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Control of closed-loop differential drive mobile robot using forward and reverse Kinematics

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***Abstract*—A "Go-to-Goal" differential-drive mobile robot, in an obstacle-free environment, has been designed and developed in this experiment. The robot is capable of moving in any direction in a 2D Cartesian plane by individually controlling the speed of both driving wheels. The robot can estimate its current position at any point in time. Forward kinematics is applied to estimate the current state of the robot, and reverse kinematics is used in achieving the goal position in the 2D Cartesian plane. A proportional controller is used to control the speed of the wheels for better maneuverability. Effectiveness of the model is tested in both real and ideal conditions. With increasing applications of mobile robots in various fields, this experiment is conducted to test and verify the applied kinematics model. Implementation is by means of a 64-bit microprocessor for processing and an 8-bit dedicated microcontroller for motor control.**

Keywords—Inverse kinematics; odometry; wheel encoders; differential drive mobile robot; state estimation; localization; proportional controller.

I. INTRODUCTION

Mobile robotics is one of the most emerging fields in the robotics family, having numerous applications in diverse fields like military, industry and commercial. Researchers are working globally to develop different mathematical models to increase efficiency and to have better control of mobile robots. Two-wheeled differential-drive robots are the most common in all categories of mobile robots. By controlling the speed of both motors individually, these robots can attain any orientation.

L. Feng et al [1] implemented an adaptive motion controller to improve accuracy and reduce system motion errors through learning from position measurements. M. Aicardi et al. [2] presented a very simple unicycle model based on Lyapunov theory capable of steering, path planning and navigation in the 2D plane. Multilayer neural network is presented by Ahmed Rubaai [3] to control the speed of DC motor with unknown load dynamics. Sung-on Lee et al [4] investigated tracking control for the unicycle model having asymptotical stable characteristics designed using the backstepping method. Shouling [5] designed a feedback linearized control system for 2 wheeled mobile robots. Eka maulana et al [6] implemented an inverse kinematic model to directly control the two-wheeled robot. Desai et al [7] presented the software framework for making distributed mobile robotics (DMR) more accurate. Hidalgo-Paniagua et al [8] used the behavior of fireflies to solve the path planning problem of mobile robotics also known as swarm intelligence algorithm. Zhang Q et al [9] proposed an integrated localization algorithm combined with a particle filter for accurate global localization. Manoharan et al [10] presented the techniques like augmented reality, supervisory control and haptic feedback to remove errors in telerobotic surgery. Smys et al [11] worked on pick and place robot for automobile industry in affordable rates.

In this experiment forward and reverse kinematics is applied using magnetic wheel encoders for localization of the differential drive robot. The robot can move to any position in an obstacle-free environment. Basic movement tasks are to move from one position to any goal position in a 2D plane.

This paper is organised into six sections. Section II shows the hardware block diagram and a picture of the working prototype. Section III describes the odometry and forwards kinematics in detail. Parameters of the two-wheeled differential drive robot and its odometry geometry are described. Section IV describes the inverse kinematics used. The "Go-to-goal" algorithm is implemented in this section. Section V discusses the results of different goal positions. Section VI concludes the experiment and discusses its future scope.

II. BLOCK DIAGRAM

A. Basic hardware block diagram

Fig. 1 shows the block diagram of the hardware used in the experiment. Hall Effect sensor-based magnetic disc encoders are used in the experiment to calculate the RPM (revolution per minute) of the motors. A dedicated microcontroller is used to drive the motors to get precise output and to give correct input to the microprocessor as well. The microcontroller counts the number of pulses per revolution of each wheel and calculates the RPM. The RPM values are then sent to the microprocessor for further calculations.

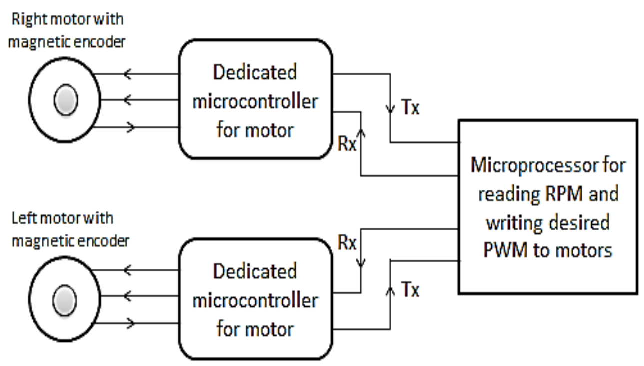

Fig. 1. Basic hardware block diagram

The Microprocessor generates the required RPM values and sends these back to the microcontroller. Finally, the microcontroller generates the desired PWM signals and feeds them to the motors. Fig. 2 shows the actual prototype used.

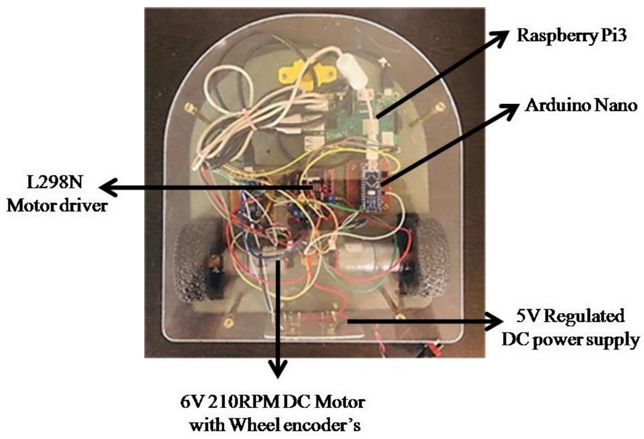

Fig. 2. Actual working prototype

III. ODOMETRY AND KINEMATICS

Odometry is a technique of determining a robot's current position, based on previously known positions [12]. Theoretically, if the parameters of the robot (i.e. the robot's structure, wheel acceleration and velocity) are known, then the robot's position can be determined. Thus by using kinematics, all this can be achieved. Fig. 3 shows the detailed block diagram of odometry and forward kinematics. Fig. 3 clearly illustrates the steps of odometry. From the number of pulses received, the RPM of the two motors can be calculated. From equations 1 to 5 it is clear that new positions can be calculated.

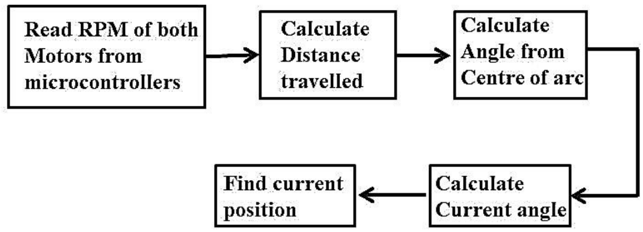

Fig. 3. Odometry (Forward Kinematics) Block diagram

Fig. 4 shows the Cartesian coordinates of the two-wheeled differential drive robot. In Fig. 4, d is the diameter of wheels, and VL, VR is the velocities of left and right wheels respectively. Edwin Olson [12] derived the odometry equations for two-wheeled differential drive robot.

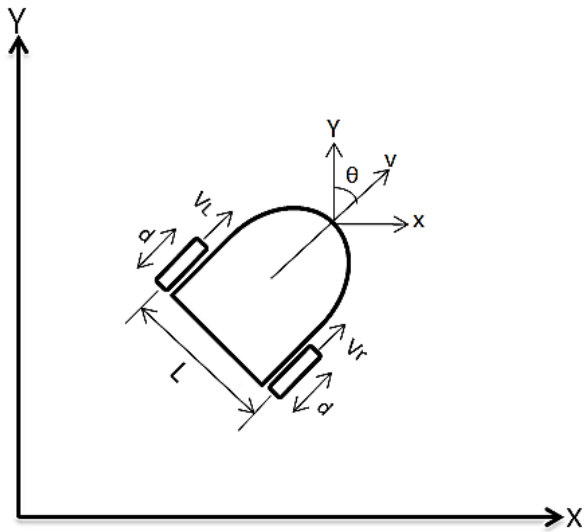

Fig. 4. The cartesian coordinate of differential drive robot

Fig. 5 shows the geometry of the odometry for a very short period. Given (x, y, θ) and L, the robot's new position (x', y', θ') can be approximated. In this experiment, odometry equations are used to find the current position of the robot as shown in equations 1, 2, 3, 4 and 5.

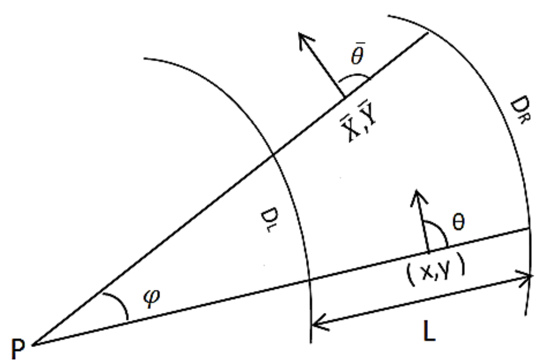

Fig. 5. Odometry Geometry [7]

$$D_C = \frac{(D_L + D_R)}{2} \quad (1)$$

$$\varphi = \frac{(D_R - D_L)}{L} \quad (2)$$

$$\overline{\theta} = \theta + \varphi \quad (3)$$

$$\overline{X} = X + D_C * \cos\theta \quad (4)$$

$$\overline{Y} = Y + D_C * \sin\theta \quad (5)$$

Here D_C is the distance travelled by the robot, and D_L and D_R are the distances travelled by the left and right wheels respectively. φ is the angle from the centre of arc's on which the robot is turning. θ is the angle of rotation of the robot. Therefore to calculate the current position of the robot, the distance travelled by the left and right wheel is required. To calculate the distance travelled by both wheels RPM (revolutions per minute) of wheels is required.

To calculate the RPM of the wheels, magnetic encoders are mounted on both the left and right wheels. These magnetic encoders count the number of pulses per revolutions of the wheel. Therefore by counting the number of pulses, RPM of motors can be calculated using equation 6.

$$RPM = \frac{No\ of\ ticks * 60}{Pulses\ per\ revolution} \quad (6)$$

Both motors are independently controlled using a dedicated microcontroller to precisely count the number of ticks. Numbers of ticks are then fed to the microprocessor for processing tasks. Distance travelled for both left and right wheels are calculated using many ticks using equation 7.

$$Distance\ travelled = \frac{(2 * 3.14 * wheel\ radius) * RPM}{60} \quad (7)$$

Fig. 6 shows how to compute the current position of the robot to the given parameters.

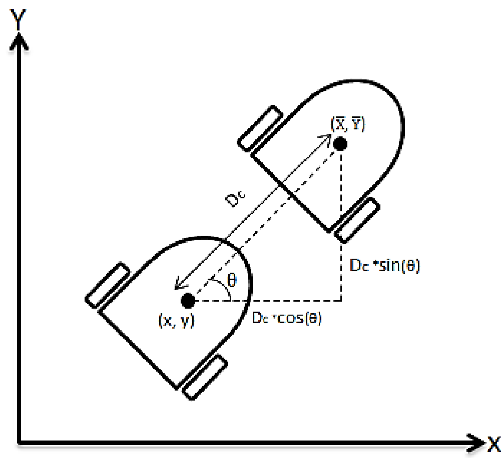

Fig. 6. Change in x and y coordinate

IV. INVERSE KINEMATICS

Fig. 7 shows the detailed block diagram of the Inverse kinematic model applied to two-wheeled differential drive robots. From equations 8, 9, 10 it can be observed that if the robot can calculate the desired velocities for each wheel, it can reach any desired position.

By using inverse kinematics, the robot can reach any given goal position. The robot needs to calculate the velocities for both right and left wheels. To find the desired angle, the robot first subtracts the current angle (θ) from the desired angle. Proportional control is then applied to the error as in equation 8. Then the velocity of both right and left wheels is calculated by using equations 9 & 10.

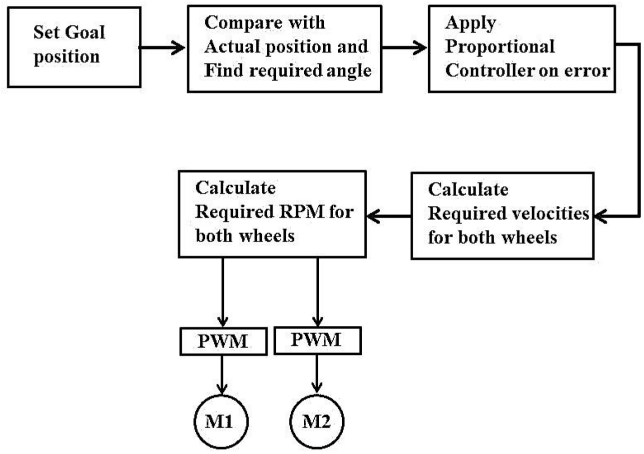

Fig. 7. Reverse Kinematics Block Diagram

$$W = Kp * error \quad (8)$$

$$V_R = \frac{(2 * (D_C) + W * L)}{2 * tyre\ radius} \quad (9)$$

$$V_L = \frac{(2 * (D_C) - W * L)}{2 * tyre\ radius} \quad (10)$$

$$W_R = \frac{V_R}{tyre\ radius} \quad (11)$$

$$W_L = \frac{V_L}{tyre\ radius} \quad (12)$$

$$D_{R_R} = \frac{W_R}{tyre\ radius} \quad (13)$$

$$D_{R_L} = \frac{W_L}{tyre\ radius} \quad (14)$$

$$RPM_R = \frac{D_{R_R} * 60}{2 * 3.14 * tyre\ radius} \quad (15)$$

$$RPM_L = \frac{D_{R_L} * 60}{2 * 3.14 * tyre\ radius} \quad (16)$$

Equations 11 & 12 calculate the required angular velocity for both wheels based on required VL and VR. Equation 13 & 14 calculate the desired travelling distance for left and right wheels. Equation 15 & 16 calculate the desired RPM for both left and right wheels. Proportional control is used to generate the desired RPM values. Finally, the desired RPM is converted into appropriate PWM signals which are then fed to the motors through the microcontroller.

V. RESULTS

Different goal positions in the Cartesian coordinate are given to the robot in all 4 quadrants. Fig. 8 shows the path followed by the robot to reach different positions. At the origin, the robot's direction is set towards the x-axis by default. In Cartesian coordinates, the robot can navigate to any given position.

Fig. 8 shows the route of the robot from origin to its desired goal positions. Position x = 100, y = 100 goal is set for the first quadrant. The dark blue line shows the path followed by the robot. Initially, the robot starts with the same PWM values for both of the wheels. Therefore from the arc, it can be seen that initially, the velocity of the left wheel is greater than the right wheel. Finally, the robot adjusts to its required velocities for both wheels and tires to reach goal position. Similarly x = - 100, y = 100 is set for 2nd quadrant, x = - 100, y = - 100 is set for 3rd quadrant and x = 100, y = -100 for 4th quadrant. The designed algorithm can easily go to any given goal as verified in Fig. 8.

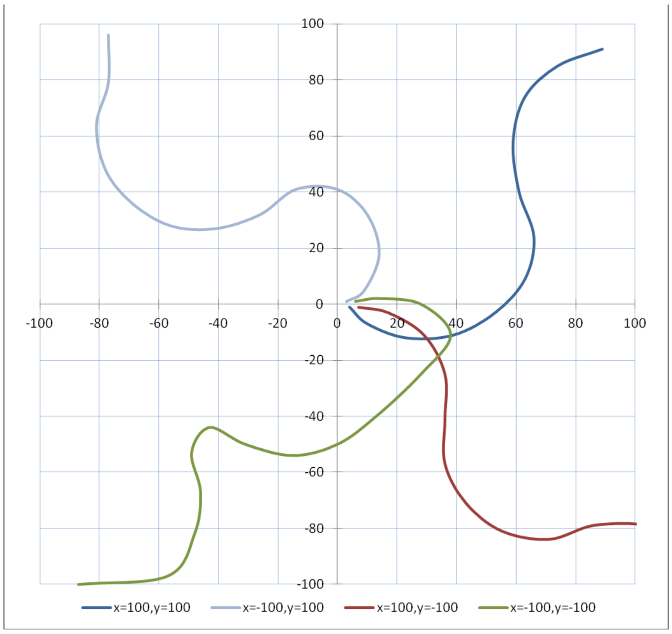

Fig. 8. Route and goal position on cartesian coordinate

VI. CONCLUSION AND FUTURE SCOPES

A two-wheel differential drive robot is designed and developed in this experiment. The robot can navigate to any desired location in cartesian coordinate. While odometry is used to track the current position of the robot, inverse kinematics enables the robot to reach any desired goal position. Desired velocities of both wheels are calculated using inverse kinematics. Finally, the desired velocities are converted into the desired RPM and then RPM to PWM signals which are finally fed to the motors for control. In this experiment, the robot's position is tracked only based on wheel encoders. Future robots can be equipped with different sensors like accelerometers, cameras and ultrasonic sensors for better state estimation and localization. A camera can be used for lane detection. By using sensor data fusion in future robots, accuracy can be improved.

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