RFID Based Navigation System for Indoor Mobile Robots

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Abstract: A new navigation method is described for indoor mobile robots. The robot system is composed of a Radio Frequency IDentification (RFID) tag sensor, a laser range scanner, and a commercial three-wheel mobile platform. The RFID tags are used as landmarks for global path planning and the topological relation map which shows the connection of scattered tags through the environment is used as course instructions to a goal. The robot automatically moves along hallways using the scanned range data until a tag is found and then refers to the topological map for the next movement. Our proposed technique would be useful for real-world robotic applications such as intelligent navigation for motorized wheelchairs.

Keywords: Autonomous mobile robots; Navigation systems; Path planning.

1. INTRODUCTION

This paper describes a navigation system for mobile robots which are assumed to move autonomously to a given goal in man-made environments such as hallways in a building. The main part of our navigation system is global path planning and local path planning. A key function of the global path planning is to dictate a direction to a goal at a particular place such the intersection of two hallways in a building. The local path planning plays a role of moving the robot along walls avoiding obstacles. The navigation system, therefore, requires a mechanism for recognizing such particular places in the building and locating them on a world map that gives course directions to a goal. Additionally, it requires a function of generating a free space map in a hallway.

Two common approaches to global path planning are metric-based and landmark-based navigation [Murphy(2000)]. Metric-based navigation relies on metric maps of the environment, resulting in navigation plans such as move forward five meters, turn right ninety degrees and move forward another eight meters. For position-sensing schemes, this approach relies on dead-reckoning based on information about the motion of the robot derived from the wheel encoders, or absolute position estimation using the global positioning system (GPS) [Hofmann-Wellenof(2003)]. These metric data are, however, likely to be corrupted by sensor noise and this navigation method is vulnerable to inaccuracies in position estimates.

To avoid reliance on error-prone metric data, an alternative approach is landmark-based navigation [Kubits(1997), Kawamura(2002)]. Landmark-based navigation relies on topological maps whose nodes correspond to landmarks (locally distinctive places) such as corridor junctions or doors. Map edges indicate how the landmarks connect and how the robot should navigate between them. A typical landmark-based navigation plan might be to move forward to the junction, turn into the corridor on the right, move to its end, and stop. This may involve a complete absence of metric data and then the method does not depend on geometric accuracy. It has apparent analogies with human spatial perception, so it is easy to make a map of the environment. In addition, topological representations avoid the potentially massive storage costs associated with metric representations.

One problem to be solved in the landmark-based approach is to decide what are suitable for landmarks in the environment. Landmarks should be a distinctive one and easy to recognize without special costs. In a building intersections, corners, and doors are very important places for navigation and they could be a landmark. However, they are often repetitively similar and suffer from problem of occasionally sensors not being able to distinguish between similar landmarks, such as different doors of the same size. This can lead to both inefficiency and mistakes. Although such landmarks with an artificial sign could be reliable and useful, painted marks on walls would require special image processing to extract them from the scene. This would entail a complicated and costly process.

Therefore, we propose a method using passive Radio Frequency IDentification (RFID) tags as a landmark. The RFID tags are a passive, non-contact, read-only memory system and can store a unique number for identification of the location. The tag data can be read from one meter away via electromagnetic waves. The tags are pasted on walls at particular places in a building. Robots just pass by the tags. The tags allow the acquisition of location information at remarkable speeds without the accurate control of robot positions for sensing the tags. The passive RFID tags do not need an on-board power supply like a battery and generate operating power from the received electromagnetic waves. The tags are very light and thin. They therefore can be embedded easily in the environment and offer a virtually unlimited operational lifetime.
Man-made environments such as hallways are usually constructed with vertical planes (walls, pillars, and doors) and a horizontal plane (a floor area). In our method the RFID tags are pasted sparsely on walls. The precise positions of the tags in a hallway is not known. Also, the robot is not aware of the length of hallways. The robot just follows the walls of hallways until it finds a tag. It is essential that an mobile robot be able to realign itself relative to a wall and then proceed if it becomes disoriented due to obstacles on the floor, open doors or pillars. Such local path planning requires knowing where vertical planes are in the scene or where an empty space is on the floor. Range-sensing makes it possible to get such geometrical information on objects on the floor. Considerable effort has been invested to the development of methods for extracting geometrical information from scenes. Range-sensing for the navigation of mobile robots is typically done by stereo vision [Urmson(2002), Hamzah(2010)], wherein, for example, line segments are used as features to determine corresponding pairs in two images. Stereo vision systems can produce the 3D location of the corresponding pairs. This is a costly process. Sonar range finders [Ray(2080)] are also possible to sense distance to a wall and measuring the orientation of a robot with respect to the wall. The data processing is very simple and speedy. However, they are are apt to overlook small, thin objects in hallways due to low spatial resolution. Therefore, we adopt a compact laser range scanner to get geometrical information. The laser range scanner [L.Kneip(2009), Ogaz(2009)] can create 2D maps of the proximity to nearby objects both very fast and with adequate resolution. Image processing for extracting free space from the 2D map can be done in a small computer mounted on a robot.

2. RFID TAGS AS LANDMARKS

Figure 1 shows an RFID tag and the antenna box of the RFID tag sensor system mounted on a mobile robot. The RFID tag (shielded in a 12cm square plastic plate) is an IC memory (115 Bytes) with a built-in antenna, which is pasted on a wall near particular places in a building. Each IC memory has a unique ID number which can provide information on its location within the building. The RFID tag sensor consists of an RF transceiver and an antenna. The RF transceiver illuminates an RFID tag with a short pulse of electromagnetic waves (2.45GHz, 0.3w). The tag receives the RF transmission, rectifies the signal to obtain DC power, reads its memory to get the ID number, and modulates the antenna backscatter in response to the interrogation. The RF transceiver obtains the ID number and reports it to a host computer through an RS-232c serial port. Since the induction area of a tag is 40cm wide and 100cm depth from the antenna the robot does not need precise positioning mechanisms to locate and access the tags. The robot just passes by tags without the accurate control of position for sensing their numbers.

3. MAP FOR NAVIGATION

Figure 2(a) shows an example of a floor plan in a building. The letters a, b, c, d, e, f, g, and h in the floor plan denote the intersections of two hallways, the junctions or near the door, which can be a particular place for a mobile robot. At these places the robot has to choose an action to reach a given goal; left-turn, right-turn, straight ahead, U-turn, or stop if the place is a destination. The robot repeats one of these actions at every particular place. The particular places can be considered a sub-goal. Global path planning tasks requires a world map for deciding a sequence of sub-goals to a given goal. Figure 2(b) describes
the topological relation of these particular places in the building. The nodes of the graph with a letter correspond to the particular places such as an intersection in the floor plan, respectively. An edge between two nodes denotes that a hallway exists and a robot can pass along it to the next particular place. Using graph search techniques you can generate a sequence of particular places to lead the robot to a given goal, if a starting node is given on the graph. Therefore, the topological relation of particular places through hallways can be used as a world map.

To distinguish particular places in the building we use the RFID tags. The tags are pasted on the left side walls near the intersections of two hallways, the junctions or doors. Figure 3 illustrates an example of the location of four RFID tags at an intersection. Actually, it is very difficult to paste a tag precisely in a fixed position in a hallway or to measure its position. The role of tags is to give just information that the robot is coming upon an intersection and what the name of the intersection is. Figure 4(a) illustrates the configuration of the tags in the floor plan. The dots near particular places show the positions of RFID tags and the numbers are an ID number which the navigation system uses to identify upcoming intersections in the robot path. The scattered tags through hallways are used as a cue to decide the next action. In our scenario the robot moves along the left side of hallways finding tags and then the navigation system recognizes the robot’s location on a world map based on the tag’s ID number and decides the next movement of the robot toward a given goal.

In global path planning the navigation system must decide a travel direction to the next sub-goal at an intersection. To do this the order of the adjacent edges which join at a node should be explicitly described in the world map. In other words this means to describe on the map which hallway is on the left or right side with respect to a hallway. One possible way is to draw up a list of hallways in the data structure of each node, maintaining the clockwise order of the hallways. However, this is likely to confuse the order when you trace the topological map from an entire floor plan. In our scenario robots pass through hallways in a building. They are usually intersected like a cross. Therefore, we use compass points such as North (N), South (S), East(E), West (W) for a rule of the notation of directions. When you make a world map, first, you should assign the North direction on the floor plan for the reference bearing.

The data structure of a node include the list of adjacent nodes with a compass point and tag ID numbers which a robot will find coming to a particular place. Figure 4(b) illustrates examples of the data structure of a node of the graph. The mark "..." in the node d denotes there is no hallway in this direction, because the node d is a junction. The mark "?" means that a hallway exists but the name of an adjacent node is unknown at the moment. If a robot finds a tag with the ID number 9 in a hallway, for example, the navigation system searches all the node data of the graph for the tag number and then finds it in the data structure of the node c. Consequently, the navigation system recognizes the robot is coming into the intersection c from the East side. Suppose that the next sub-goal is the junction d, the navigation system searches the node c for the next node direction. It is found that the node d is adjacent to the node c and the direction is the North. The robot is coming from the East side, turns to the right at the intersection and going out to the North side. Finally it will find another tag with the ID number 11. This process is repeated until the robot reaches the goal.

We have developed an interactive system for making the database of map information from a floor plan. The system was built up on a Linux computer with the graphical toll kit GTK+ and the graphical user interface (GUI) is shown in Figure 5. The small window in the upper right corner displays the menus for editing. The main window is used to draw the topological connection of intersections and junctions the robot can pass through. First, the user assigns the North direction on the floor plan for the reference bearing. The mouse button is clicked on the screen and the mouse is dragged in one of the four directions (North, South, East or West), then two nodes with an edge is displayed and the data structures for the nodes as shown in Figure 4(b) are created in the system. After this, the mouse button is clicked on one of the nodes and the mouse is dragged to extend the graph. Next, the user changes the editing mode to compile the data structure of a node and clicks each node on the screen. Then another small window (in the lower left corner) appears to input the RFID tag numbers which are set near the node. This process is repeated for every particular place on the floor plan. Finally, the user selects the menu to save the database in a file, which the robot can use for path planning.

4. LOCAL PATH PLANNING

In our method the RFID tags are pasted on the left side walls of hallways. The position of the tags in hallways is not known. Also, robots are not aware of the length of hallways. A Robot just follows walls keeping to the left side of hallways, until it finds a tag. In local path planning it is essential that a robot is able to realign itself relative
to a wall and then proceed if it becomes disoriented due to skids or obstacles. The navigation system corrects such movements of the robot based on scanned range data to walls and obstacles in a hallway.

The laser range scanner [Kneip(2009)] for local path planning is mounted on the top of the mobile robot as shown in Figure 1. The size of the range finder equals to 50 x 50 x 70mm and its weighs 160g. The laser range scanner uses amplitude modulated laser light and deduces the target distance from the phase shift measurement between the emitted light wave and its reflection. The inner rotating mirror deflects the laser beam into horizontal direction. This allows the laser beam to scan a planar area around the sensor with a broad opening angle of 240 degrees (see Figure 6). The modulation frequencies allow the sensor to measure 2cm to 5.6m. The detector measures 683 steps on 240 degrees and therefore a resolution of 0.36 degrees. Complete scans are taken with a frequency of 10Hz. The measurement accuracy should be +/- 1% of the measurement value for distances between 1 and 4m for a white sheet of paper. The range data is reported to a host computer through an RS-232c serial port.

Local path planning is as follows. When a robot starts, first, the navigation system finds a wall in the whole scene, because the robot is not always set down near a wall. Hallways are surrounded with vertical planes (walls, pillars and doors). The cross section of such a scene, which is generated by the scanned range data, becomes a group of interspersed linear segments. The longest linear segment is chosen in the group, because it can be thought of as a reliable wall in the scene. Image precessing for extracting linear segments from the scanned range data can be done by Hough Transform [Ogaz(2009)].

The robot approaches near the wall and turns its direction such that it views the wall to the left side. The rangefinder scans again to the left side in the range of 60 degrees as shown in Figure 7. From the measured distances to the wall, the orientation of the wall with respect to the robot is calculated precisely and the robot’s pose is adjusted to become in parallel with the wall. Then, the robot starts moving along the wall. The rangefinder is invoked every few meters of movement to keep a constant distance between the robot and a wall.

The navigation system also makes sure other objects such as protruding pillars or trash cans are not in the robot’s way. The surface of small cylindrical objects such as a trash can is described roughly as a linear segment, because the aim of this process is to find free space to avoid obstacles. If there are obstacles a big break among linear segments is found and the robot veers to the break (see Figure 8). After that, the robot approaches to another wall and moves maintaining the distance to the wall.

If a tag is detected while the robot is moving the navigation system recognizes the robot’s location on the topological map from the tag number and then decides the next direction: the robot turns to the left or to the right, goes ahead or turns back. While in an intersection the rangefinder is invoked frequently. In the case of turning to the right, for example, the robot moves forward measuring distances to the right side wall and stops at a big change of the distance. At the center the distance changes greatly because of no walls. Then, the robot turn to the indicated direction. After the robot passes an intersection the rangefinder is invoked again at every few meters of movement and the robot follows another hallway until it finds a tag.

5. ROBOT SYSTEM

A prototype of a mobile robot is shown in Figure 1, which was used in the experiments described in the next
The mobile robot consists of a mobile platform, the RFID tag sensor, the laser range scanner, and a laptop computer. The mobile platform (approx. 45cm in diameter) is equipped with an on-board micro-controller, a two-wheel drive system with one rear free wheel, an odometer with optical encoders, seven sonars, and an RS-232c serial port. The sonar units are mounted at the front of the robot for forward and lateral sensing and are used for emergency stops due to sudden obstacles. The micro-controller manages the motion control for running the drive system and collecting position and speed information from the drive encoders, including firing the sonar sensors and retrieving echo signals. The laptop computer running on Linux has three RS-232c serial ports. It is responsible for handling the data from the RFID tag sensor and laser range scanner through serial ports, and sending commands to the on-board micro-controller through another serial port.

Figure 9 illustrates the architecture of the navigation system, which is implemented to the laptop computer of the robot. The system mainly consists of a navigation planning module, a graphical user interface (GUI) for tracing maps and a database of map information. The GUI as shown in Figure 5 enables us to make the database of map information from a floor plan. The database is a set of the data structure of nodes shown in Figure 4(b), which shows the relation of the particular places of the floor plan and assigned RFID tag numbers to each particular place. The navigation planning module decide a route from a departure point and a place of arrival in the database of map information, using graph search techniques. However, a robot does not always start near a RFID tag. It is very difficult to give a starting point to the navigation planning module. Therefore, in our method, when the first tag is detected after a robot starts, the navigation planning module recognizes the robot’s location on the topological map from the tag number and then generates a sequence of tag numbers to lead the robot to the goal. If a place of arrival is indicated on the map the robot can start at any place without any route to the goal.

Figure 10 shows the control sequence for the robot by the navigation system. The laser rangefinder are invoked every few meters of movement and the navigation planning module computes the angle formed by a wall and the robot’s direction and the perpendicular distance to the wall from the robot. These data are used to adjust the orientation of the robot and the distance between the robot and the wall. If a tag is detected while the robot is moving the navigation planning module indicates the next direction based on the sequence of tag numbers to the goal. If there is not the detected tag in the sequence of tag numbers, the robot is considered as going the wrong way. The navigation planning module make a new sequence of tag numbers to lead the robot to the given goal.
of the hallway is 1.6m and the traveling distance along the hallway is about 10m. The tags are set up on the walls at a height of 33cm. The robot was scheduled to start out near the tag number 1 and move to the tag number 3.

In the test run, the robot moved for a while under the control of the odometer and then checked if the right side of the robot was a free space (i.e. no walls) using the laser range scanner. This process was repeated until sufficient clearance was found on the right side. After that, the robot turned to the right. The robot moved along the hallway and after every 1m of movement, the rangefinder was invoked. From the geometrical information the navigation system decided the rotation angle of the robot to reorient the robot parallel to the wall, and the distance needed to draw the robot near to the wall. To sense the RFID tags reliably the robot must move along a wall at a distance of less than 1m. In this experiment the distance was 0.6m. The sensor guidance with iterative sensing and motion continued until the tag number 2 was found. After that, the robot turned to the left through the doorway and stopped by the tag number 3.

Figure 11(b) shows the case of missing a tag by accident and reorganizing a sequence of tag numbers to a given goal. In this case the tag number 2 was covered with a metal plate, so the tag can not receive electromagnetic waves from the robot. The robot started out near the tag number 1 and predictably ignored the tag number 2. The robot passed by and found the tag number 5. At this time the navigation system recognized that the robot was going the wrong way because this number was not an expected one. The navigation system generated immediately a new sequence of tag numbers to the goal. Then, the robot turned back and followed the hallway. When the tag number 4 was found the robot turned to the right and stopped at the tag number 3.

7. CONCLUSIONS

Mobile robots are a very imprecise mechanism. Navigation systems for mobile robots should have a mechanism to accomplish tasks without an adequate degree of precision. We thus proposed a topological navigation system using RFID tags and a scanning rangefinder system. The rangefinder was used to reorient the robot parallel to a wall keeping the distance to it. We also introduced a topological connection map of the RFID tags, which can be built without precise 3D representation of the environment. Robots just follow the tags under instructions of the topological map. A graphical user interface for making the world map conveniently is indispensable for the application of the navigation method. We have built an interactive system running on the Linux. The equipment setup is very simple and the navigation system is easily combined with the robot’s computer systems. This is both practical and acceptable for the application of mobile robots to the real world.

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REFERENCES