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Navigating the Corridors of Power : Using RFID and Compass Sensors for Robot Localisation and Navigation

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Navigating the Corridors of Power: Using RFID and Compass Sensors for Robot 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 *Radio frequency identification* (RFID) based absoloute localisation has been found to be especially successful in supporting navigation. In this paper we examine the feasibility of an RFID and compass based approach to robot localisation and navigation for indoor environments that are dominated by corridors. We present a proof of concept system and show how it can be used to localize within and navigate through an environment.**

I. 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 localization 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 localization systems, using GPS [8], Radio frequency identification (RFID) [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 consider 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 examine the feasibility of the approach we have developed a proof of concept Lego robot system equipped with an RFID reader, a compass sensor, and three ultrasonic sensors. This system has successfully localized within and navigated through an environment using a topological map that specifies the directional relationships between RFID tags in the environment. It is worth noting that the precise coordinates of the tags are not used by the system.

Overview: This paper is organized as follows. In Section II we review background work and motivate out approach. In Section III we describe the system architecture. In Section IV the implementation of the system is described and an illustrative worked example is presented. Finally, in Section V we describe the directions we intend to expand on this work in the future.

II. 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 broad types of localization methods: *relative localization* and *absolute localization*. Relative localization [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 computationally expensive [14].

Absolute localization [13] relies on the existence of beacons or landmarks whose global positions within an environment are known. A robot's observation of specific beacons or landmarks absoloutely locate the robot 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]. Absoloute localization 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 absoloute 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 localization [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. Wi-Fi based approaches [17]).

In an RFID system an *RFID reader* reads information from

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RFID tags using radio waves. The use of radio waves means that this communication does not require touch or line of sight – both 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 powered *active* RFID tags which 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 way in which localisation is achieved through this approach is to use what is known as a *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, the 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] was one of the earliest papers to propose 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 absoloute headings can be inaccurate due to the presence of interfering magnetic fields (e.g. from computer monitors) and large metal objects. However, locally digital magnetic compasses have been shown to have high levels of accuracy and repeatability [24]. For some applications, including our own, this is sufficient.

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.

III. SYSTEM ARCHITECTURE

Our system is designed to work in a corridor-dominated indoor environment that has been augmented with RFID tags marking key locations. 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 and 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, Sonar and Compass)
- the rectangles with dashed outlines represent a conceptual decomposition of the system into three levels: planning, task and behavior levels
- 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.

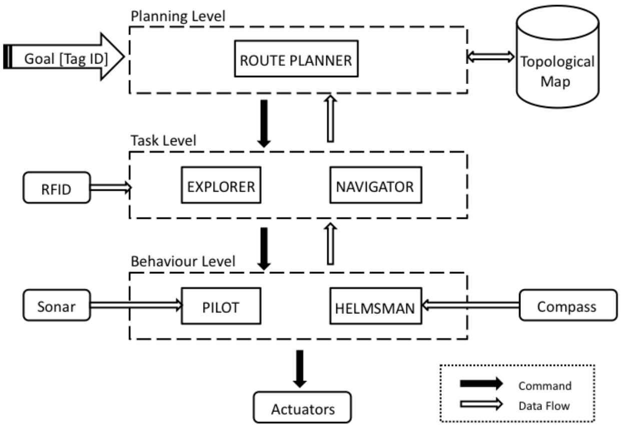

Fig. 1: System architecture

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. During this random walk the explorer may trigger the pilot behavior to navigate corridors or the helmsman behavior to reorient the robot's bearing (more on these behaviors 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 between RFID tags, where bearings are from the set {N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, NNW}. While it would be straightforward to use numeric bearings in the range [0 °– 360 °] we have found that the granularity of the defined set suits our requirements and simplifies implementation. A path is defined in the following format:

tag number + direction + tag number + direction …

For example, the path "1S2NE5E8" specifies that the robot is proximal to tag 1 and should drive south to tag 2; it should then turn north east and drive to tag 5; then continue east to tag 8, the goal tag. The navigator can invoke the helmsman behavior to orient the robot in a particular direction and the pilot behavior to follow a corridor to the next tag.

The lowest software level of architecture is the behavior level. There are two processes at this level: the pilot and the helmsman behavior. The **helmsman** behavior 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 issuing 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** behavior is responsible for navigating along corridors. It uses input from an array of 3 sonar sensors (one pointing forward and one pointing to each side of the robot) to implement obstacle avoidance and where possible to keep the robot traveling along the center of a corridor.

In the next section we present a worked example that illustrates the abilities of this system.

IV. WORKED EXAMPLE

In order to examine the feasibility of the system described in the previous section, we have implemented a prototype in which a robot navigates a scale model of an indoor environment. Our robot platform is a Lego Mindstorm NXT (mindstorms.lego.com) that is equipped with a Parallax USB RFID reader (www.parallax.com), a HiTechnic NXT Compass Sensor (www.hitechnic.com), and three NXT ultrasonic sensors. In this prototype processing is not done onboard the robot but on an external PC via a Bluetooth connection. The Lejos API (www.lejos.org) was also used in developing our system.

In order to experiment with the system a test environment has been built comprised of a number of corridors and labeled locations. These corridors have had a collection of RFID tags placed within them, the relationships between which are stored in a pre-defined topological map (the relationship between each tag is just a compass direction, e.g. *north-north-east*). Fig. 2 shows a picture of the robot in the test environment.

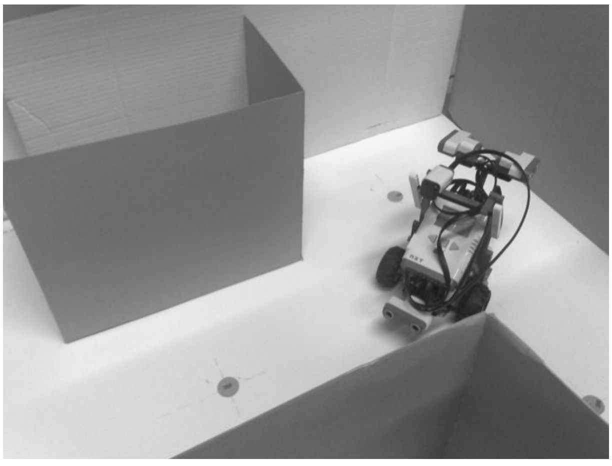

Fig. 2: The prototype robot featuring three ultra-sonic sensors, a compass sensor and an RFID reader (underneath) in the test environment

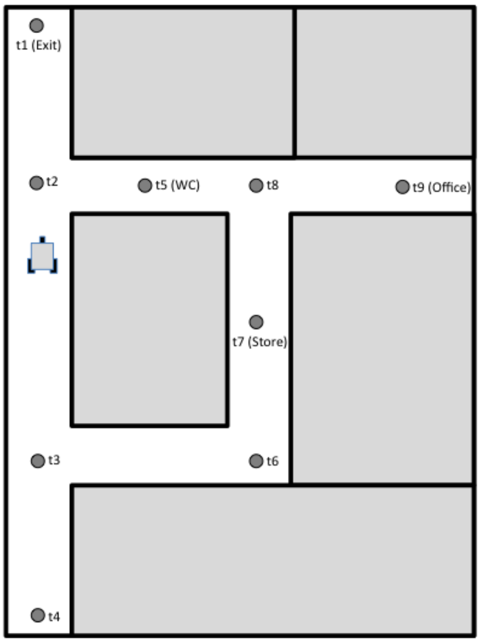

Fig. 3: A schematic of the test environment in which our system operates.

A schematic of the test environment itself is shown in Fig. 3. Some of the landmarks in this map are labeled to indicate important locations (e.g. *office*), while others act only as navigation nodes (e.g. *t1*). The robot can initially be placed at any location within the environment, however, for this example we will assume that the robot starting position is as shown in Fig. 3. The user then requests that the robot navigate to some location – in this case *Office* (or *t9*).

However, at this point the robot is not aware of its location and so the route planner process instigates the explorer task. Under the explorer task the robot performs a random walk through the corridors in the environment until it successfully reads an RFID tag, in this case *t3*, shown in Fig. 4. At this point the Route Planner process, now aware of the robot's location, plans a route across the topological map to get to the location marked *Office*. This route is represented as "3E6N7N8E9" and shown in Fig. 5.

The route planner process then invokes the navigator task to which it passes the route to follow. The navigator begins by calling the helmsman behaviour to turn the robot to face east and then using the pilot task navigates down the corridor until it reaches *t6*. Control then passes again to the helmsman behaviour which turns the robot to face north before the pilot behaviour navigates down the corridor. This repeats on reaching *t7*, which leads the robot to *t8*. The helmsman behaviour takes over again to turn the robot east before the pilot behaviour navigates down the corridor to *t9*, the goal.

We have performed a range of tests using our prototype robot in this scaled environment and have found it to be reliably able to navigate between the locations shown. The following section will explain how we plan to develop this work in the future.

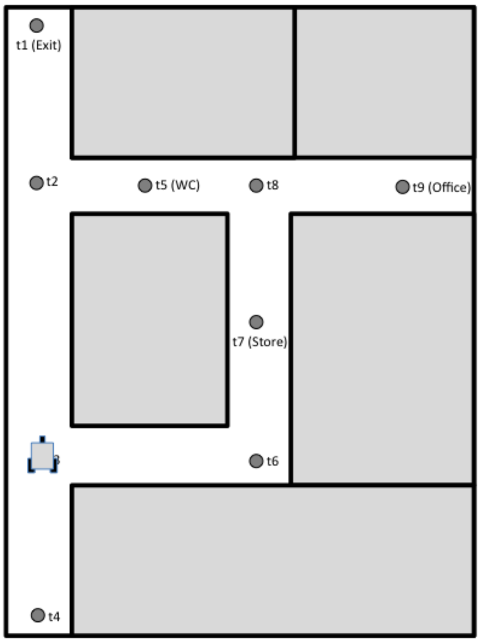

Fig. 4: The test environment after the explorer task has found an RFID tag.

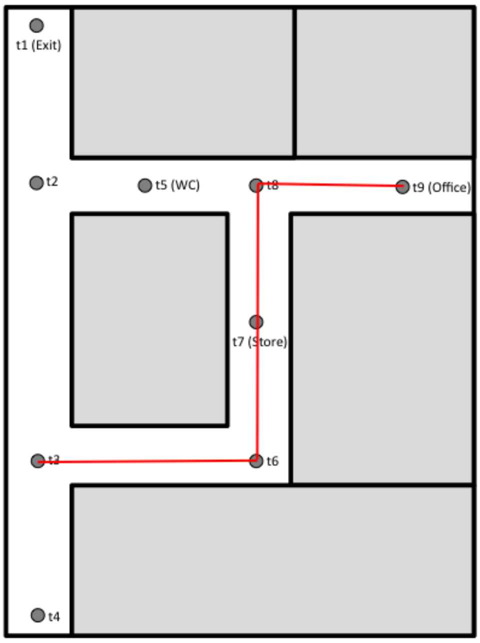

Fig. 5: The route found through the environment

V. CONCLUSIONS & FUTURE WORK

This paper reports on a feasibility study that tested an approach to robot localization 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. Our immediate plan is to upgrade the system with a recovery model, so that the robot can recover itself from missing RFID tags. The recovery model also deals with the condition when an RFID that is expected is not there.

```
// the target tag exists in the environment
While (ProcessingTime < RecoveryTime)
{
    if the discovered tag is the Next Target Tag
        Correct
    if not
        if the discovered tag is part of the Target Route
            Continue to process the navigation using the route from current tag to the Target Tag
        if not
            Recalculate the Target Route from current tag to the Target Tag and process
}
//the target RFID tag expected is not in the environment (miss the target)
Stop robot motors and report the result
```

Where the "ProcessingTime" is the time from navigation starts until now; "RecoveryTime" is the maximum time that allowed for the robot to finish one navigation process; "Discovered tag" is the last RFID tag found; "Next Target Tag" is the next expected tag in the navigation process; "Target Route" is the route from a tag to the target tag.

Also 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.). More importantly, however, a hardware upgrade is a prerequisite to: (1) testing the cross-sensitivity of the proposed sensor array (RFID, compass, laser, etc.); and (2) the carrying out of larger scale experiments to test the approach. 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 deemed interesting for navigation.

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