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MOBILE ROBOT LOCALIZATION FROM LANDMARK BEARINGS

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Abstract - Mobile robots need their position in the workspace. A standard GPS will allow an absolute positioning of the robot in the field, but the position accuracy is not enough to perform unmanned field task. This paper proposes a system for robot localization based on landmark bearings measured by the robot. Since the equipment setup is very simple our proposed technique would be useful for real-world robotic applications such as lawnmowers. Some results are presented to show the performance of the proposed technique.

Keywords : mobile robot, localization, landmark bearing

1. INTRODUCTION

When a mobile robot is moving in its workspaces such as fields and large floors in pavilions, one of the basic problems which need to be solved is for the robot to know its position in the plane as accurately as possible. The precise robot's position in real time allows to optimize trajectories in unexpected situations, assuring the success of the mission. The problem of self-location has received considerable attention and many techniques have been proposed for solving it [1,2]. In general, the knowledge of the position can be achieved by two distinct methods: dead reckoning and absolute positioning [3].

Dead reckoning provides location data by accumulating the traveled distance from a known initial position. The moving distance and direction of a robot can be detected with sensors such those based on the vehicle's an odometer with optical encoders, and gyrocompass. On the rough of the ground the traveled distance produce a high accumulated error. This error is caused mainly by wheel slip. Therefore, it can not be used as an unique method for attaining a precise position of the vehicle during a large period of time.

Absolute positioning approaches refer to navigation with respect to a coordinate system based on the environment. The methods are useful in tasks in large workspaces because they are not affected by changes in the environmental conditions. The absolute positioning systems usually rely on trilateration or bearings to known positions in the environment. Trilateration is the determination of robot's position based on distance measurements to known beacon sources or passive landmarks. GPS (general positioning system) techniques are an example of trilateration. Many methods for navigation task use GPS techniques, but the position accuracy is not enough to perform unmanned field task. A differential GPS can achieve an acceptable navigation task precision for performing this (position errors between 5 meters to less centimeters). On the other hand, these differential techniques highly increase the price of the equipment. One more inconvenience of the GPS including a differential one to consider is obstacles in the environment like trees, or buildings, that can block the satellite's signal.

A common real-world situation is one in which bearings to landmarks are easily available but the distances from the robot are not. Using the angular separation or relative bearing between two landmarks with a known position constrains the robot's position to lie on one circle. Additional landmarks to the constraint uniquely determine the robot's position. The proposed method for performing this task is to place active RFID (radio frequency identification) tags with a near infrared detector at known positions in the workspace. A laser scanner mounted on the robot allows the recognition of the landmarks. In the workspace, the robot measures the bearings to a sufficient number of these landmarks. Using three or more such measurements, the robot is able to estimate its position in the plane. This can achieve an acceptable precision for performing this. This can be used in both outdoor and indoor environments. The equipment setup is very simple and reasonable. The algorithm to find solution is fast, because the simple geometry is used.

2. PRINCIPLE OF THE POSITIONING METHOD

In this section we present an overview of the localization from landmark bearings. The geometry of our problem is illustrated in Figure 1. Here, a set of landmarks are at known positions A, B, and C with respect to the world coordinate system (X, Y). The robot is at an unknown position P. The landmarks are viewed by the robot in directions ϕ_A, ϕ_B, and ϕ_C respectively with respect to the robot coordinate system (x, y). The goal is to find the robot's position P and orientation ϕ in the plane.

The geometric method is based on the following constraint. When given two landmarks in positions A and B, and their measured relative bearing is α, there exist only two possible circles going through A and B such that the inscribed angle is α. The relative bearing between two landmarks with a known position constrains the robot's position to lie on a pair of circular arcs. If the robot can determine the clockwise enumeration of the landmarks (or label them uniquely), the position is constrained to only one of these two circles. Landmarks B, C, and their inscribed angle β also form another unique circle (see Figure 2). From the information available (landmark locations and the angles α, β) the equations of the circles can be determined. The two circles intersect at landmark B and the robot's location. Landmark B's location is already known and the robot's location is the other intersection point.

The formula for calculating the robot position is given as follows. The coordinates of the known positions A and B are denoted by (X_a, Y_a) and (X_b, Y_b), respectively. The center position (X_1, Y_1) and radius r_1 of the circle O_1 going through A and B such that the inscribed angle is α are given by (1), (2) and (3).

$$r_1 = \frac{l}{2\sin(\alpha)} \tag{1}$$

$$X_1 = X_a + r_1 \cos(\gamma_1 - \theta_1) \tag{2}$$

$$Y_1 = Y_a + r_1 \sin(\gamma_1 - \theta_1) \tag{3}$$

where l is the distance between the positions A and B. The angle γ_1 is the slope of the line through the points A and B. θ_1 is $\angle O_1AB$. These angles are given by equations (4) and (5).

$$\theta_1 = \cos^{-1}(\frac{l}{2r_1}) \tag{4}$$

$$\gamma_1 = \tan^{-1}(\frac{Y_b - Y_a}{X_b - X_a}) \tag{5}$$

The center position (X_2, Y_2) and radius r_2 of the circle O_2 going through B and C such that the inscribed angle is β are given in the same manner. From the two circles the robot position (Xp, Yp) is given by (6) and (7).

$$X_p = X_1 + r_1 \cos(\theta_2 - \gamma_2) \tag{6}$$

$$Y_p = Y_1 + r_1 \sin(\theta_2 - \gamma_2) \tag{7}$$

where the angle γ_2 is the slope of the line through the points O_2 and O_1. θ_2 is $\angle O_2O_1P$. These angles are given by (8) and (9).

$$\theta_2 = \cos^{-1}(\frac{r_1^2 + k^2 - r_2^2}{2r_1k}) \tag{8}$$

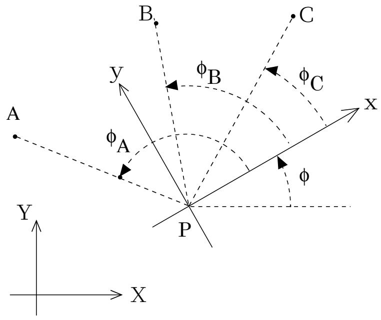

Figure 1: *Illustration of a planar mobile robot which detects three known landmarks in directions ϕ_A, ϕ_B, ϕ_C.*

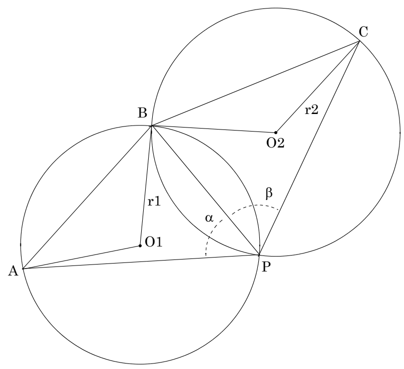

Figure 2: *Possible robot position lie on an intersection of the two circles.*

$$\gamma_2 = \tan^{-1}(\frac{Y_2 - Y_1}{X_2 - X_1}) \tag{9}$$

where k is the distance between the centers of the circles O_1 and O_2.

The orientation ϕ of the robot can be calculated from the robot position (X_p, Y_p) and one landmark position, for example (X_c, Y_c), by simple geometry. In the geometric circle intersection algorithm, there exists an inherent ambiguous situation when the robot's position is co-circular with the positions of the three landmarks. In this case, the robot's position can only be estimated to lie anywhere on the circle on which the landmarks lie, and additional landmark bearing measurements are needed to disambiguate the robot's position.

3. SYSTEM OVERVIEW

The self-location measurement system based on landmark bearings consists of RFID tags with a near infrared detector, a near infrared laser light source (wavelength 830 nm) on a small rotating table, and a laptop computer with an RFID sensor.

Figure 3 illustrates an RFID tag with a near infrared detector which is set at a known position in the field.

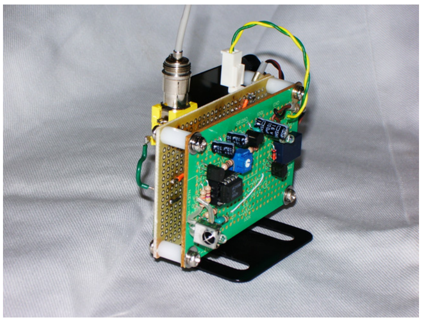

Figure 3: RFID tag with a near infrared detector

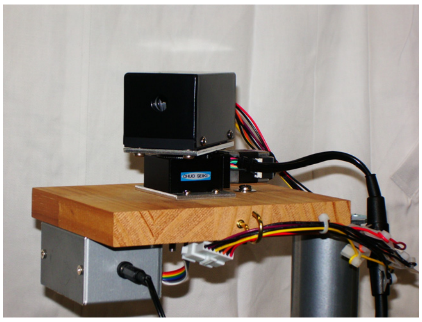

Figure 4: Laser light source mounted on the driving gear

Each RFID tag has a unique ID number which can provide its location information in the field. The near infrared detector is a photo diode of 5 mm in diameter and it has a view angle of 90 degrees. This device is designed to detect only the near infrared rays modulated by 38KHz rectangular wave to avoid ambient near infrared rays by the sun or light fixtures. The RFID tag detects a laser beam from the robot, switches on the internal transmitter and sends back radio frequency signal (315MHz) with the ID number, in response to the interrogation. The RFID sensor receives the RF signal, obtains the ID number and reports it to the robot system through an RS-232c serial port on the laptop computer.

Figure 4 shows a prototype of the laser light source which is mounted on the driving gear that can rotate the light source horizontally. The light sources is a small laser diode equipped with a cylindrical lens on the front. The light source modulated by 38KHz rectangular wave projects a vertical slit light. The width of light beam 7mm and the vertical length is 2m at a distance of 15m from the light source. The driving gear consists of a stepping motor and mechanical reduction gears, which is controlled numerically and one step minimum angle of the rotating table is 0.18 degrees. The light source is rotated step by step and the horizontal scan angle is approximately 300 degrees in maximum.

In our scenario the self-location measurement system

Figure 5: Scene of measuring bearing angles to landmarks in a field from the light source on a mobile platform

is supposed to use in mid-range areas such as ground fields or pavilions. The landmarks are scattered sparsely in the workspace. Figure 5 shows a scene of measuring bearing angles to landmarks in the field from the light source on a mobile platform. The viewer (mobile robot) observes the angles of orientation to these RFD tags. Due to the constrain of the power of the light source, the range of detection is 15 meters in maximum. The computer is responsible for controlling the laser scanning and receiving RFD tag data, and calculating the vier's position based on three ID tag numbers.

In our system the accuracy of position depend on the errors of measured relative angles between landmarks, which are caused by the deviation between the centers of the photo diode and the laser beam, and the step angle of the rotating light source. The width of the slit laser beam is very narrow and the size of the photo detector of an RFID tag is enough small. The position error by the deviation could be neglected. Therefore, the position errors depend mainly on the resolution of the step angle of the rotating table. When the light source rotates step by step in the counterclockwise direction the measured relative angles might decrease or increase by one step angle at maximum. Considering the scanning time of the light source the step angle could be one or 0.5 degrees. Table 1 and 2 shows the limit of position errors in the case that the two relative angles have the error of 1 or 0.5 degrees, respectively. Table 1 shows the case that the three landmarks are supposed to be set from 8 meters from the viewer and the relative bearings are 46 and 54 degrees. In the case of Table 2 the three landmarks are supposed to be set from 9 meters from the viewer and the relative bearings are 35 and 29 degrees. In general to reduce position errors landmarks should be chose such that their relative bearing are wide and their positions are near to the viewer. If the position errors are expected within the range of 30cm, the step angle of the rotating table should be less than one degree.

4. EXPERIMENTAL RESULTS

Experiments for investigating the validity of the mea-

	45.0	45.5	46.0	46.5	47.0 (degrees)
53.0	19.2	15.1	19.2	27.7	37.6
53.5	19.4	9.5	9.5	18.7	29.3
54.0	23.7	11.7	0	11.4	22.6
54.5	30.2	18.8	9.3	9.4	18.5
55.0	37.7	27.0	18.4	14.7	18.6
(degrees)					(cm)

Table 1: *Limit of position errors at the relative bearings 46 and 54 degrees*

	34.0	34.5	35.0	35.5	36.0 (degrees)
28.0	32.8	34.6	43.6	55.8	69.2
28.5	26.0	16.1	21.4	34.6	49.4
29.0	35.2	17.3	0	16.6	32.6
29.5	51.8	35.0	20.9	15.6	24.4
30.0	70.1	54.4	41.0	32.2	30.9
(degrees)					(cm)

Table 2: *Limit of position errors at the relative bearings 29 and 35 degrees*

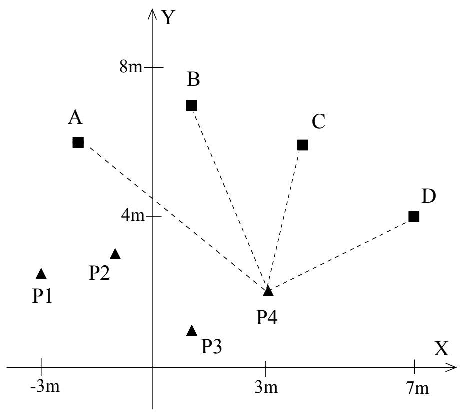

Figure 6: *Layout of landmarks (A, B, C, D) and viewer positions (P1, P2, P3, P4) for the experiments.*

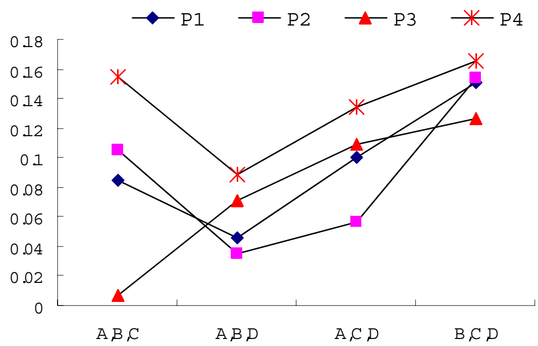

Figure 7: *Range of position errors caused by the measurements. The vertical axis denotes errors in meters and the horizontal axis shows combination of landmarks used for calculations.*

surement system was run in the open air as shown in Figure 5. Figure 6 shows the configuration of four RFID tags denoted by A, B, C, and D in the field and self location measurements were run at the points denoted by P_1, P_2, P_3, and P_4, where the laser light source was set at a height of 90 cm above the ground. A theodolite was used to decide precisely the landmark's and viewer's positions in the field. The error of measurement with the theodolite is less than 3mm at the distance 100m.

The direction angle was measured by 1 degree in the experiments. The laser light source was rotated in the manner of "coarse to fine" to reduce the scanning time. The light source rotates by 10 degrees to receive the signal from the RFID tags. If there is a signal then the light source is rotated back by 10 degrees and moves at 1 degree interval. This process repeated until the four landmarks were detected. Consequently, the approximate scanning time was 60 seconds.

In our method the viewer's position can be calculated with three landmarks in the field. When three landmarks are chose among the four landmarks four kinds of combination can be made. The viewer's position errors were calculated with each combination of landmarks and the range of position errors is illustrated in the Figure 7. By the position error of each viewer we mean the distance between the position of the viewer obtained with the measurement system and the expected position that was measured with the theodolite. As shown in Figure 7 the range of position errors were within 18 cm. However, according to the results shown in Table 2 the bearings by the unit of 1 degree might cause the range error of up to 70cm. To avoid the worst case scenario practically you should use four landmarks for the measurement and the obtained positions should be averaged.

5. CONCLUSIONS

Mobile robots should have a mechanism to find their location with an adequate degree of accuracy for navigation. The equipment setup should be simple and be easily combined with the robot's computer systems. We thus proposed the self-location system using active RFID tags with a near infrared detector as a landmark. The Laser scanner mounted on the robot allows to recognize the landmarks. The experimental results showed this system achieved an acceptable precision for performing mobile robot navigation. In any place in the workspace, robots should be able to measure the bearings to a sufficient number of these landmarks. So, we plan to design RFID tags with an omnidirectional photo detector. This is an on-going project.

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