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"Helmsman, Set a Course": Using a Compass and RFID Tags for Indoor Localisation and Navigation

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Abstract. Localisation and navigation are still two of the most important issues in mobile robotics. In certain indoor application scenarios RFID (*radio frequency identification*)-based absolute localisation has been found to be especially successful in supporting navigation. In this paper we evaluate the feasibility of an RFID and compass based approach to robot localisation and navigation for indoor environments that are dominated by corridors. We describe our system and evaluate its performance in a small, but full-scale, test environment.

Keywords: robotics, rfid, localization, compass, evaluation.

1 Introduction

Localisation (the ability to position yourself in a model of the world) and navigation (the ability to follow a path specified in a model of the world) are fundamental abilities for autonomous mobile robot systems. The dominant approaches to robot localisation and navigation - such as Extended Kalman Filters [1], [2] Graph-Based Optimization Techniques [3], [4] and Particle Filters [5], [6] - are based on a probabilistic integration through time of odometry and range sensor (e.g., laser, sonar) data. Unfortunately, range sensor data is often noisy and systems that iteratively integrate noisy data are prone to failure with the passage of time, as errors accumulate [7]. In response to the problem of accumulated errors, absolute or landmark based localisation systems - using GPS (global positioning system) [8], RFID (*radio frequency identification*) [9], [10] or visual patterns [11] - have been proposed. Of these, RFID-based solutions have been shown to be well suited for structured indoor environments.

Contribution: In this paper, we evaluate the feasibility of an RFID and compass based approach to robot localisation and navigation for indoor environments that are dominated by corridors. The advantages of this approach are that it is relatively simple, low cost and robust. In order to evaluate the feasibility of the approach we have developed a proof-of-concept Lego robot system equipped with an RFID reader, a compass sensor, and a simple light sensor. This system uses a topological map that specifies the directional relationships between RFID tags in the environment that is augmented with lines drawn on the floor to assist with corridor following. The system is evaluated in a series of experiments that show how it can reliably navigate its environment.

Overview: This paper is organized as follows. In Section 2 we review background work and motivate our approach. In Section 3 we describe the system architecture. In Section 4 we present our evaluation scenario and results. Finally, in Section 5 we discuss the performance of the system and suggest directions for future work.

2 Background

Thrun et al [12, pg 191] define mobile robot localisation as "*the problem of determining the pose of a robot relative to a given map of the environment*". There are two basic approaches to localisation: *relative* localisation and *absolute* localization. Relative localisation [13] attempts to determine the location of a robot using information from various on-board sensors (e.g. laser range finders, gyroscopes, and encoders) and either integrating this information from a known starting position, or matching this information to a stored map. However, these techniques can be particularly error prone due to the accumulation of errors [7], and are computationally expensive [14].

Absolute localisation [13] relies on the existence of beacons or landmarks whose global positions within an environment are known. When a robot observes a specific known beacon or landmark it is absolutely located within the environment. Examples include GPS [8], visual pattern matching [15], triangulation of Wi-Fi signals [16], [17], and recognition of RFID tags [18]-[20], [21]. Absolute localisation methods are typically computationally inexpensive, not as prone to error as relative approaches and allow the addition of functional information at landmarks (e.g. room names or types). However, they suffer from the facts that they require an instrumented environment and do not localise a robot between observations. So, absolute localisation approaches are only suitable for certain applications [8].

RFID technologies [22] have been widely used in mobile robotics since the early 1990s [23], and offer an especially attractive solution to absolute localisation [18]. In contrast to GPS, RFID systems work indoors; they also have an advantage over visual solutions in that they do not require line-of-sight and are not affected by environmental conditions (e.g. lighting); and, finally, RFID-based solutions do not require the extensive calibration required of some other solutions (e.g. approaches based on Wi-Fi signals [17]).

In an RFID system an *RFID reader* reads information from *RFID tags* using radio waves. The use of radio waves means that this communication does not require touch or line of sight – both of which attractive properties. The simplest form of RFID system uses *passive* RFID tags that require no power and are only activated in the presence of a reader. These passive tags can store a small amount of information (e.g. a unique identifier or a simple sensor measurement) that is transmitted to the reader when both are in close proximity to each other. Passive tags have the advantage that they are very inexpensive (circa €0.10 per tag). An alternative is to use *active* RFID tags which are powered, can be read over greater distances and include more information. Active tags are, however, considerably more expensive (circa €10.00 per tag) than passive ones. RFID technologies are used extensively outside of robotics – e.g. in supply chain management [24] and ubiquitous computing [25].

For robot localisation there are two common ways that RFID technology is used (for a good overview of the use of RFID for robot localisation see [10]). An RFID tag can be attached to a robot and read when in proximity to RFID readers distributed throughout an environment. In this way the readers essentially act as beacons in the environment and triangulation is used to locate the robot based on the signal strength between the tag carried by the robot and the readers that can read it. While this approach has been successfully applied [26], long range RFID readers tend to be relatively expensive and so large environments would require a prohibitive number of them to ensure accurate localisation.

Alternatively, and more commonly, robots can be equipped with RFID readers which read RFID tags distributed throughout an environment. One example of this approach the *smart floor* [27] in which very large numbers of tags are embedded in the floor of an environment. These tags can be arranged in a regular [14], [18] or pseudo-random [20] pattern and localisation can be achieved through monitoring the progression of a robot across the tags. Some work has gone as far as using smart floors to extract orientation information as well as position [28]. However, a smart floor implementation requires such extensive instrumentation of an environment that it is not always appropriate.

Alternatively, RFID tags can be associated with important landmarks in an environment (both functionally important landmarks - such as a person's office - and navigationally important landmarks - such as a corridor junction). Olaf et al [29] describe one of the earliest examples of the use of RFID tags for mobile robot navigation. Kulyukin et al [30] provides a nice example of an implementation of such an RFID based navigation system in which a mobile robotic walking frame was built to assist people with visual impairment navigate indoor environments. This system used a topological map in which the links between nodes were annotated with behaviours such as turn left, turn right etc. MyungSik et al [31] took a different approach in which two RFID readers mounted on a mobile robot were used to orient the robot in order to dock at a tagged docking station. Other research also uses RFID readers to infer orientation as well as position [32] based on the signal strength recorded by the readers. However, global orientation requires the exact coordinates of the RFID tags to be known and is prone to error due to signal reflections and distortions.

Another option to measure orientation is to use a digital magnetic compass. Magnetic compasses are often overlooked in indoor robotics applications because absolute headings can be inaccurate due to the presence of interfering magnetic fields (e.g. from computer monitors) and large metal objects. Locally, however, digital magnetic compasses have been shown to have high levels of accuracy and repeatability [24]. For some applications, including our own, this local reliability is sufficient and the global problems can be ignored

The following section will describe the architecture of our system which uses RFID and compass sensors to perform localisation and navigation in corridor-dominated indoor environments.

3 System Architecture

The system is designed to work in a corridor-dominated indoor environment that has been augmented with RFID tags marking key locations. The current implementation of the system also assumes that the corridors have been further augmented with a coloured strip down the centre to aid navigation. Fig. 1 provides a schematic of the system architecture. In this figure:

- the arrow labeled *Goal[Tag ID]* represents the user giving the system a command to travel to a location marked with the RFID tag specified by the ID parameter (this command is passed to the robot via Bluetooth)
- the black arrows represent commands
- the clear arrows represent data flow
- the cylinder marked *Topological Map* represents a topological map that specifies the relative directional relationships between connected RFID tags (for example, given that there is a direct path between *Tag 1* and *Tag 2* the map might specify that *Tag 1* is *north* of *Tag 2*) and an optional functional label for each tag (e.g. *kitchen*)
- the rectangles with rounded corners represent sensors (RFID reader, Light Sensor and Compass)
- the rectangles with dashed outlines represent a conceptual decomposition of the system into three levels: planning, task and behaviour
- the rectangles with sharp corners represent processes, we will describe the roles of each process in detail below

The *route planner* process is the only process in the planning level of the system. This process is triggered by a command from the user that the system should go to a particular tag. The task of this process is then to use the information in the topological map, and the current location of the robot to plan a route to the goal tag. If the system does not know where it is currently located in the environment the route planner triggers the explorer process to locate the robot by finding the closest RFID tag. If the system does know where it is, the route planner uses an A* search [33] through the topological map to find a path from the current tag to the goal. Hence, each RFID tag is treated as a node of a target robot path. Once this path has been constructed the route planner triggers the navigator process to follow the path to the goal.

There are two processes at the task level of the architecture: the explorer process and the navigator process. These processes are both triggered by the route-planner process to carry out specific tasks.

The task of the *explorer* process is to find an RFID tag so that the system can locate itself in the topological map. This ability to locate itself within the topological space is a prerequisite to the robot planning a path from the current location to the goal. Once triggered, the explorer process implements a random walk search of the environment that continues until an RFID tag is located.[1] During this random walk

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[1] It is worth mentioning that the RFID reader used in our current implementation is a Parallax RFID Reader Module (available from www.parallax.com) with a reading range of approximately 2-5 cm. Due to this small reading range, as soon as an RFID tag is identified

the explorer may trigger the pilot behaviour to navigate corridors or the helmsman behaviour to reorient the robot's bearing (more on these behaviours anon).

The task of the *navigation* process is to follow a path from the current position to the goal position as specified by the route planner. This path consists of directional bearings (in the range [0° – 360°]) between RFID tags. A path is defined in the following format: **tag number + direction + tag number + direction…**

For example, the path "1+150+2+36+5+240+8" specifies that the robot is proximal to tag 1 and should drive on a bearing of 150° to tag 2; it should then turn to bearing 36° and drive to tag 5; then continue on bearing 240° to tag 8, the goal tag. The navigator can invoke the helmsman behaviour to orient the robot in a particular direction and the pilot behaviour to follow a corridor to the next tag.

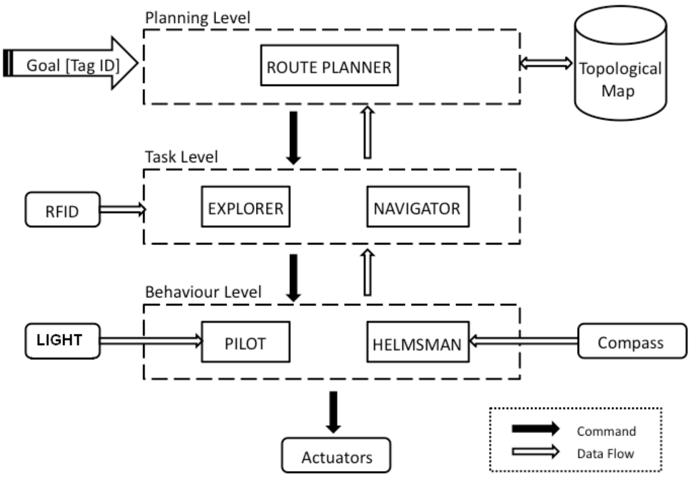

Fig. 1: A schematic of the system architecture.

The lowest level of the architecture is the behaviour level. There are two processes at this level: the pilot and the helmsman behaviour. The *helmsman* behaviour is responsible for orienting the robot in a particular direction. It does this by using the compass to check the current orientation of the robot and then turning commands to the motors until the desired orientation is reached. It is worth noting that our current robot uses a two-wheel differential drive configuration and can consequently turn within its own footprint. The *pilot* behaviour is responsible for navigating along corridors. In our current implementation the robot uses a light sensor to follow a coloured strip stuck to the ground along the middle of all corridors. This simplifies corridor following for this experiment but can be replaced with any appropriate corridor following behaviour (for example using range sensors to remain in the centre of a corridor).

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the robot can be assumed to be positioned at that RFID tag. Although this does introduce some small inaccuracies, their scale is negligible compared to the scale of the robot, and this approach greatly simplifies tag detection.

In the next section we present the experimental scenario in which the performance of the system was evaluated.

4 Evaluation

In order to evaluate the feasibility and performance of our architecture we implemented it on a Lego robot system and deployed the Lego robot in a full-scale multi-room test. Our robot platform is a Lego Mindstorm NXT[2] on which the native firmware has been replaced with the custom Lejos[3] firmware so that the Lejos API can be used. The robot is equipped with a HiTechnic NXT Compass Sensor[4].

The test environment consisted of a series of corridors connecting different rooms in a lab environment. Fig. 2 shows a topological map of the test environment and marks its salient features. The black circle indicates the start point used. The grayed circles numbered 1 through 5 represent decision points on the path where the robot had to change direction, in some instances onto a new path. The boxes labeled A, B, C, and D each marks a goal point in each of the four rooms used in the test. RFID tags were positioned at the start point, the decision points and the goals points. Fig. 3 shows the Lego robot following paths in the test environment.

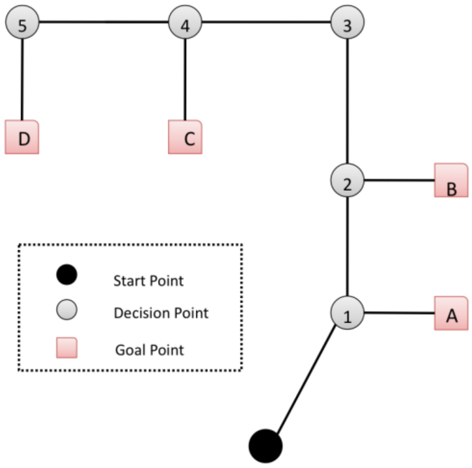

Fig. 2: A topological map of the test environment, showing the starting position, possible destinations and decision points.

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[2] For information on the Lego Mindstorms NXT platform see: mindstorms.lego.com

[3] For information on Lejos see: lejos.sourceforge.net

[4] For information on HiTechnic NXT Compass Sensor see: hitechnic.com

Fig. 3: A selection of photographs of the Lego robot and the test environment.

The robot had access to a topological map of the environment in which the bearings required in order to navigate between each pair of connected tags were given. Table 1 shows a sample of the topological data used by the robot. It is important to note that no absolute locations or distances between nodes in the map were available to the robot.

Table 1: A portion of the topological map used by the robot.

Node	Node	Bearing
Start Point	Decision Point 1	205°
Decision Point 1	Goal A	165°
Decision Point 1	Decision Point 2	284°
Decision Point 2	Goal B	164°
Decision Point 2	Decision Point 3	278°
Decision Point 3	Decision Point 4	5°
…	…	…

Following the architecture described in Section 3, when an RFID tag was encountered at a decision point the navigation process triggered the helmsman behaviour to orient the robot in the right direction, using the compass sensor. Black lines drawn on the floor marked the paths between the tags. The pilot behaviour was responsible for controlling line following. As an indication of the overall scale of the test environment Table 2 lists the distances from the start point to each of the goals.

Table 2. Distances from the start point to each of the goals.

From	To	Distance (cm)
Start Point	Goal A	285
Start Point	Goal B	404
Start Point	Goal C	736
Start Point	Goal D	813

A trial in the test consisted of requesting the robot to navigate from a start location to one of the rooms in the test environment. The same start location was used for all trials and five trials were run for each room. We recorded the number of successful and non-successful trials. A successful trial was one in which the robot navigated to the requested room and signaled that it had arrived. An unsuccessful trial was one where the robot lost the path

Table 3 lists the results of the test broken down by target. Overall, while allowing for the fact that the environment was augmented with lines to aid corridor following, when one considers the scale of the test environment relative to the actual robot the results are encouraging. Both of the two failed trials occured at decision point 1. In both instances this was caused by the robot overruning the tag and, consequently, losing the path. It should be noted that in both of these trials the helmsman behaviour did kick in and orient the robot in the right direction, unfortunately however the robot was not able to find the path again. It is encouraging that this is not a failure of the localisation or navigation components of the system, but rather of the corridor following which can be easily improved.

Table 3. Trial success rate by target goal.

Target	Success rate over 5 trials
Goal A	5
Goal B	5
Goal C	4
Goal D	4

5 Conclusions & Future Work

This paper reports on a feasibility study that tested an approach to robot localisation and navigation that integrates RFID technology with a compass. As such, it would not be appropriate to draw conclusions beyond the fact that the feasibility of the approach has been initially verified. That said the work does provide a good basis for future work. This kind of system offers a cheap and robust way to achieve reliable localisation and navigation within indoor, corridor-dominated environments without requiring overly extensive augmentation of the environment. Our immediate plans for future work are to extend the system with a recovery model to deal with cases where the robot does not encounter an RFID tag as expected, or when an unexpected tag is encountered; and to replace the use of coloured strips on the ground for corridor following with a range based corridor following solution based on the use of sonar sensors.

In the longer term we will port the system to a *MobileRobots PeopleBot* platform. This hardware port with its concomitant sensor upgrade will facilitate the implementation of more sophisticated behaviours (obstacle avoidance, corridor following, etc.). Following the hardware port there are a number of research directions we are interested in addressing. In particular, we are interested in removing the need for a pre-computed topological map of the RFID tags in the environment. To address this issue we would like the robot to be able to autonomously construct this map. A further refinement, inspired by [34], would be for the robot to place the tags in the environment to mark locations that it deems interesting for navigation.

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