI values the closer from the access point (AP) or antenna. Attenuation of signal strength is inversely proportional to the distance from AP in the outdoor. In contrast, it is complex in an indoor environment because of the existence of many obstacles such as furniture, equipment windows and doors, which may cause multipath propagation, such as reflection, refraction and diffraction. Fingerprinting algorithm follows the way stated earlier in the fingerprinting technique [1].

Theoretically, a propagation model can be applied to calculate the distance according to signal strength or time-of - arrival. In unobstructed free space, Friis transmission equation [10] shows that the signal strength level decreases at a rate inversely proportional to the distance travelled [11].

$$P_r = P_t \frac{G_t G_r \lambda^2}{16L\pi^2 d^2} \tag{1}$$

where P_r is the power received by receiver antenna, Pt is the power input to transmitter antenna, G_t is transmitter antenna gain, G_r is receiver antenna gain, L is system loss factor, λ is wavelength, and d is the distance between transmitter and receiver antennae.

Based on this relationship, the distance estimation between the RFID tag and the reader if the RSSI is known. In real world applications, this model becomes less useful because phenomena such as fading, absorption and blocking reduce the signal strength; reflection and refraction result in multi-paths of propagation; multi-source signal may interfere with each other and collide at the receiver. For this reason, other methods such as statistical analysis were developed to calibrate the relationship between signal strength and distance.

First, it is necessary to calibrate the system so that a mathematical model is obtained. For each calibration position, two tests were executed. The first one is used to estimate a mathematical model and the other one is used to validate the model using an Analysis of Variance (ANOVA). Then some experiments are performed to verify the IPS performance estimating the root mean square (RMS). The ultrasound sensor is used as the reference or the true value.

IV. EXPERIMENTAL SETUP

In the calibration, 100 samples were collected for each position. The approximated calibration positions presented in the Table I were defined by previous experiments and the experimental setup scheme as shown in the Fig. 2. The position obtained using the ultrasonic sensor is used as the reference to calibrate the IPS.

TABLE I. CALIBRATION POSITIONS

Calibration Positions	Position						
	1	2	3	4	5	6	7
Distance [cm]	20	30	40	50	60	70	80

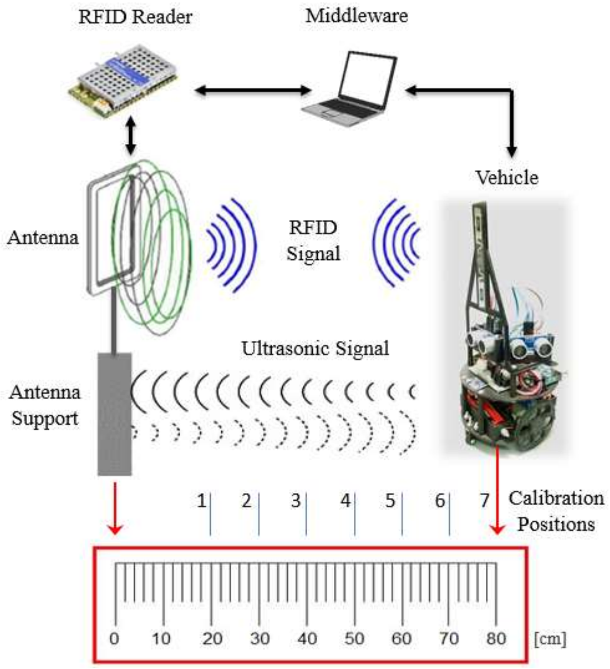

Figure 2. Experimental setup for calibration tests.

The antenna is 52 cm above the floor. Experiments with the vehicle in linear movement and constant velocity were performed to analyze the model performance. The scheme of the experimental setup, as shown in the Fig. 3 and the real environment of the experimental setup is presented in the Fig. 4. The position obtained using the ultrasound sensor is used as the reference to compare with the RSSI position estimation.

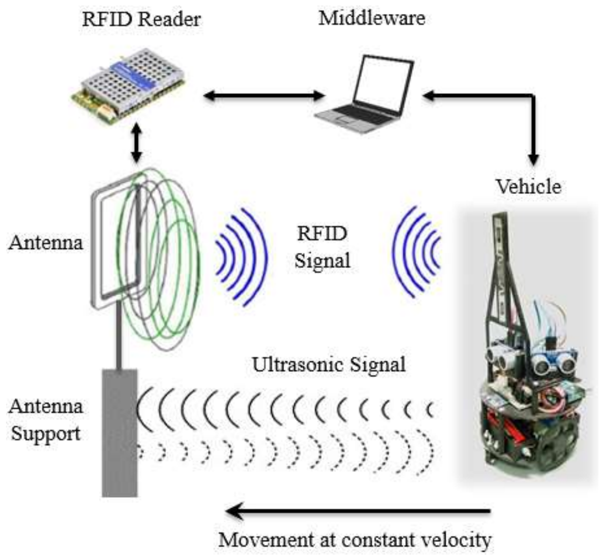

Figure 3. Experimental setup for the validation tests

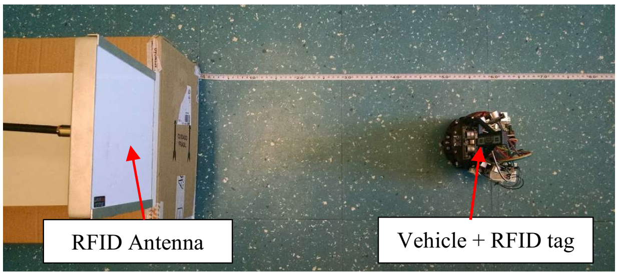

Figure 4. Real environment experimental setup

V. RESULTS AND ANALYSIS

As explained before, two types of calibration were performed. Fig. 5 represents the experimental data acquired during the tests that were then used in the calibration process, with two being needed for the validation analysis. Two different mathematical models were considered, a first-degree and a second-degree models. Fig. 6 represents the calibration curve obtained when considering the first-degree model, described by Eq. 2.

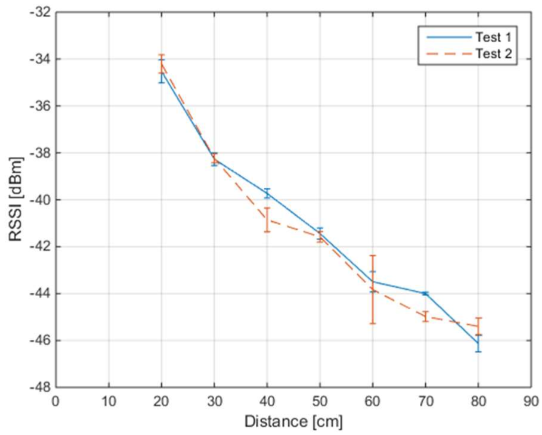

Figure 5. Experimental data acquired

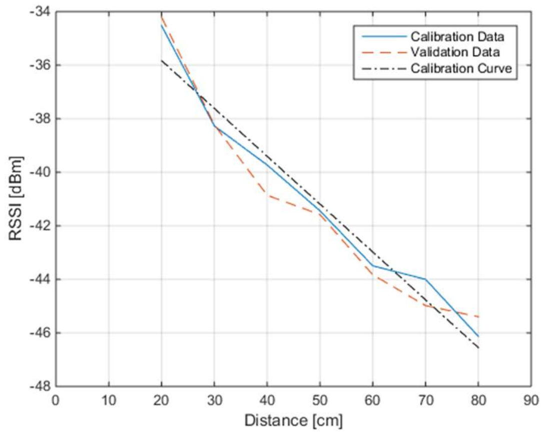

Figure 6. Calibration curve obtained considering the first-degree model

$$RSSI(d) = -0{,}1787d - 32{,}2564 \tag{2}$$

The calibration curve obtained using a second-degree model is represented in Fig. 7, with Eq. 3 as its respective equation.

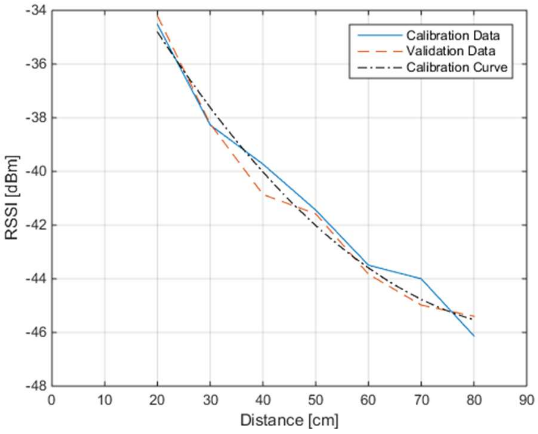

Figure 7. Calibration curve obtained using a second-degree model

$$RSSI(d) = 0{,}0021d^2 - 0{,}3841d - 27{,}9433 \qquad (3)$$

To select the best model to represent the distance measuring system a set of ANOVAs were performed. Tabs. II and III expose the tests regarding the first and second-degree models respectively. As shown by the percentage of explained variance, the second-degree model describes the system's behavior to a better extent and, therefore, was selected and used in all further tests to obtain the distance measure from the RSSI value.

TABLE II. ANOVA TABLE FOR THE FIRST DEGREE MODEL

Source of Variance	Sum of Squares	Degrees of Freedom (dof)	Mean Squares
Regression	178.8	1	178.8
Residual	10.7	12	0.9
Misadjustment	9.2	5	1.8
Error	1.5	7	0.2
Total	189.5	13	179.7
% explained variance: 94.4 % maximum explainable variance: 99.2			

TABLE III. ANOVA TABLE FOR THE SECOND DEGREE MODEL

Source of Variance	Sum of Squares	Degrees of Freedom (dof)	Mean Squares
Regression	185.9	2	93.0
Residual	3.6	11	0.3
Misadjustment	2.1	4	0.5
Error	1.5	7	0.2
Total	189.5	13	93.2
% explained variance: 98.1 % maximum explainable variance: 99.2			

To verify the system's aptitude in measuring distances of a moving vehicle, a set of tests were conducted with the mobile robot starting 80 cm away from the antenna at a constant speed and stopping 20 cm away. Since a reference measuring system was necessary, an ultrasonic sensor was used since it presents greater accuracy than what is expected from the proposed measuring system. Greater distances were not used because preliminary tests evidenced that the measures obtained were too unreliable to be useful. Fig. 8 displays the results from these tests without any post processing technique.

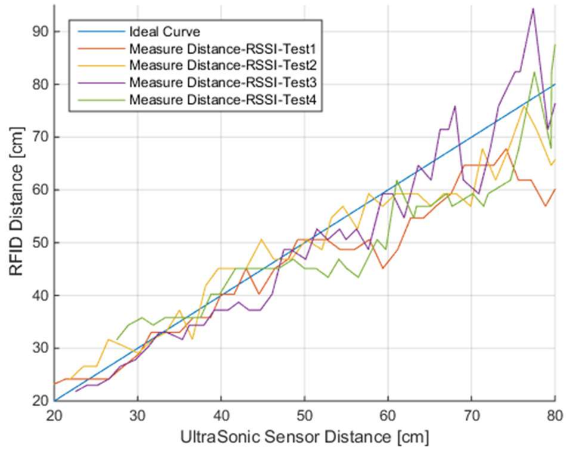

Figure 8. Distance measurements with the vehicle in movement

As the resolution of the reader M6e-micro is 1 dBm, according to Eq. 3, the minimum variation of distance that can be read is 4.8 cm.

In order to improve the measuring results presented in Fig. 8, given that the response seems to suffer from a significant noise level, a low-pass third-order Butterworth filter was applied to the data using a 0.5 Hz cutoff frequency. Fig. 9 displays the post-filtering results from the tests mentioned previously.

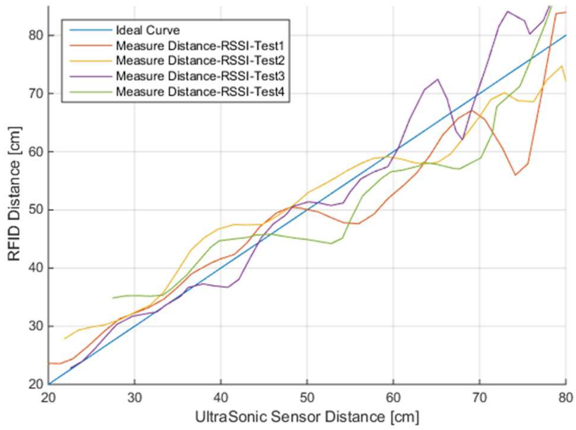

Figure 9. Filtered measurements with the vehicle in movement

To determine whether the filtering improves or not the resulting measures, it is necessary to perform a statistical analysis comparing the RMS of the error in all tests in both configurations. Table IV shows the maximum and RMS errors for the tests, their mean value and their standard deviation for both setups.

TABLE IV. EXPERIMENTAL RESULTS WITH THE VEHICLE IN MOVEMENT

	Unfiltered (cm)		Filtered (cm)	
	RMS	**Maximum**	**RMS**	**Maximum**
Test 1	7.5	22.0	5.8	18.2
Test 2	5.5	14.9	4.8	14.1
Test 3	7.3	17.7	6.0	14.1
Test 4	8.5	17.4	6.3	14.8
Mean	7.2	18.0	5.7	15.3
Standard Deviation	1.3	2.9	0.7	1.9

To verify the filter's improvement to the data, a test of the difference between two means was performed using the t-s*tudent* distribution and it was possible to check whether zero is contained in the obtained confidence interval. The borders calculated was 0.0643 and 2.8104 for a 90% confidence level, so it can be assumed that the filter does improve the measuring system's response by reducing the deviation between the obtained values and the ideal curve.

While performing the experiments, the error sources notice that the vehicle does not move in a straight line, also the vehicle's vibration produces angle variation, which influence on the RSSI value read. Another source of error is the electromagnetic noise produced by the electronic circuits present in the vehicle. Moreover, RF wave's reflection may cause a negative or positive interference on the backscattered RSSI tag signal.

VI. CONCLUSION AND FUTURE WORK

An IPS based on the RSSI of a RFID system is feasible to locate a vehicle within the range specified with a mean error of 5.7 cm, regarding the variation due to the RSSI reader resolution of 4,8 cm (1 dBm variation) . For a 90% confidence level, it can be assumed that the filter improves the IPS precision. But the localization system is still less accurate than other technologies.

The results obtained depend on the reader and tag used to perform the experiments and estimate the propagation model. To reproduce these results in practice it is needed to make a new calibration, and any site modification requires another one.

For future works, tests trying to control the position of the vehicle can be performed. Also other passive UHF tags and readers can be used and stochastic filters, such as extended Kalman filter, can be implemented in order to reduce measurement errors. Either, two dimensional test are going to be made. Tests with more than one vehicle are required to evaluate RSSI error and interferences. Also other passive UHF tags and readers can be used.

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