International Conference on Electrical, Control and Computer Engineering
Pahang, Malaysia, June 21-22, 2011

Development of an Automatic Parallel Parking System for Nonholonomic Mobile Robot

Fairus M.A, Sy. Najib Sy. Salim, Irma Wani Jamaludin, M. Nizam Kamarudin.
Faculty of Electrical Engineering
University Teknikal Malaysia Melaka (UTeM)
Hang Tuah Jaya 76100 Durian Tunggal, Melaka, Malaysia
Email: mfairus@utem.edu.my, syednajib@utem.edu.my, irma@utem.edu.my , nizamkamarudin@utem.edu.my

***Abstract*— This paper depicts the development of backward automatic parallel parking system for nonholonomic mobile robot. The configuration of the system consists of ultrasonic sensor, rotary encoder, controller, and actuators. The path planning algorithm is developed based on the data acquired from the sensor. The proposed idea of the path planning is based on the geometrical equations in which the needed information is referring to the distance between the mobile robot and the adjacent object. The ultrasonic sensor and rotary encoder respectively used to detect parking area and measure the detected space. A PIC32MX360F512L microcontroller is used in order to generate the algorithm and control the movement of the mobile robot. System implementation is briefly described to depict the system as a whole. Experimental results are presented to demonstrate and validate effectiveness of the technique used.**

***Keywords* – Automatic Parallel Parking, Path Planning, Ultrasonic, Nonholonomic system.**

I. INTRODUCTION

The automatic parallel parking is one of the important studies that can help the driver automatically park the car. This maneuver requires high degree of focus and experience which can be difficult especially for a new driver. Presently, the driver need to guess the parking space with minimum guidance thus the collision might be occurs. The objective of this research is to overcome this problem by designing an automatic parallel parking system. For that reason, a mobile robot is developed to mimic the unmanned car. Hence studies on nonholonomic dynamics and behavior of the robot can be conducted.

Previous researches on this area have been presented based on various control approaches i.e. fuzzy logic control [1], neuro-fuzzy control [2], neural network [3] and fuzzy gain scheduling method [4]. Each mentioned approaches having its own advantages and disadvantages. Most of the approaches are quite costly due to sensors and other devices involved. As such, this paper deals with a low cost path planning technique by using single ultrasonic sensor as well as encoder respectively for measuring adjacent parking space and travelling distance calculation.

According to [5], [6] and [7], the automatic parallel parking involve with scanning, positioning and maneuvering phase in order to complete the parking process. The process is depicted in Fig. 1. The proposed approach in this paper involve the same procedure with some additional in which the safety distance as well as minimum parking space are also taking into account in the process.

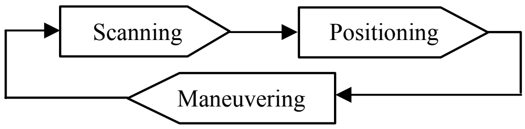

Figure 1. Automatic parallel parking phase

II. METHOD OF PATH PLANNING

In nonholonomic mobile robot parallel parking process, the safety distance and minimum parking space is put under consideration during the scanning, positioning and maneuvering phase. In the scanning phase ultrasonic sensor and encoder perform a parking space measurement to identify an acceptable parking size. There are three important phases involved in order to park the nonholonomic mobile robot safely. The first phase is the scanning phase where the mobile robot scans the parking environment by the ultrasonic distance sensors. The purpose is to measure and detect the lateral and longitudinal length of the parking space. The appropriate range of lateral sense is from 2cm to 8cm. The minimum distance for nonholonomic mobile robot parking space is visualized by Fig. 2. Subsequently, the predefined and the physical mobile robot parameters involve in this method are tabulated in Table I.

TABLE I. PARAMETERS

Symbol	Parameter
W_{park}	Width of free space (22 cm)
W_{robot}	Width of robot (20 cm)
m	Safe distance between the back of robot and the back of obstacle (3 cm)
n	Length from the back of robot to the center back axle (4 cm)
R_{min}	Minimum radius of robot circular motion
L	Length between robot front and back axle (26 cm)
D	Length between robot back axle to the front bumper (32 cm)
Δy	Measured distance between test subject and side of the robot

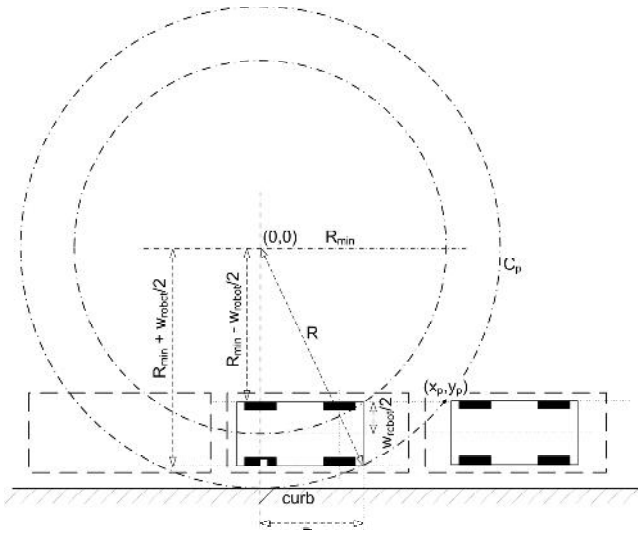

Figure 2. Minimum distance for nonholonomic mobile robot parking space

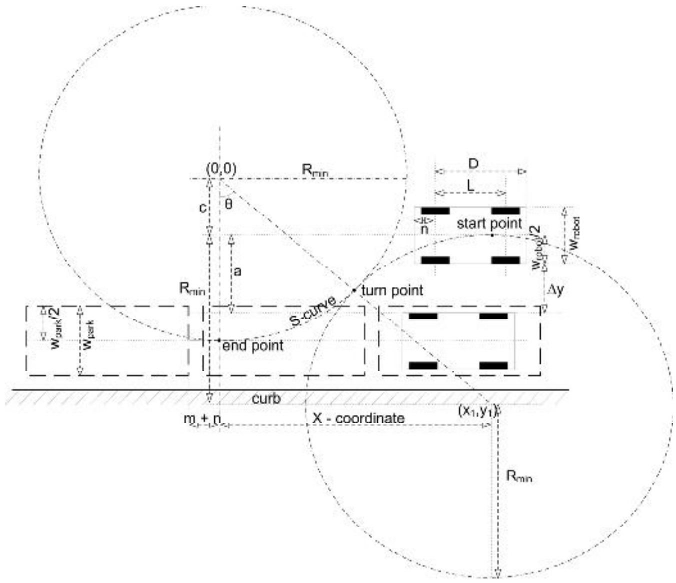

Figure 3. Path planning

From Fig. 2, the general equation for circle C_p can be expressed as

$$x^2 + y^2 = (R_{min} + w_{robot}/2)^2 + D^2 \quad (1)$$

and

$$y_p = R_{min} - w_{robot}/2 \quad (2)$$

Thus x_p can be obtained as

$$x_p = (2w_{robot}R_{min} + D^2)^{1/2} \quad (3)$$

A safety distance should be considered to prevent a collision with the back obstacle. Thus, the (3) must be added with predefined parameters m and n to take into account this safety distance. Hence, the minimum distance, d_{min}, from front and back obstacle in order to park safely is obtained as

$$d_{min} = (2(20)(60) + 32^2)^{1/2} + 3 + 4 \approx 66\text{cm} \quad (4)$$

If the detection of empty space is larger than d_{min}, then the second phase, which is the positioning phase, will be implemented, where the mobile robot will moves forward and backward. The purpose is to adjust the suitable distance from the start point to turn point before proceed to maneuvering phase. Fig. 3 shows the path planning from the start point to the turn point and from turn point to end point.

From Fig. 3, the robot will drives backward from the start point to the turn point along the arc length of a circle with radius R_{min} centered at (x_1,y_1). To implement this movement, the following algorithm is used.

Let

$$a = \Delta y + w_{robot}/2 \quad (5)$$

$$c = R_{min} - a - w_{park}/2 \quad (6)$$

Thus, the y_1- coordinate can be obtained as

$$y_1 = R_{min} + c = 2R_{min} - (\Delta y + w_{robot}/2 + w_{park}/2) \quad (7)$$

Using the trigonometry properties, the value of θ is calculated as

$$\theta = \cos^{-1}(y_1/(2R_{min})) \quad (8)$$

And hence the x_1-coordinate can be obtained as

$$x_1 = 2R_{min}\sin\theta \quad (9)$$

The main objective is to drive the robot from start point to end-point. A safe distance must be considered to prevent a collision with the back obstacle. Thus, the x_1 - coordinate must be shift forward to take into account this safe distance. Therefore,

$$x_s = x_1 + m + n \quad (10)$$

Therefore, the start point is located at x_s. The robot needs to drive backward after positioning the steering to the right at maximum angle from the starting point to the turning point along the arc length of a circle of radius R_{min}. The robot needs to stop at the distance of S-curve which calculated as

$$S_1 = R_{min}\,\theta \quad (11)$$

and after that the steering needs to be positioned to the left at maximum angle from the turning point to the end point at the distance of

$$S_1 = S_2 \quad (12)$$

The path planning process is depicted in Fig. 4.

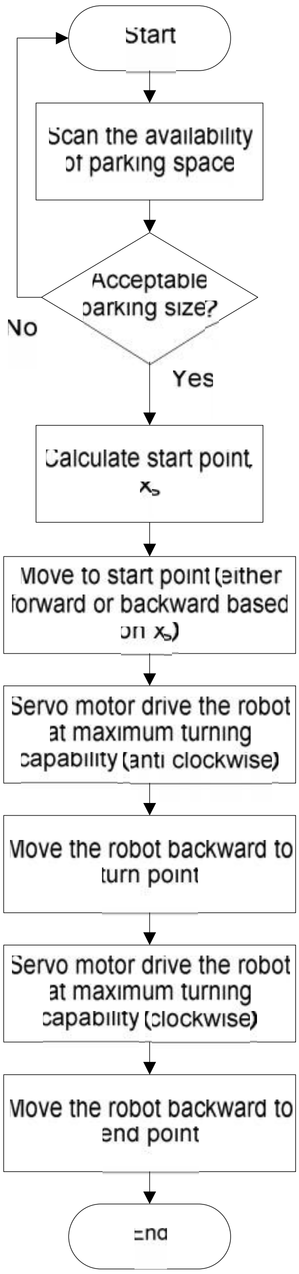

Figure 4. Path planning process

III. SYSTEM IMPLEMENTATION

The system configuration for nonholonomic mobile robot is shown in Fig. 5. The system is equipped with motor driver circuit, encoder and decoder circuit.

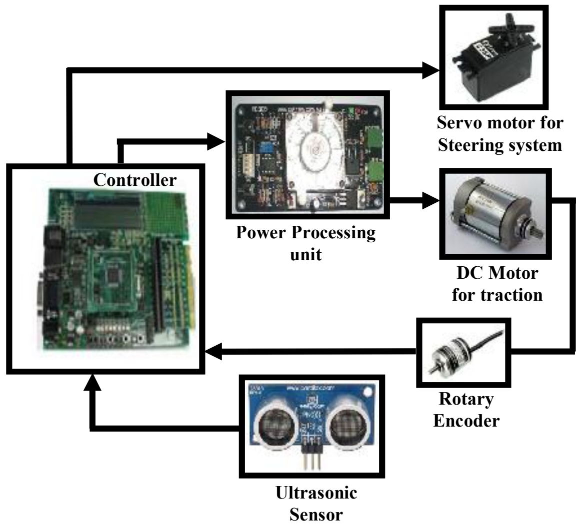

Figure 5. Configuration of nonholonomic mobile robot

The ultrasonic sensor senses the parking space and obstacle. Power processing unit prevent armature over current by applying a limit to the loop and secured the system from damage. During development process, the controller deals with the dynamics of the power processing unit and armature circuit of the motor. The power processing unit must be fast enough to be seen by the controller so that the motor dynamics are vital to the algorithm. As such, the switching PWM frequency of the power electronic devices is set to 9 KHz. This paper is not going more deep into designing the controller as this knowledge could be easily explained in control system theory. Though, the control block diagram for traction system only is shown in Fig. 6 for clarification. Ultrasonic sensors provide the value of Δy to the controller for computational purpose. The controller provide control signal to the power processing unit for intelligent traction of the robot via DC motor. Encoder sense d(k) traction pulse that transferred to the controller for collision avoidance. The steering control is done directly from the controller via servo motor.

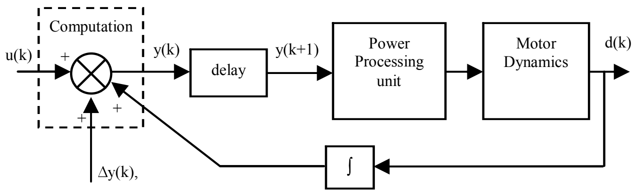

Figure 6. Control block diagram for traction system

IV. Result

In the experiment phase, system performance is measured by testing the system with various distances with respect to adjacent object. As the system focuses on parking performance of the robot, the velocity and angular acceleration are not considered. In order to measure this performance, a robot like mobile robot is developed whereas the control system is based on microchip PIC32MX360F512L. The physical parameters of the mobile robot are shown in Table II. Whereas Fig. 7 shows an experimental phase where the robot make a pause before proceed to the next step of parking phase.

TABLE II. PHYSICAL PARAMETER OF THE MOBILE ROBOT

Length (D + n)	38cm
Width (w_{robot})	20cm
Front wheel steering (α)	0°-52°
Back wheel steering (β)	0°
Back axes (L)	26cm.

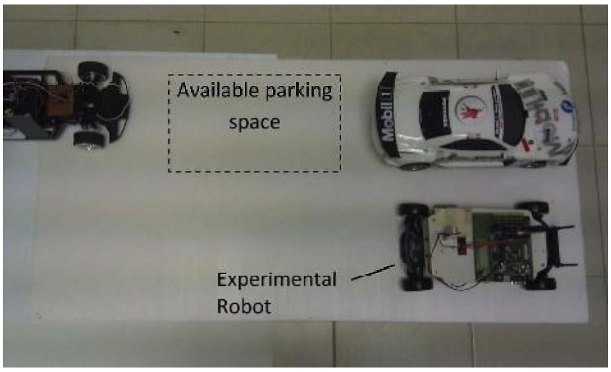

Figure 7. Parking size for adjacent distance 2.5cm

One of the objectives of the experiments is to test the effectiveness of the Parallax PING ultrasonic sensor distance sensor regarding on the detection of ample parking space. Fig. 8, Fig. 9 and Fig. 10 are obtained based on 80cm length of parking space with various adjacent distances, Δy which are 2.5cm, 5cm and 7.5cm respectively.

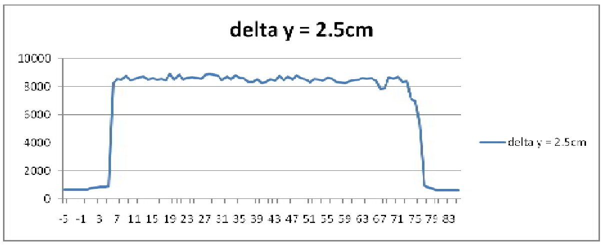

Figure 8. Parking size for adjacent distance 2.5cm

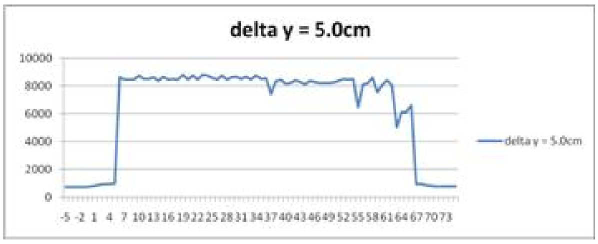

Figure 9. Parking size for adjacent distance 5cm

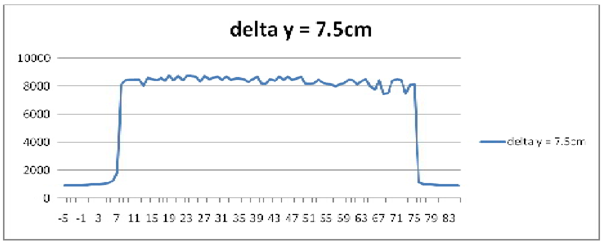

Figure 10. Parking size for adjacent distance 7.5cm

According to the result, it is clear that the sensor able to detect the parking space. There is a slight difference between the detected space and the exact space due to the ultrasonic sensor beam characteristic. The error resulted from the data obtained is around 14%. This information is taken into account while performing the parking procedure. The acceptable of the adjacent distance based on this mobile robot is 2.5cm – 10 cm.

Collision is one of the important issues to be considered while performing the parking procedure. Regarding to this matter, a safe distance is set based on (4) as mention in part II. Table III shows the measurement of the distances obtained from various adjacent distances, Δy.

TABLE III. SAFE DISTANCE MEASUREMENT

Δy (cm)	Safe Distance (cm)	Time (s)
0.31	3	11
1.11	2.5	10.6
2.14	2.5	11.6
3.26	3	10.2
4.29	2	10.6
5.08	2	10.2

According to the measured distance shown in Table III, the safe distances are within 2 cm – 3 cm. By comparing with the reference value, this range is considered acceptable. Subsequently, the average time taken for the mobile robot to drive backward from the starting point to complete the task is around 10.7s. As such, it is observed that the technique capable to perform parallel parking with only single ultrasonic sensor. The performance of the robot could be improved by exploiting more ultrasonic sensor to the system.

CONCLUSION

In this paper, the concept of geometrical for parallel parking was presented. This concept has been described in detail and the derivations of the mathematical equations are shown in Part II. The effectiveness of the proposed method is confirmed and verified through experiment. Through this technique, the robot possesses good tracking performance as it able to park on the designated space without collision. As the robot can only perform a backward automatic parallel parking scheme, the improvement can be done to develop a forward automatic parallel parking scheme in future work.

ACKNOWLEDGEMENT

Part of this work is sponsored by Fundamental Research Grant Scheme under MOHE in the Universiti Teknikal Malaysia Melaka (UTeM), Malaysia.

REFERENCES

[1] R. Cabrera-Cosetl, M. Z. Mora-Alvarez, and R. Alejos-Palomares, "Self-Parking System Based in a Fuzzy Logic Approach," in Electrical, Communications, and Computers, 2009. CONIELECOMP 2009. International Conference on, 2009, pp. 119-124.

[2] Z. L. Wang, C. H. Yang, and T. Y. Guo, "The design of an autonomous parallel parking neuro-fuzzy controller for a car-like mobile robot," in Proceedings of the SICE Annual Conference, Taipei, 2010, pp. 2593-2599.

[3] M. R. Heinen, F. S. Osorio, F. J. Heinen, and C. Kelber, "SEVA3D: Using Artificial Neural Networks to Autonomous Vehicle Parking Control," in Neural Networks, 2006. IJCNN '06. International Joint Conference on, 2006, pp. 4704-4711.

[4] L. Kuang-Yow, C. Chian-Song, and C. Tung-Sheng, "Parallel parking a car-like robot using fuzzy gain scheduling," in Control Applications, 1999. Proceedings of the 1999 IEEE International Conference on, 1999, pp. 1686-1691 vol. 2.

[5] Y. K. Lo, A. B. Rad, C. W. Wong, and M. L. Ho, "Automatic parallel parking," in Intelligent Transportation Systems, 2003. Proceedings. 2003 IEEE, 2003, pp. 1190-1193 vol.2.

[6] K. Jiang and L. D. Seneviratne, "A sensor guided autonomous parking system for nonholonomic mobile robots," in Robotics and Automation, 1999. Proceedings. 1999 IEEE International Conference on, 1999, pp. 311-316 vol.1.

[7] K. Jiang, "A sensor guided parallel parking system for nonholonomic vehicles," in Intelligent Transportation Systems, 2000. Proceedings. 2000 IEEE, 2000, pp. 270-275.