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RFID-Based Mobile Robot Positioning - Sensors and Techniques

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ABSTRACT

Mobile robot navigation using analog signal strength of a Radio Frequency Identification (RFID) device is a promising alternative of different types of robot navigation methods in the state of the art. Skilled navigation in mobile robotics usually requires solving two problems: the knowledge of the position of the robot, and a motion control strategy. Moreover, when no prior knowledge of the environment is available, the problem becomes even more challenging, since the robot has to build a map of its surroundings as it moves. Exact knowledge of the position of a vehicle is a fundamental problem in mobile robot applications. In search for a solution, researchers and engineers have developed a variety of systems, sensors, and techniques for mobile robot positioning.

This paper provides a review of relevant mobile robot positioning technologies. The paper defines seven categories for positioning systems: 1. Odometry; 2. Inertial Navigation; 3. Magnetic Compasses; 4. Active Beacons; 5. Global Positioning Systems; 6. Landmark Navigation; and 7. Model Matching. The characteristics of each category are discussed and examples of existing technologies are given for each category. The field of mobile robot navigation is active and vibrant, with more great systems and ideas being developed continuously. For this reason the examples presented in this paper serve only to represent their respective categories, but they do not represent a judgment by the authors.

Keywords – RFID, Mobile Robot, Vechicle.

I. INTRODUCTION

This paper surveys the state-of-the-art in sensors, systems, methods, and technologies that aim at finding a mobile robot's position in its environment. In surveying the literature on this subject, it became evident that a benchmark-like comparison of different approaches is difficult because of the lack of commonly accepted test standards and procedures. The research platforms used differ greatly and so do the key assumptions used in different approaches. Further challenges arise from the fact that different systems are at different stages in their development. For example, one system may be commercially available, while another system, perhaps with better performance, has been tested only under a limited set of laboratory conditions. For these reasons we generally refrain from comparing or even judging the performance of different systems or techniques. Furthermore, we have not tested most of the systems and techniques, so the results and specifications given in this paper are derived from the literature.

Finally, we should point out that a large body of literature related to navigation of aircraft, space craft, or even artillery addresses some of the problems found in mobile robot navigation [1]. (e.g., [Farrell, 1976; Battin, 1987]. However, we have focused our survey only on literature pertaining directly to mobile robots. This is because sensor systems for mobile robots must usually be relatively small, lightweight, and inexpensive. Similarly we are not considering Automated Guided Vehicles (AGVs) in this article. AGVs use magnetic tape, buried guide wires, or painted stripes on the ground for guidance. These vehicles are thus not freely programmable and they cannot alter their path in response to external sensory input (e.g., obstacle avoidance). However,

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the interested reader may find a survey of guidance techniques for AGVs in [Everett, 1995].

The fundamental idea behind dead-reckoning navigation systems is the integration of incremental motion over time [1]. In this navigation method a small precision errors and sensor drifts inevitably lead to increasing cumulative errors in the robot's position and orientation, unless an independent reference is used periodically to correct the error [2]. The studies in [3], [4] are developed based on the integration of dead reckoning and visual landmark recognition methodologies for the navigation control of a vehicle along a predetermined path in a forest.

II. REVIEW OF SENSORS AND TECHNIQUES

2.1 Odometry

Odometry is the most widely used navigation method for mobile robot positioning; it provides good short-term accuracy, is inexpensive, and allows very high sampling rates. However, the fundamental idea of odometry is the integration of incremental motion information over time, which leads inevitably to the unbounded accumulation of errors. Specifically, orientation errors will cause large lateral position errors, which increase proportionally with the distance traveled by the robot. Despite these limitations, most researchers agree that odometry is an important part of a robot navigation system and that navigation tasks will be simplified if odometric accuracy can be improved. For example Cox [1991], Byrne et al. [1992], and Chenavier and Crowley [1992], propose methods for fusing odometric data with absolute position measurements to obtain more reliable position estimation. Odometry is based on simple equations (see [Borenstein et al., 1996a]), which hold true when wheel revolutions can be translated accurately into linear displacement relative to the floor.

However, in case of wheel slippage and some other more subtle causes, wheel rotations may not translate proportionally into linear motion. The resulting errors can be categorized into one of two groups: *systematic errors* and *non-systematic errors* [Borenstein and Feng, 1996]. Systematic errors are those resulting from kinematic imperfections of the robot, for example, unequal wheel diameters or uncertainty about the exact wheelbase. Non-systematic errors are those that result from the interaction of the floor with the wheels, e.g., wheel slippage or bumps and cracks. Typically, when a mobile robot system is installed with a hybrid odometry/landmark navigation system, the density in which the landmarks must be placed in the environment is determined empirically and is based on the worst-case systematic errors. Such systems are likely to fail when one or more large non-systematic errors occur.

2.2 Inertial Navigation

Inertial navigation uses gyroscopes and accelerometers to measure rate of rotation and acceleration, respectively. Measurements are integrated once (or twice, for accelerometers) to yield position. Inertial navigation systems have the advantage that they are self-contained, that is, they don't need external references. However, inertial sensor data drift with time because of the need to integrate rate data to yield position; any small constant error increases without bound after integration. Inertial sensors are thus mostly unsuitable for accurate positioning over an extended period of time.

III. SYSTEM ARCHITECTURE

The high level architecture of the proposed navigation system consists of an RFID communication module and a Fuzzy Logic Controller (FLC). The RFID communication module provides the robot with an analog signal (i.e. phase difference in this case) and the IDs of all the RFID tags in its operating region. The FLC helps the robot to take the necessary action(s) to move from one point to another point in its work space.

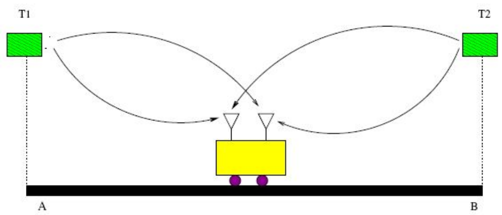

Fig. 1. High-level system configuration with two RFID tags

A. RFID Communication Module

The high level architecture of the custom-designed RFID communication module is depicted in Fig. 2. It is worth mentioning that none of the commercially available RFID readers to date is capable of providing the analog information (phase difference in our case) to implement a navigation algorithm. This is simply because all what these readers currently offer is the ID number of the transponders within its communication ranges. As a result, preliminary studies were conducted using a custom-built RFID reader and a digital oscilloscope to confirm the fact that the phase difference defined in (1) can indeed be used to know if the tag lies on the left or the right of the vertical plane perpendicular to the ground and dividing the line segment connecting the two receiving antennas of the RFID reader at their midpoint. The left and right antennas provide the signal's phase angles Ø1 and Ø2, respectively, which are used to calculate the phase difference defined by

$$\Delta\phi = \phi_1 - \phi_2$$

This technique can be easily implemented using any future commercial readers capable of computing the phase information of the signals received by the RFID tags.

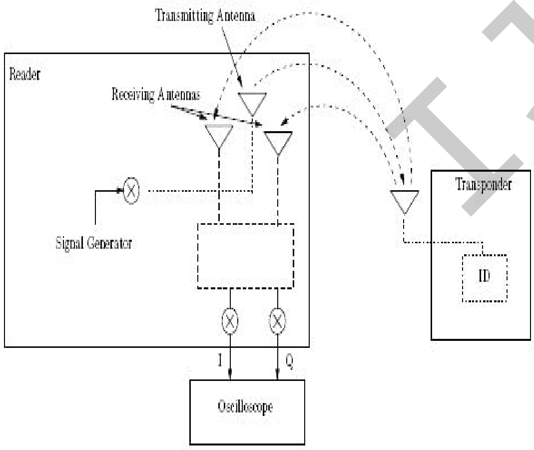

Fig. 2. RFID system setup to compute the phase difference.

B. Fuzzy Logic Controller (FLC)

The FLC of our navigation algorithm is dedicated to provide intelligent actions to be taken by the robot to navigate from one point to another. The reason why an FLC is chosen in this application is the convenient framework it provides to incorporate human knowledge in operating machines in an intuitive manner. This controller acts as the inference engine to decide on the robot's next orientation given the current phase difference of the signal transmitted by the RFID destination tag. In the current work, we use a single-input single-output Mamdani-type FLC as shown in Fig. 3. The aim of the FLC is to decide on the amount of tuneup **Δθ**that the robot has to apply to its direction **θ** to converge to its target position. The FLC's input is the phase difference **Δθ** provided by the two directional antennas mounted to the RFID reader on the robot. The robot then uses this information to update its direction following the update rule.

$$\theta^{(\text{new})} = \theta^{(\text{old})} + \Delta\theta$$

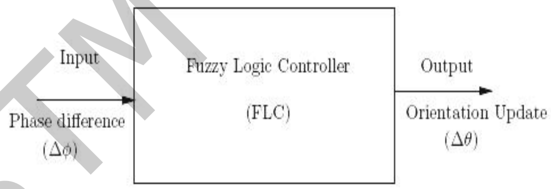

Fig. 3. FLC model used by the mobile robot.

IV. LANDMARK NAVIGATION

Landmarks are distinct features that a robot can recognize from its sensory input. Landmarks can be geometric shapes (e.g., rectangles, lines, circles), and they may include additional information (e.g., in the form of bar-codes). In general, landmarks have a fixed and known position, relative to which a robot can localize itself. Landmarks are carefully chosen to be easy to identify; for example, there must be sufficient contrast relative to the background. Before a robot can use landmarks for navigation, the characteristics of the landmarks must be known and stored in the robot's memory. The main task in localization is then to recognize the landmarks reliably and to calculate the robot's position. In order to simplify the problem of landmark acquisition it is often assumed that the current robot position and orientation are known approximately, so that the robot only needs to look for landmarks in a limited area. For this reason good odometry accuracy is a prerequisite for successful landmark detection.

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They use sensors to sense the environment and then extract distinct structures that serve as landmarks for navigation in the future. Our discussion in this section addresses two types of landmarks: “artificial” and “natural” landmarks. It is important to bear in mind that “natural” landmarks work best in highly structured environments such as corridors, manufacturing floors, or hospitals. Indeed, one may argue that “natural” landmarks work best when they are actually man-made (as is the case in highly structured environments). For this reason, we shall define the terms “natural landmarks” and “artificial landmarks” as follows: natural landmarks are those objects or features that are already in the environment and have a function other than robot navigation; artificial landmarks are specially designed objects or markers that need to be placed in the environment with the sole purpose of enabling robot navigation.

4.1 Natural Landmarks

The main problem in natural landmark navigation is to detect and match characteristic features from sensory inputs. The sensor of choice for this task is computer vision. Most computer vision-based natural landmarks are long vertical edges, such as doors, wall junctions, and ceiling lights (see TRC video clip in [Borenstein et al., 1996b]).
When range sensors are used for natural landmark navigation, distinct signatures, such as those of a corner or an edge, or of long straight walls, are good feature candidates. The selection of features is important since it will determine the complexity in feature description, detection, and matching. Proper selection of features will also reduce the chances for ambiguity and increase positioning accuracy.

One system that uses natural landmarks was developed jointly by the Atomic Energy of Canada Ltd (AECL) and Ontario Hydro Technologies with support from the University of Toronto and York University [Jenkin et al., 1993]. This project aimed at developing a sophisticated robot system called the “*Autonomous Robot for a Known Environment*” (ARK).

4.2 Artificial Landmarks

Detection is much easier with artificial landmarks [Atiya and Hager, 1993], which are designed for optimal contrast. In addition, the exact size and shape of artificial landmarks are known in advance. Size and shape can yield a wealth of geometric information when transformed under the perspective projection. Researchers have used different kinds of patterns or marks, and the geometry of the method and the associated techniques for position estimation vary accordingly [Talluri and Aggarwal, 1993]. Many artificial landmark positioning systems are based on computer vision. We will not discuss these systems in detail, but will mention some of the typical landmarks used with computer vision.Fukui [1981] used a diamond-shaped landmark and applied a least-squares method to find line segments in the image plane. Other systems use reflective material patterns and strobed light to ease the segmentation and parameter extraction [Lapin, 1992; Mesaki and Masuda, 1992]. There are also systems that use active (i.e., LED) patterns to achieve the same effect [Fleury and Baron, 1992]. The accuracy achieved by the above methods depends on the accuracy with which the geometric parameters of the landmark images are extracted from the image plane, which in turn depends on the relative position and angle between the robot and the landmark. In general, the accuracy decreases with the increase in relative distance. Normally there is a range of relative angles in which good accuracy can be achieved, while accuracy drops significantly once the relative angle moves out of the “good” region.

V. CONCLUSION

This paper presented an overview over existing sensors and techniques for mobile robot positioning. We defined seven categories for these sensors and techniques, but obviously other ways for organizing the subject are possible. The foremost conclusion we could draw from reviewing the vast body of literature was that for indoor mobile robot navigation no single, elegant solution exists. For outdoor navigation GPS is promising to become the universal navigation solution for almost all automated vehicle systems. Unfortunately, an indoor equivalent to GPS is difficult to realize because none of the currently existing RF-based trilateration systems work reliably indoors. If line-of sight between stationary and onboard components can be maintained, then RF-based solutions can work indoors as well. However, in that case optical components using triangulation are usually less expensive. The market seems to have adopted this thought some time ago, as can be seen in the relatively large number of commercially available navigation systems that are based on optical triangulation. Despite the variety of powerful existing systems and techniques, we believe that mobile robotics is still in need for a particularly elegant and universal indoor navigation method. Such a method will likely bring scientific recognition and commercial success to its inventor.

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