International Journal of Science and Engineering Applications
Volume 7–Issue 12,499-503, 2018, ISSN:-2319–7560

Path Tracking Control of Obstacle Avoiding Robot Using Ultrasonic Sensor

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Abstract: The control algorithm of path tracking is very important for wheeled mobile robot. This paper proposes an algorithm that drives a wheeled mobile robot to a desired path, including obstacle avoidance capabilities. The main objective of this paper is to obtain a collision-free trajectory from the starting point to the target in monitoring environments. In this work, ultrasonic sensors are adopted to implement a real-time obstacle avoidance system for wheeled robots, so that the robot can continually detect surroundings, and avoid obstacles. In this paper, the position of the motor is controlled by using PID controller and PD controller was used in the wall-following method to achieve the optimized path design. In this paper, experimental results of motor control and simulation results for mobile robot's path were shown using MATLAB software. Microcontroller was used as a brain of mobile robot.

Keywords: Wheeled mobile robot, Ultrasonic sensor, Object detection and avoiding, Control algorithm, PID controller, MATLAB simulation, Microcontroller.

1. INTRODUCTION

The sensor-based system is utilized an unknown or changing environment, to perform real-time obstacle avoidance and real-time path planning functions. The sensing elements that are most commonly found in the literature include infrared and ultrasound, CCD camera or CMOS image sensors, laser light pens, global positioning systems (GPS), etc. [1].

Obstacles can be detected by using infrared sensor according to [2], [3]. In Robotino of Festo Didactic, nine infrared sensors are supplied which placed at the both of Robotino 40° apart from each other by Ali, Tariq Younis, and Mohammad M. Ali. The maze solving vehicle is designed with three infrared sensors of which two is used for wall detection to avoid collision and the third is for obstacle detection for picking and placing the objects to clear its pathway with the help of robotic arm by Kamur, Raul, et al. the trajectory path planning on designated path was proposed byYamada, Taichi, Yeow Li Sa and Akihisa Ohya with the use of laser range scanner, called URG-04LX which has an optimum point distance detection of 4 meters with scanning range of 240 degrees. In these research, in order to get the surrounding environment of robot in all directions, an additional sensor is mounted on the front and back of the robot [4].

Automatically driving for intelligent vehicle requires the integration of many technologies including path planning, position and orientation sensing, path tracking, vehicle control, and obstacle avoidance. Path tracking is the process concerned with how to determine steering and speed settings at each instant of time for the vehicle in order to follow a desired path. Until now, many path tracking algorithms have been proposed for intelligent vehicles or mobile robots [5]. As the robotic vehicle moves along the waypoints from the starting point to the goal point sent from the global motion planner, the local motion planner determines the instant motion of a vehicle. When the local motion planner generates the vehicle's reference motion, difficulties can appear due to the motion constraints of the vehicle. At a low speed of the vehicle, the longitudinal traction and lateral forces which are exerted on the tires do not exceed the maximum static friction between the tires and the road, preventing the vehicle from moving in the direction orthogonal to its forward direction. Thus the vehicle cannot move directly to the side due to this constraint. Moreover, the minimum turning radius of vehicle exists because of the limited steering angle. These motion constraints make the motion planning problem particularly complex [6]. Thus the local motion planner should generate the feasible local motion for the vehicle without violating the motion constraints. If the constraint equations are written as non-integrable differential expression, then the constraint of this type are known as nonholonomic constraints. The kinematic effect of a nonholonomic constraint is to constrain the direction of the allowable motions at any given point of configuration space. However, the nonholonomic constraint does not reduce the number of dimensions in the configuration space. This means that the vehicle can reach any position and orientation by using the forward and backward motions in the obstacle-free space [6]_[8].

Kinematic modeling of the autonomous wheeled mobile robots is analyzed. Then the fuzzy control of a wheeled mobile robot motion in an unknown environment with obstacles is proposed. Output of the fuzzy controller are the angular speed difference between the left and right wheels of the vehicle and the vehicle velocity. Finally, the simulation results show the effectiveness and the validity of the obstacle avoidance behavior in an unknown environment of the proposed fuzzy control strategy by Mester,Gyula[9]. To control the differential drive wheeled mobile robot, PID controller can be used as an another way. Agarwal, Kunal, Shadan Mahtab, Sourav Bandyopadhyay, and S. Das Gupta used Proportional-Integral-Derivative (PID) controller to control the navigation of the robots, The most suitable set of values of PID parameters implemented for safe and effective navigation of the robots have been presented. Computer simulation is done using MATLAB software [10].

2. SYSTEM DEVELOPMENT

2.1 Motor Control

The mobility of the obstacle avoiding robot is obtained with two DC geared motors which are attached to the wheels of the car. Control for the two motors in the system is carried out by using the L298N integrated circuit H Bridge. The driving signals are generated by the microcontroller which produces appropriate PWM according the position of the robot.

2.2 Sensor Placement

Sensor arrangement for object detection, two ultrasonic sensors are used and the arrangement is shown in Figure 1 which is placed at the top and side of the robot. This arrangement is used for accurate detection of object for rectangular shape.

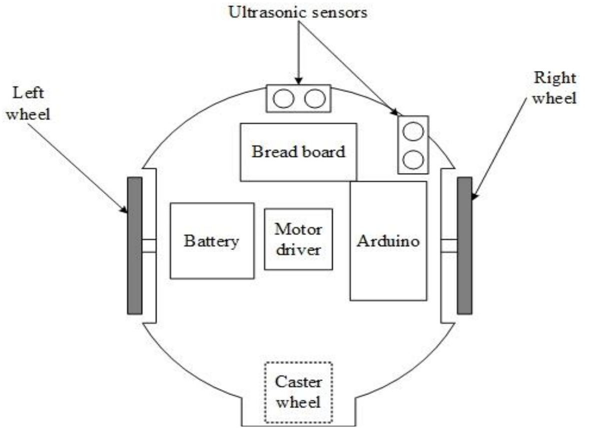

Figure 1. Layout Design of Mobile Robot

In this system, the test robot is a two-wheel mobile robot with differential drive. A caster wheel provides third point contact to ensure stability. The robot is driven by two high speed miniature permanent magnet gear motors coupled to wheels. The robot is battery powered, with the motors supplied with regulated power supply to ensure consistent motor power at all operating scenarios. To move the robot forward, both motors are rotated in the forward direction.

To make the robot turn to the left or to the right, the speed of one motor is reduced. The amount of turn increases as the speed difference increases. Maximum amount of turn is achieved when one motor is turned in a backward direction at maximum speed. This results in maximum speed difference and robot just spin in place. The brain of the robot is an Arduino Mega 2560. Bidirectional motor speed control is achieved by using an H-bridge motor driver circuit. The power applied to the motor is varied by using PWM generated by the microcontroller.

Two ultrasonic sensors are installed on the top of robot and robot's side for object detection. Ultrasonic sensor is used to detect and maintain a specific distance from the object. Ultrasonic sensor generates high frequency sound waves and evaluates the echo which is received back by the sensor. The ultrasonic sensor accurately works with in a range of 4 meters. Ultrasonic sensor operates by calculating the time differences.

Time distance= (high level timexvelocity of sound(340m/s))

3. ROBOTIC VEHICLE MODEL

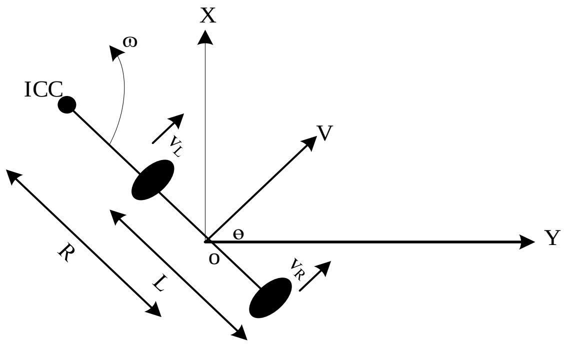

Figure 2 Kinematic Model of Mobile Robot

The kinematics scheme of the differential drive mobile robot is as shown in Figure. 2, where R is the instantaneous curvature radius of the robot trajectory, L is the distance between two driving wheels, ω is the angular velocity of the mobile robot, V is the linear velocity, v_L and v_R are the velocity of the left and right driving wheel, the angle θ indicates the orientation of the robot. For navigation of the robot autonomously it has to know its position at all times, when we change the velocity of the wheels to have different motions the robot must rotate about a point that lies along the common axis of both the driving wheels, this point is known as the Instantaneous Centre of Curvature (ICC). The configuration of the robotic vehicle can be defined as $q = \begin{bmatrix} x & y & \theta \end{bmatrix}^T$.Then the kinematic model of the robotic vehicle is expressed by

$$\dot{q} = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} u \qquad (1)$$

where $u = \begin{bmatrix} v & \omega \end{bmatrix}^T$ is the control input vector that contains the linear velocity and the angular velocity.

In this kinematic model, the motion of the robotic vehicle is constrained by a nonholonomic constraint.

$$\dot{x}\sin\theta - \dot{y}\cos\theta = 0 \qquad (2)$$

That is, it is assumed that the robotic vehicle is slow enough that the longitudinal traction and lateral force exerted on the tires do not exceed the maximum static friction between the tires and the floor. This is called the no-slip condition [6].

4. PATH TRACKING SYSTEM

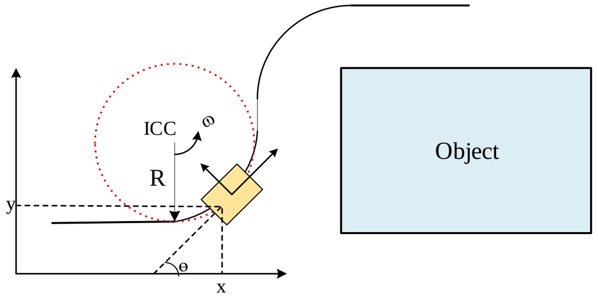

Figure 3. Path Tracking of Mobile Robot

Figure 3 shows the path tracking of mobile robot. The curvature radius of trajectory described by left wheel is $R-{}^{L}\!/_{2}$ and right wheel is $R+{}^{L}\!/_{2}$. Hence, the following equation hold:

$$\begin{aligned}\omega(R+L/2)&=v_R\\ \omega(R-L/2)&=v_L\end{aligned}\tag{3}$$

Solving for ω and R yields;

$$\begin{aligned}R&=L/2(v_R+v_L)/(v_R-v_L)\\ \omega&=(v_R-v_L)/L\end{aligned}\tag{4}$$

From equation (4) v(t) can be defined as

$$v(t)=\omega(t)\times R=\frac{1}{2}(v_R(t)+v_L(t))\tag{5}$$

Additionally, dynamic function of the robot are as follows:

$$\begin{aligned}\dot{x}(t)&=v(t)\cos\theta(t)\\ \dot{y}(t)&=v(t)\sin\theta(t)\\ \dot{\theta}(t)&=\omega(t)\end{aligned}\tag{6}$$

Re-arranged Equation (6) as a matrix yield:

$$\begin{bmatrix}\dot{x}(t)\\ \dot{y}(t)\\ \dot{\theta}(t)\end{bmatrix}=\begin{bmatrix}\cos\theta & 0\\ \sin\theta & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}v(t)\\ \omega(t)\end{bmatrix}\tag{7}$$

where $\dot{x}(t)$ and $\dot{y}(t)$ are transformed point of x, y.

5. PID CONTROLLER DESIGN

PID controller is the mathematically based routine that processes the sensor data and control the position of the robot to keep it on the course. This PID controller is used to control the robot with quick response time and to minimize the overshoot as much as possible [11] and to reduce error between actual and desired position.

A robot without the controller would oscillate a lot about the line, wasting time and battery power. Using the PID controller, the robot will go smoothly keeping its centre always. In straight forward moving, the robot will gradually stabilize itself and this will enable the robot faster and more efficiently. A standard PID controller action can be expressed by

$$u(t)=k_P x e(t)+k_I x\int_0^t e(t)xdt+k_D x\frac{de(t)}{dt}\tag{8}$$

where e(t) = error signal, k_P = proportional gain, k_I=integral gain, k_D=derivative gain. The block diagram of PID controller is described in figure 4.

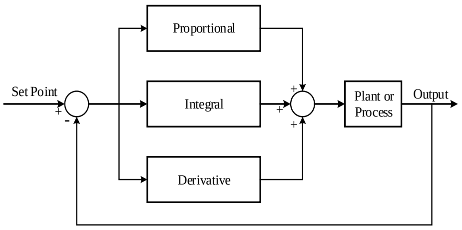

Figure 4. Block Diagram of PID Controller

6. ULTRASOUND OBSTACLE AVOIDANCE STRATEGY DESIGN

When the wheeled mobile robot moves forward along a straight line toward an object, its linear velocity is V and the angular velocity for straight forward motion is $\omega=0$. After every t sec sampling time, the robot will obtain distance information between the front of wheeled mobile robot and obstacle from ultrasonic sensors U1. If U1 detects an obstacle straight ahead, and the distance between the two is less than the safe distance (20cm), the robot will stop from moving and start to turn its direction.

If U1 < 20,
Then MR stop, MR turn left.
After turning the direction of mobile robot to 90°, the ultrasonic sensor U2 is worked. Until object is not missed from U2, the mobile robot moves forward and follows by the object. After missing target of U2, the mobile robot turns its direction to 90° again. And then, the mobile robot moves straight way and follows by object.

While (U2=1)
MR go forward,
While (U2=0)
MR turn right.
When the forward direction of the robot is parallel with the obstacles, the wall-following method can be initiated. A PD controller is introduced here to adjust the posture and direction of the front and rear of the robot. The control algorithm of the linear velocity V and the angular velocity ω were designed as follow

If $U2\geq 20$ cm then MR turn right
e_k=d-U2, $de_k=e_k-e_{k-1}$, $\omega_{P1}=k \text{ x } e_k + k_{D1} \text{ x } de_k$
where e_k is the error measurement and e_{k-1} is the previous error measurement of sensor.

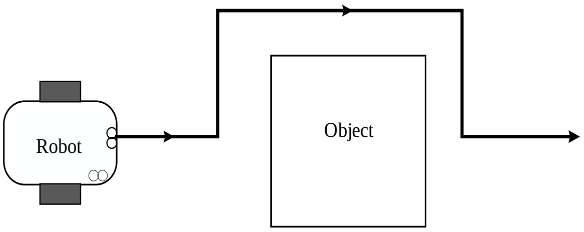

Figure 5. Route of Mobile Robot

The route of the mobile robot is shown in figure 5.

7. EXPERIMENTAL RESULTS FOR POSITION CONTROL

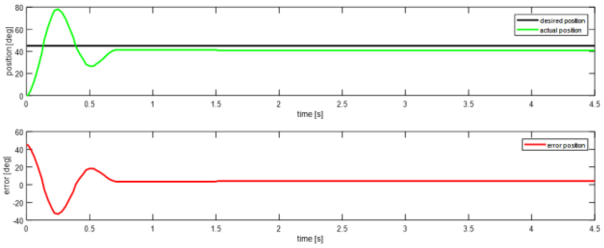

Figure 6. Position Control of DC motor with P Controller

Figure 6 shows only the tuning result of P controller. The proportional response can be adjusted by multiplying the error by a constant K_P. In this figure, the actual result is close to the desired result and there has overshoot and undershoot.

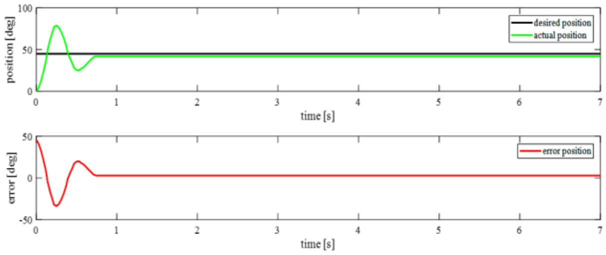

Figure 7. Position Control of DC motor with PI Controller

Figure 7 shows the tuning result of Proportional Plus Integral. In this figure, overshoot and undershoot occurred but the actual result has reached to the desired result. An integral control (K_I) will have the effect of eliminating the steady-state error, but it may make the transient response worse.

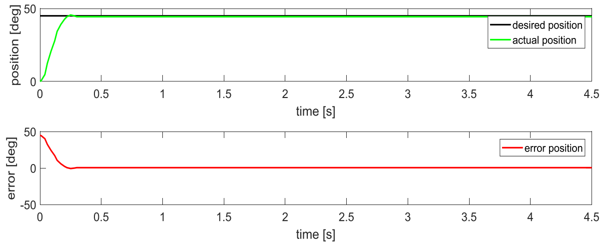

Figure 8. Position Control of DC motor with PD Controller

Figure 8 shows the result of Proportional Plus Derivative. In this figure, the result is almost stable between actual result and desired result. The derivative term slows the rate of change of the controller output. A derivative control (K_D) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response.

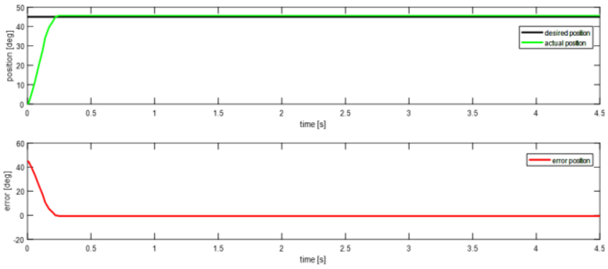

Figure 9. Position Control of DC motor with PID Controller

Figure 9 shows the tuning parameter result of PID controller. By adding PD and PI, the result achieved the good condition. In this result, overshoot disappeared and the actual result reached to the desired condition. The gain of the PID controller can be adjust the reset time for any offset within an acceptable period. Finally, increase the rate of the PID loop until overshoot is minimized. The manual tuning parameter values of DC motor are described in Table 1.

Table 1. Parameter Values for Position Control

Control mode	K_P	K_I	K_D
P	0.114	---------	----------
PI	0.116	0.0000155	----------
PD	0.1185	---------	0.00902
PID	0.1194	0.0000155	0.00905

8. SIMULATION

Figure 10 shows the path tracking of mobile robot plotted in simulation software. In this system, the path of mobile robot is shape in rectangular path because of using the two ultrasonic sensors. In this system, mobile robot moves forward in a straight line and ultrasonic sensor 1 which installed top of the robot senses the object. When object is detected by U1, the robot turns its direction left 90° and U2 sensor measures the distance. After missing the target by U2, the robot turns its direction right 90° and follows by the object. After passing the corner, the robot turns its direction right 90° again, by the use of U2 sensor. And when the robot had spent 5 secs, mobile robot turns its direction to left and go forward. If an object is detected, it will do again.

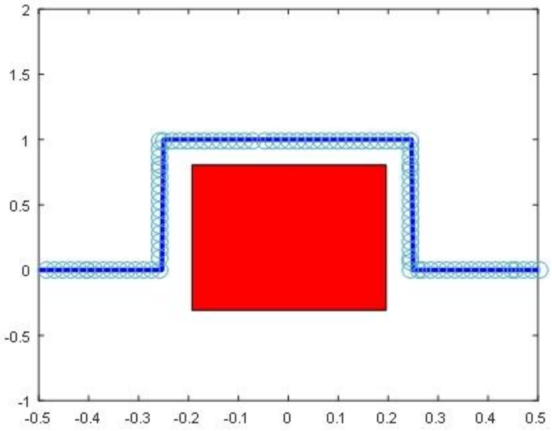

Figure 10. Path Tracking of Mobile Robot

9. CONCLUSION

This paper proposed an algorithm how to track the path of mobile robot using the ultrasonic sensors. The ultrasonic sensor is used to detect and maintain the distance between mobile robot and object. The position control results of obstacle avoiding robot by using PID controller are proposed. The value of PID tuning results are gotten by manually. The manually tuning results are shown using “CoolTerm” software. There has any limitation. This robot used only two ultrasonic sensors, so the mobile robot’s path must be in known environment. As future research, global positioning system (GPS) should also be added to this system how to integrate optical encoders or how to determine the coordinates and orientation of the robot. And then, two ultrasonic sensors are installed in this system. Moreover, by upgrading the sensor integration, the mobile robot can avoid any shape of object and can go to any desired path.

ACKNOWLEDGEMENT

The author is greatly thankful to Dr.Theingi, Rector of Technological University Thanlyin, for her encouragement, invaluable permission and her kind support in carrying out this paper work. The author is deeply grateful to all the teachers from Department of Mechatronic Engineering, Technological University(Thanlyin), who work in Research. For their support, encouragement and all persons who have given support during the preparation period of this research work.

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