Smart Global Positioning System for Autonomous Delivery Robots in Hospitals

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Abstract— **Autonomous delivery robots have been employed in several hospitals across the United States to transport medical equipment, medicine, and food. However, they still face many difficulties, especially with the localization of robots within buildings, since most robots are currently using outdated techniques such as landmark recognition, beacons, or RFID tags. These methods are not only imprecise and unreliable but they also require a careful setup/distribution of special hardware in the hospital. Additional sensing and computing power are also needed for searching and detecting of landmarks, ultimately increasing manufacturing costs.**

We propose an innovative solution with a Smart Global Positioning System (S-GPS) framework and a novel algorithm for tracking delivery robots using multilateration technique with optimal number of references. The S-GPS framework enables to compute coordinates of all static sensors and mobile robots within the building and allows for fault tolerance in case of sensor failures. The algorithm provides precise localization of patients and delivery robots for improved navigation.

I. Introduction

Advances in robotics have permitted the development of delivery robots to be employed in hospitals. These robots are fully autonomous and move around the building without human intervention. The robots' main purpose is to transport medical equipment, medicine and food.

As this is a new technology, the autonomous delivery robots still face many difficulties, one of which is the localization of the robots within the hospital building.

Outdated positioning methods like landmark recognition and RFID tags are currently being used by many of the delivery robots [1]. Landmark recognition is used to determine the current position of the robot by observing the environment and recognizing the observed objects, associating them with known landmarks on a geographic map [2]. An RFID (Radio-Frequency Identification) tag consists of a small integrated circuit attached to a small antenna, which transmits a unique serial number to a reading device [3]; localization is achieved by equipping the robot with a reader, distributing RFID tags around the hospital building and having the robot keep a table of the location of each tag within the building.

Not only are these positioning methods imprecise and unreliable, but they also require the acquisition and setup of special hardware. Searching and detecting landmarks is a computationally expensive process which requires additional sensing and computing power. Solutions like beacons and RFID tags require the careful distribution and installation of specific hardware throughout the hospital. These factors ultimately contribute to increased manufacturing and purchasing costs.

II. State of Art

The TUG by Aethon, which currently operates in over 100 hospitals in the United States [4], requires a map of the building to be preloaded into the units. It uses the blueprints of the hospital to estimate its location. In order to navigate, the TUG employs an array of sonar, infrared and laser sensors, which help to avoid bumping into walls [5]. However, the TUG requires an additional guiding system which needs adequate maintenance. Moreover, it needs more sensing devices and computing power.

The MiNT-2 localization framework by Vikram Munishwar, et al, uses RFID tags to autonomously navigate through a space. The tags must be installed at a maximum distance of 4.50 centimeters from each other for the robot to always be in range of at least one. These tags must be distributed in all directions where the robot will be moving [6], so this solution is highly impractical.

Wang Hongbo proposes an omnidirectional mobile robot that navigates by communicating with previously set up references. The robot approximates its location by measuring its distance to these references through the technique of RSSI (Received Signal Strength Indication). In addition, the robot uses the contour of the ceiling as landmark to aid in the navigation [7]. However, RSSI is accurate only at short distances and the robot needs significant computing power to recognize the ceilings as a landmark.

Our proposed solution should overcome the excesses employed in the current systems.

III. Proposed Solution

We propose an innovative solution with a Smart Global Positioning System (S-GPS) framework and a novel algorithm for tracking mobile sensors using a multilateration technique employing an optimal number of references.

The S-GPS framework enables to compute coordinates of all static and mobile sensors within the building and allows for fault tolerance in case of sensor failures.

Some hardware is needed in order to establish the desired network architecture. Every robot will feature an RF module equipped with a Time of Flight (ToF) engine, such as the one provided by NXP in their JN5148 modules [8]. ToF allows for the measurement of the distance between two wireless modules. In order to perform the first mapping of the network, three or more of these modules must be set as

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static nodes and configured with their locations so that they can act as references.

The S-GPS framework can be implemented as a master-slave architecture, where the individual wireless modules represent the slaves and a central server represents the master. The server is in charge of performing the calculations required for the multilateration solution and managing permissions.

Multilateration is a positioning technique that involves measuring the distances from three or more known references to a target of unknown location. As previously stated, the distance measurement can be achieved by using a ToF engine, calculating the time spent by a signal to travel from the reference to the target and back to the reference node. These signals can be assumed to be traveling at the speed of light, which leaves us with an easily-solvable distance equation. It is important to mention that the distances obtained from the ToF measurements contain errors which will be accounted for later in the algorithm.

The distance obtained can be thought of as the radius of a circle whose center is the coordinate where the reference node is located. Finding the unique point where these circles intersect, effectively, gives us the location of the target node.

However, if more than three references are used, an overdetermined system of linear equations is obtained. The method of Least Squares is a standard approach to approximately solving overdetermined systems. The least squares procedure also minimizes the errors obtained from the calculated distances.

For an overdetermined system in the form $A \cdot x = b$, the least squares approximation can be obtained by multiplying both sides of the equation by the transpose of matrix A, such that

$$A^T \cdot A \cdot x = A^T \cdot b$$

The accuracy of the localization of the target improves with the addition of more references. But references cannot be added indefinitely to obtain a perfect localization. The ideal situation is to perform the localization using an optimal number of references in order to minimize energy consumption and the cost of the system.

IV. Simulation Result

Experiments were performed using the JN5148 wireless microcontrollers by NXP as depicted at Fig.1. As explained before, these modules feature the Time of Flight engine necessary for distance measurement.

Figure 1: *NXP JN5148 module used in distance measurement.*

Four hundred distance measurements were made with the purpose of determining the error produced by ToF on the NXP modules. These experiments were executed by placing two modules apart a set distance, ranging from 10 to 200 meters, in a clear hallway. The error was normalized to be ± 10.97333 meters, as shown in Table 1.

The data obtained from the distance measurements allowed us to simulate the application of our algorithm in a real setting. The simulation was run using an 11 meter error on the distance measurement. References, with a range of 200 meters, were randomly placed around the simulated delivery robot. Each test was run one hundred time and the results were averaged. As depicted in table 2, the simulation shows that, by using thirty-one references, the error in localization can be reduced to less than 3 meters.

Actual (m)	Average error (m)
10	0.717
20	0.469
30	1.214
40	4.54
100	12.44
200	46.46
Normalized	**10.97333**

Table 1: *Summary of errors obtained from experiments.*

References	Error (m)
3	52.35495
7	6.29307
11	4.92236
15	4.44344
19	4.14434
23	3.62092
27	3.34281
31	2.82235

Table 2: *Selected simulation results.*

V. Conclusion

In this paper, we propose a solution to the inefficient and expensive navigation techniques currently used by autonomous delivery robots in hospitals. Our framework and novel algorithm allows these robots to have a very accurate localization inside the hospital building, without the need of multiple positioning methods or distribution of special hardware in the hospital.

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