NAVIGATION SYSTEM FOR UNMANNED GROUND VEHICLE

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The main objective of this study is to design and develop the navigation system for Unmanned Grounded Vehicle (UGV) using the ultrasonic sensor and encoder. This study used the differential drive type mobile robot and the robot was equipped with five ultrasonic sensors, two units of DC geared motor with encoder and controller board. It was started with the enhancement of encoder and robot trajectory using UMBmark method. From this study, it was difficult to ensure that the motor speed has 100% efficiency by using this method. The study was also identified that UMBmark method failed to improve the motor speed as well. However, by using the CBmark method, the motor speed reading can be improved significantly. It’s also enhanced the encoder reading while correcting the robot trajectory. The second model is used to enhance the ultrasonic sensor reading using Extended Hessian Normal Form Feature Prediction (EHNFP). This method managed to improve the ultrasonic sensor reading and extract the infinite plane. And, the last model is combined two sensors to perform localization system of the mobile robot using Extended Kalman Filter (EKF). It shows that the mobile robot can perform the basic task using localization system.

1. Introduction

Navigation system for mobile robot can be a hard topic to understand. For the past few years, researchers have been trying to develop methods in order to make robots fully autonomous systems and able to help human in solving critical problems that might arise. In general, navigation system means a capability of a system to have fully automated in controlling its path and according to prediction using mathematical method or logic. In robotic applications, navigation means the ability to determine a robot own position in its frame of references and then to plan a path towards some goal locations. Furthermore, navigation also consist of combination of the three fundamentals areas: self-localization, path planning and map building. Self-localization means the ability of a robot to locate its position in a global map, while path planning refers to the way of a robot to make decision for its target and map building require the robot to locate and mark it position while it navigates.

2. Problem Statements and Objectives

Conventionally, in order to use Automatic Guided Vehicle (AGV) robot, manufacturers have to take into account many considerations on the plan layout for the robot to follow. This type of path follower could waste many valuable spaces. The conventional paths of the mobile robot are planned based on the availability of spaces that the robot could move and not variable control. Variable control means the navigation path for the robot can be adjusted according to their environment easily. A fixed sensor such as one sensor for one program of the robot also may cause the limitations to the robot, in other words, it is not reliable if different condition or environment changes. Fix sensor in this context refer to the dead reckoning sensor such as an encoder and other positioning sensor which can only give one reading at a certain time. For example, AGV robot uses line following sensor to move according to the path planning by the programmer and the sensor only detect the line to navigate the robot. In other words, if the layout changes, engineer should design the track again to meet with the new programming. Current problem faced in mobile robot navigation is the ability to track the changes of its environment while it moves. Meanwhile, sensor reading and data acquisition need to process carefully during operation as it will accumulate and make the whole system output incorrect. Multi sensor methods are the best solutions in getting the best result but the problems here is how to combine all the readings including error and compile it to be useful information. The objectives of this project are to investigate the types of error in the robot navigation system and develop the UGV (Unmanned Grounded Vehicle) localization system based on EKF (Extended Kalman Filter) method.

3. Methodology

The kinematics model of the mobile robot

The mobile robot is a unicycle-like differential drive platform whose control signals are the linear and angular velocities ($u$ and $\omega$). A sketch of the robot navigating towards its goal in a free space is given in Figure 1.

![Kinematic model of differential drive robot](image)

Figure 1: Kinematic model of differential drive robot

In general, the position of the mobile robot is representing by equation 1 below:

$$\rho = r$$

The mobile robot used the differential drive terrain. The position can be estimated starting from a known position (where $x=0$, $y=0$) by integrating the movement (summing the incremental travel distances). Figure 2 shows the movement of robot from its starting point to the desired position.

![Movement of differential drive robot](image)

Figure 2: Movement of differential drive robot

For a discrete system with a fixed sampling interval the incremental travel distances ($\Delta x$, $\Delta y$, $\Delta \theta$) are:
\[ \Delta x = \Delta S \cos(\theta + \Delta \theta/2) \]  
\[ \Delta y = \Delta S \sin(\theta + \Delta \theta/2) \]  
\[ \Delta \theta = \frac{\Delta \alpha}{b} \]  
\[ \Delta S = \frac{(\Delta \alpha - \Delta S)}{2} \]  

Where \( b \) is a distance between the two wheels of differential drive robot, \( \Delta S \) and \( \Delta \theta \) is a travel distance between left and right wheel respectively, and \( \Delta x, \Delta y, \Delta \theta \) are the path travel in the last sampling interval. By using equation 2 - 5, the updated position of \( p' \) can be calculated by replacing the value in equation 1, thus the updated position is:

\[ p' = f(x, y, \Delta S, \Delta \theta) = \left[ \begin{array}{c} x' \\ y' \\ \theta' \end{array} \right] = \left[ \begin{array}{c} \Delta \cos(\theta + \Delta \theta/2) \\ \Delta \sin(\theta + \Delta \theta/2) \\ \Delta \theta \end{array} \right] \]  

By using relations of equation 4 and 5 into equation 6, the basic equation to update the encoder position of the mobile robot is shown below:

\[ p' = f(x, y, \Delta S, \Delta \theta) = \left[ \begin{array}{c} \frac{\Delta S \cos(\theta + \Delta \theta/2) - \Delta S \cos(\theta)}{2} \\ \frac{\Delta S \sin(\theta + \Delta \theta/2) - \Delta S \sin(\theta)}{2} \\ \Delta \theta \end{array} \right] \]  

Equation 7 represents the basic odometric equation of the mobile robot.

**Odometry calibration using offline method**

Online odometry calibration is used to increase the pose estimation accuracy during mobile robot navigation in an unknown working environment or to estimate the random errors variance (Martinelli and Siegwart, 2009). The encoder will only gives reading based on rotation of its shaft and it can simply make an error when it rotating. There are few parameters need to be adjusted using offline odometry calibration and one of it is trajectory error. This error need to be measured using experiments for data optimization and it must have a trajectory for both, translational and rotational systematic errors.

**Encoder tuning using UMBMark method**

According to Chang (2011), there are a few procedure that must be followed in order to get the fine tuning using UMBMark method.

**Step 1:** The absolute position encoder reading must be taken. Initially, the encoder counter is zero.

**Step 2:** Run the robot through the square shape of 1 x 1 m, 2 x 2 m, 4 x 4 m in CCW direction and ensure it stops at each 2 m and make total of four 900 turn. At each corner robot must be slowly moved.

**Step 3:** When reach at the starting point, measure the absolute position and orientation of robot.

**Step 4:** Compare the robot position to the robot calculated position based on encoder.

**Step 5:** Repeat steps 1-4 for 5 times.

**Step 6:** Repeat steps 1-5 for 5 times in CW direction.

**Step 7:** Repeat steps 1-6 for others 2 x 2 meter and 4 x 4 meter square shape

**Step 8:** Measure the experimental result.

The reason of having 5 times repeat steps are to minimize the effects of the non-systematic errors and also to get an indication of its magnitude, measuring the spread of the return position errors (ChangBae Jung, 2011).

**The CBMark tuning method and methodology**

CBMark method or known as "Circular benchmark" method is used to enhance the results after tuning the encoder with UMBMark method (Juhari K.A, 2012). The difference is, CBMark method use to tune the motor speed while improve the robot trajectory and encoder reading. The results are excellent compare to UMBMark method.

**Mobile robot localization**

Normally, dead reckoning sensor is used as localization tools because it can measure how far the robot can move from its stationary position, but it will not precisely predict the actual location of the robot due to the dead reckoning sensor cannot measure the heading of robot in global coordinate. Using Extended Kalman Filter (EKF), the nonlinear system of the robot is solved. It will update of the robot position.

**4. Result**

CBMark method is focus on odometry calibration and trajectory improvement of mobile robot. It will encounter the square error generated by the encoder reading when the motor turns.

![Figure 3: (a) Systematic error in CCW direction, (b) Systematic error in CCW direction](image)

It shows that the robot did not follow the circle correctly. In Figure 3 which is in CCW direction, there are large errors at point c and point d, where the robot did not stop at the right point. Same goes to the CW direction, the robot drift away from the target point. This is called the speed error. Speed error caused the robot drift away even the encoder is tuned (Juhari K.A, 2012). This is important to overcome the speed error of the motor in order to achieve the precise speed reading.

**5. Conclusions and future work**

The odometry problems has been encountered using UMBMark method and CBMark method. The ultrasonic sensor reading was also improved using EHNFP method. Localization of the mobile robot are based on EKF technique where the encoder and the ultrasonic sensor reading is fused together to estimate the robot position in global map. In future, the navigation system of this robot can be improve by adding real time map generator using a special technique called SLAM (Simultaneous Localization and Mapping).

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**7. References**

