# S-SHAPED ONE TRAIL PARALLEL PARKING OF A CAR-LIKE MOBILE ROBOT

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**Abstract -** In this paper, car-like mobile robot motion task is to park between the parallel posture cars for narrow parking space in an obstacle free environment. The planning of parking trajectory is purely based on the geometric approach, which can be determined by the geometry of the robot and its steering angle. The fundamental of circular concept is used as the main idea for this research. The s-shaped trajectory parking path is formed by the two identical circles tangentially connected. The starting point to be moving along the s-shaped trajectory can get from two circles subtracting idea. The working area is constrained by the wall and sensor arrangement. Ultrasonic sensor data are used as the main decision part to change the parking states for instance to find the parking space and to adjust robot orientation. Fuzzy filter is used to stabilize sensor data and quick response input. Localization system is done by odometry that mainly used the sensor output as the input command. The mobile robot will make the parking in one trail maneuver system. The proposed planning method does not depend on the initial position of the robot but it must be parallel with the parking space.

**Keywords -** Parallel Parking, Geometric Path Planning, Orientation, S-shaped Trajectory, One Trail.

## I. INTRODUCTION

Parallel parking means on a road where cars are parked in front of each other, bumper to bumper, length wise and there exists a gap, the car can be parked between it, in parallel. This kind of system is designed to improve comfort and security of driving in constrained environments where a lot of attentions and experiences are needed to maneuver the vehicle. Since the task of parallel parking requires many repeated maneuvers in a very limited space, its nature is different from the normal driving in a huge environment.

There are two different approaches to solve the parking problem. The first one, the trajectory planning approach, needs a mapping and auto-localization algorithms. In addition to this, it generates paths by using the dynamic and kinematics models of the vehicle and vehicle constraints. Then, it controls the vehicle velocity and the steering angle to ensure a position in the mapped environment [1]. On the other hand, the second approach tries to mimic the skills of an experienced driver by using Artificial Intelligence techniques such as finite automaton, fuzzy logic (e.g. Zhao and Collins Jr [2005]) or artificial neural networks (e.g. Jenkins and Yuhas [1993]. These methods do not need any path planning and their associated tracking control but they are limited to the experience of human experts and not easily extended to more general cases [2].

This research deals with the first approach. In real life, when the parking space is large enough, human driver usually steers the front wheel to maximum angle for retrieving. When the vehicle is retrieved, the driver steers the front wheel to maximum angle again but in reverse direction until the car is parallel to the road. The problem of retrieving the vehicle from the parking slot has been solved by Lo et al [3]. Since this procedure is reversible thus it can be applied in parallel parking problem. This steering scenario forms a simple path composed by two identical circles connected by a tangent point. In order to use this path for parallel parking, it is necessary to know the correct position where to begin the parking maneuvers in accordance with the initial position of the car. Geometric approach path planning method will be helped to solve this problem. In this approach, parking path will be changed in accordance with the initial position of the car; the only constraint is the car must be parallel with parking space.

This paper is organized as follows: section II is described about the system overview of parallel parking systems. Mobile robot design and its geometric properties are presented in section III. Position control and sensor arrangement are described in section IV. Working environment is explained in section V. In section VI, path planning in one trail and calculation of longitudinal starting position are described. Experimental result of the parking system is described in section VII.

## II. SYSTEM OVERVIEW

The goal is essentially to park the mobile robot between two parallel posture cars, for narrow parking space. When the user starts the parking procedure, mobile robot will find the parking space. After that the mobile robot will make decision enough parking space or not by comparing with actual detecting length of the parking space and minimum theoretical length of the parking space.

Geometric approach path planning method is used to find the starting position to be moving along the s-shaped trajectory in accordance with the lateral position from the front car. After that, the robot will be moved from the initial position to the starting position. And then, the robot will be moved along the

s-shape trajectory parking path. The system block diagram of the parking procedure is shown in Fig.1.

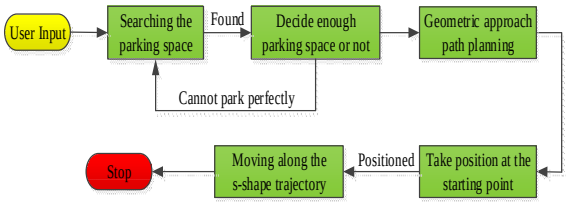


**Fig.1. System block diagram**

## III. SENSOR ARRANGEMENT AND WORKING ENVIRONMENT

### 3.1. Sensor Arrangement

The two HC-SR04 ultrasonic sensors are used in this research. Each one is fixed at the right side of the robot above the rear and front wheels' axle. Sensor transmits sound wave like a V-shape in every 10µs and collects reflection wave duration to calculate the measuring distance.

According to the sensor arrangement, there has a constraint on a measuring distance shown in Fig.2. The best data collection angle for sensor is 15 degrees. The two sensor data will be confused in one point because these are fixed parallel in one side. From this constraint, the parking robot will be working well in 2 feet.

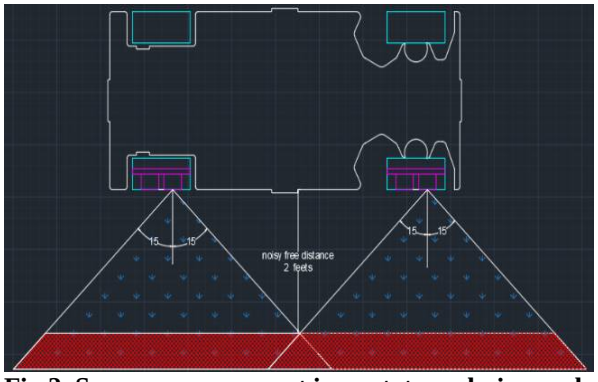


**Fig.2. Sensor arrangement in prototype design and noisy free distance**

There has still another problem with ultrasonic sensor. It can be working well in flat surface. If the detection surface is not flat, the reflection wave can be confused and the correct data can't be got. The other weak point is sensor data which are not stable even in a flat surface. From these facts, ultrasonic sensor is not suitable in a precision case. But in this research, it was used for the facts of cheaper and easy to get. These errors can be satisfied by using filter such as average filter and fuzzy filter. Experimental test can validate these facts with fuzzy filter shown in Fig.3.

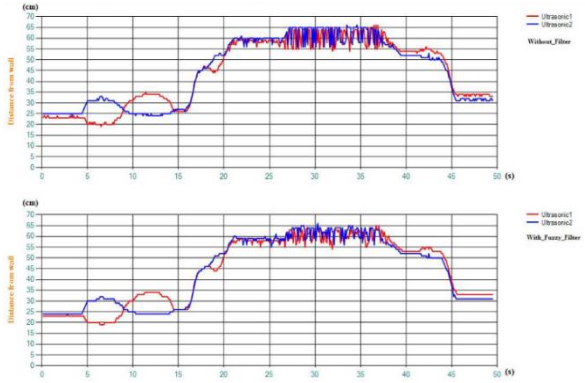

**Fig.3. Filtering with fuzzy logic and constraint distance**

Fuzzy filter is more suitable than the average filter for this research. Average filter make long programming time base on the number of sample data and it can't get quick response. Fuzzy filter can get quick response on data. The sum of coefficient value must be '1'. To be quick response relied on income data, the coefficient of income data should be greater than the coefficient of old data. According to the chart, it can be seen that shark noise can be stable with filter. Unstable condition is occurred during 27 to 38 seconds because the sensor detecting distance is over the constraint distance.

Data update = (income data*x) + (old data*y) (1)

### 3.2. Working Environment

In this research, the parking will be done in a known environment. It is assumed that there has a wall that is right side of the parking robot and there has a gap between the robot and the wall. The gap distance is constraint on two ultrasonic sensors working area. According to the prototype design and sensor constraint area, the maximum gap length is 2 feet and the two front and rear parked cars can be located in this range. It was also needed to count minimum detecting length (2cm) of ultrasonic sensor. So, the maximum located length is (2ft-2cm) and the minimum located length can be approximately zero. For the parking robot, the minimum offset from the wall must be at least its width when the parked cars are located at the minimum offset. For the parking robot, left side of the two parked car should be approximately marginally parallel. The predefined working environment is shown in Fig.4.

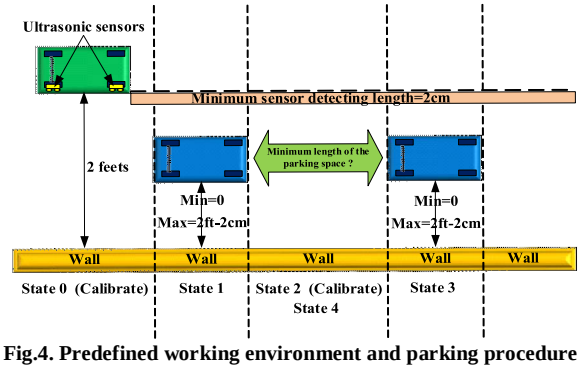


**Fig.4. Predefined working environment and parking procedure**

## IV. FUNDAMENTAL OF CIRCULAR CONCEPT

The mobile robot movement and turning angle are under the steering control of limited within the $-\beta_{max} < \beta < \beta_{max}$. While the robot is moving with constant velocity and the steering angle is in the left or right direction with constant degree, the robot maneuver is almost a circle according to the mechanical damping of the robot design. Instantaneous center of rotation (ICR) is formed by the geometry of the vehicle. ICR create simple path with circular motion

The motion planning for parallel parking necessitates the study on turning radii. The turning radii can be calculated by circular equation according to its coordinate. The basic diagram of forming circle and two circles intersection points are shown in Fig.5. The calculation of two circles intersection point is the key idea for finding the minimum lateral distance. The intersection point can be got by solving the two circular equations.

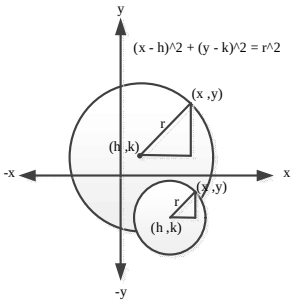


**Fig.5. Basic circle diagram**

## V. MAXIMUM AND MINIMUM LATERAL DISTANCE

Lateral distance means the amount of space between the parking robot and the second car parallel offset. The s-shape trajectory parking path can be changed based on the lateral distance. The larger the lateral distance, the longer the parking path to follow. The calculation of minimum and maximum lateral distance is shown below.

### 5.1. Maximum Lateral Distance

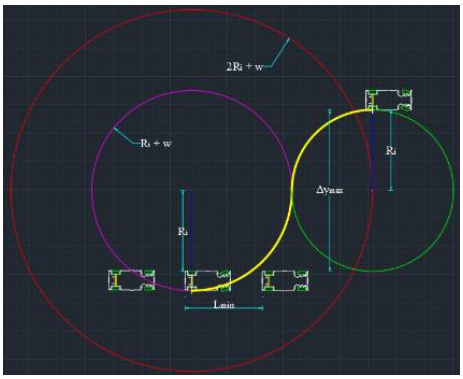


**Fig.6. Parking with maximum lateral distance**

$$\Delta y_{max} = 2R_i \quad (2)$$

### 5.2 Minimum Lateral Distance

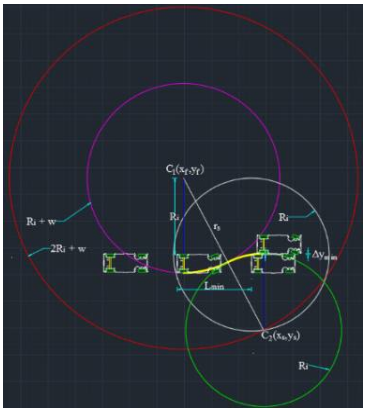


**Fig.7. Parking with minimum lateral distance**

Circular equation;

$$(x-h)^2 + (y-k)^2 = r^2 \quad (3)$$

Center of coordinate $C_f$ (0,0) is used as origin. The red circle is for the second circle moving center point to be tangentially connected with the violet circle.

$$(x-0)^2 + (y-0)^2 = {r_s}^2 \quad (4)$$

To avoid collision with the second car, the parking robot rear moving path and its circular equation is:

$$h = L_{min} - P_1$$
$$k = R_i$$
$$(x-h)^2 + (y-k)^2 = r^2 \quad (5)$$

By solving equation (1) and (2), it can be got two tangent points ($x_1$, $y_1$) and ($x_2$, $y_2$). The larger x and smaller y as ($x_s$, $y_s$) will be defined as $C_2$ center point. And then the minimum lateral distance can be calculated.

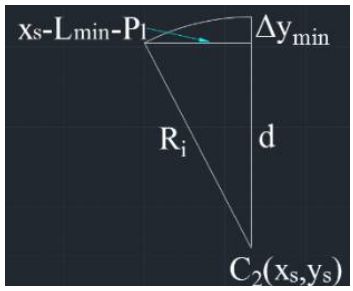


**Fig.8. Finding the minimum lateral distance**

$$d = \sqrt{{R_i}^2 - (x_s - (L_{min} - P_1))^2} \quad (6)$$

$$\Delta y_{min} = R_i - d$$

## VI. PATH PLANNING

Significant and practical keys issues in motion planning are safety and optimality. Firstly, predefined collision free path must be considered based on the geometry of the vehicle. The test of the robot maneuver is in the obstacle free indoor environment. Front and rear parallel posture cars are only needed to count for the probability of collision. Both minimum

length of the parking space and minimum lateral displacement have been solved in [5].

When the parking procedure is started, the robot will be moved in the vicinity of the parking space and taken position parallel with the front car. At the same time, the robot will measure the size of the parking space and lateral displacement $\Delta y$ offset from the front car. If longitudinal starting position $x_s$ and turning position $P_t$ in accordance with $\Delta y$ can be directly computed, the robot will be successfully parked along the s-shape trajectory. Fig.9. is shown geometrical information diagram for finding longitudinal starting position $x_s$ and turning point $P_t$.

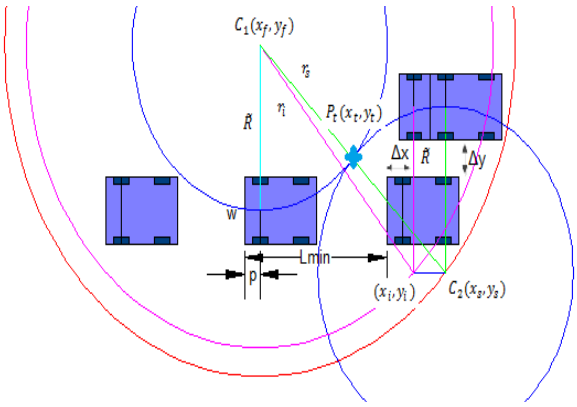


**Fig.9. Geometrical calculation of initial position to starting position**

**1.**

Firstly, the robot will be moved longitudinally $x_i$ to $x_s$ and then started steer maximum to the right while moving back to the $P_t$. Then counter-steer will be turned to the left and the robot will enter into the parking slot. In this section analytical calculation is developed for these relationships.

In this research, the path planning strategy is thought from final position to the starting position of the parking procedure. The final position of the robot is equal to the $L_{min} - p$. The ICR of $C_1(x_f, y_f)$ is always perpendicular to the final position of the parking maneuver with a distance of $R_i + w/2$ and define this distance by radius $\tilde{R}$. The origin of coordinate (0, 0) is denoted at $C_1(x_f, y_f)$. Similarly the ICR of $C_2$ is always perpendicular to the starting position of parking maneuver $(x_s, y_s)$ with a distance of $\tilde{R}$. Each radius of these two circles is the same and their arcs are tangentially connected. The circle of center $C_1$ is always in a fixed position at the end of the maneuver but the circle of center $C_2$ will be moved and tangentially connected along the arc of $C_1$ in accordance with the lateral displacement $(\Delta y)$. It seems center $C_2$ moving on the arc of radius $2 \times \tilde{R}$ with center $C_1$. The initial position of the car can be calculated as follow:

$$x_i = L_{min} - p + \Delta x \quad (7)$$

$$y_i = \left[\tilde{R} + \frac{w}{2}\right] + \left[\tilde{R} - \left(\Delta y + w + \frac{w}{2}\right)\right. \quad (8)$$

The radius of initial position with the center of $C_1$ can be calculated by using circular equation:

$$x_i^2 + y_i^2 = r_i^2 \quad (9)$$

The initial position and starting position of lateral displacement are the same:

$$y_i = y_s \quad (10)$$

The radius of starting position with the center $C_1$ is

$$r_s = 2 \times \tilde{R} \quad (11)$$

Now, the longitudinal starting position $x_s$ can be calculated by subtracting the circular equation:

$$\begin{array}{r} x_s^2 + y_s^2 = r_s^2 \\ -\ x_i^2 + y_i^2 = r_i^2 \\ \hline x_s^2 - x_i^2 = r_s^2 - r_i^2 \\ x_s^2 = r_s^2 - r_i^2 + x_i^2 \end{array}$$

$$x_s = \sqrt{r_s^2 - r_i^2 + x_i^2} \quad (12)$$

Now, the point $P_t(x_t, y_t)$ can be calculated that is where the vehicle counter-steers.

$$y_t = \frac{y_s}{2} \quad (13)$$

$$x_t = \frac{x_s}{2} \quad (14)$$

The central angle can easily be calculated from the two circle tangent point.

$$\text{Central angle} = \sin^{-1}\left(\frac{x_t}{R}\right) \text{ (Degree)} \quad (15)$$

The arc length is calculated for the robot to be followed the s-shape path.

$$\text{Arc length} = R \times \left(\text{central angle} \times \frac{180}{\pi}\right) \quad (16)$$

## EXPERIMENTAL RESULT

In this section, experimental result of parking procedure is presented step by step shown in Fig. 10. Firstly, the robot will find the parking space by using ultrasonic sensors shown in Fig.10. (a). If the length of the parking space is not large enough, the robot will not be parked.

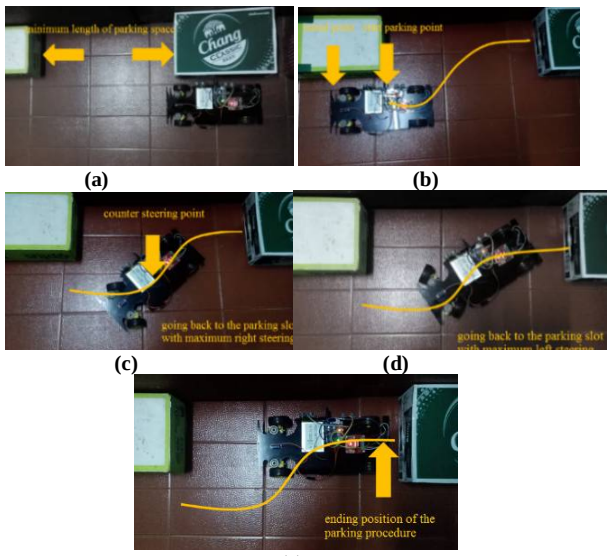


**Fig.10. Experimental testing photo**

When there has the minimum parking space, the robot will be moved from initial parallel position to

the starting position according to the lateral distance. In Fig.10. (b), the robot is stopped at the initial position.

Fig.10. (c) is shown that the robot is entering to the parking slot with maximum right steering. Firstly, the servo motor will rotate to become maximum right steering and then DC motor will rotate the rear shaft with constant speed until the counter steering point.

In Fig. 10. (d), when the robot is reached at the counter steering point, the servo motor will rotate again to become maximum left steering and the robot will move back to the final point. While the steering angle is changing, the linear velocity will be zero.

The robot is stopped at the end of the second parking length as shown in Fig. 10. (e). After that, the robot will be parallel with two parked cars.

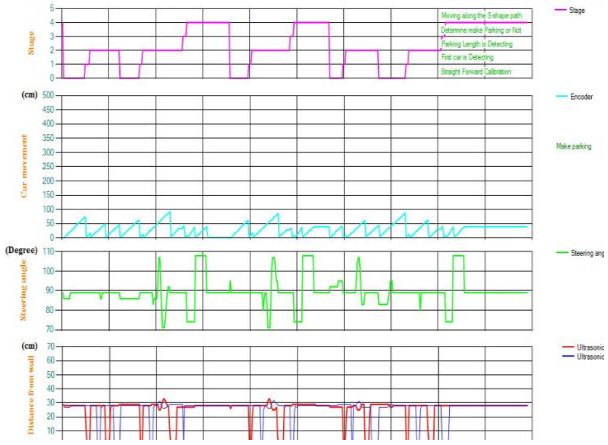


**Fig.11. Overall parking chart**

The experimental result is validated with the Visual Basic Simulink shown in Fig.11. According to the overall parking chart, it can be seen that the parking is done three times in 50s. The function of each chart is operated at the same time and related each other. It can be known that doing parking is obviously seen from steering angle chart and state chart. In steer angle chart, the rectangular wave means the robot is moving along the s-shape path. The ultrasonic 1 and 2 difference is used as the input for the changing of parking state. The steering angle will also be variable with this difference in calibration state. Robot movement is decided there have enough parking space or not in state 2. If there have not enough parking spaces, the robot will be finding the next parking space.

## CONCLUSION

The proposed parallel parking mobile robot is based on a geometric approach in a known environment. When the robot is positioned in parallel in the vicinity of the parking space, it can be parked well independent of the initial position of the robot according to the simple path composed of 2 identical circular arcs of minimum radius and the straight line segment. In real life, when the parking space is narrow even experience drive may not take parking in case of collision. According to this approach, the parking procedure can be taken in a narrow parking space without collision. For the extension of this research PID control should be added for the robot movement to be followed the path more satisfied. Vision control system can also support to detect the parking space and obstacle for the unknown environment.

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## REFERENCE

[1] Kleber de Oliveira Andrade, André Carmona Hernandes and Marcelo Becker "A rule-based controller simulation for an autonomous parallel parking of a car-like robot using laser sensors", *Mobile Robotics Lab –Center for Robotics of São Carlos*, Brazil, 2012.

[2] Laumond, P. E. Jacobs, M. T aix and R. M. Murray "A motion planner for nonholonomic mobile robots" *IEEE Trans. Robotics and Automation*, vol. 10 (5), October, 1994.

[3] K. Lo, A. B. Rad, C. W. Wong and M. L. Ho "Automatic parallel parking" *IEEE Conf. Intelligent Transportation Systems*, October, 2003.

[4] Lee, M. Kim, Y. Y oum, and W. Chung "Control of a car-like mobile robot for parking problem" *Proc. IEEE Internat. Conf.Robotics and Automation*, 1999.

[5] Bourke. "Intersection of the two circles" http://local.wasp.uwa.edu.au/~pbourke/geometry/2circle/April, 1997.

[6] Sungwoo CHOI, Clément Boussard and Brigitte d'Andréa-Novel "Easy Path Planning and Robust Control for Automatic Parallel Parking" Preprints of the 18th IFAC World Congress Milano (Italy) September 2, 2011.

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