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DEVELOPMENT OF AUTOMATED PARALLEL PARKING SYSTEM IN SMALL MOBILE VEHICLE

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ABSTRACT

Collisions can happen during reversing or parking the car especially in the limited space. Since many drivers acknowledge that parallel parking is a very tedious task. This research aims to develop the parallel parking system by developing small mobile vehicle as a model. Design of prototype vehicle is considered for the real-life parallel parking. Hence, it can detect a parking space, execute the parking maneuver, avoid hitting the front, rear obstacles and reduce the time for parking. The parking maneuver is simplified by choosing the optimum turning angle for both the first and second parts of the parking maneuvers. At the first stage, ultrasonic sensors sense the parking environment and if the space is sufficient, a safe parking maneuver is generated. In second stage, positioning phase, the mobile vehicle will execute reverse motion into the parking space without any collisions. The last stage, it moves to the correct parking position in the parking space while adjusting itself to a safe distance from front and rear obstacles respectively. It is discovered from the result that developed system required just 1.33 times longer parking space than vehicle overall length**.** Small mobile vehicles successfully able to manage the parallel park itself without hitting or touching front and rear obstacles.

Keywords: mobile vehicle, parallel parking, path planning, optimum turning angle.

INTRODUCTION

Nowadays, several car manufacturers have introduced parking assist system and it has been well accepted due to the fact that parallel parking is a troublesome task. This automated parallel parking feature is a great help when visibility behind the vehicle has decreased because of aerodynamic design. Eventually, this system will prevent the car from hitting at the rear and subsequently reduces the error due to human judgement. However, it can be found that there are still some gaps and the new directions such as such as the control of stall and brake, performances of sensors, diagonal parking and system disturbances and environment uncertainties for the future research (Wang, W.*et al.* 2014)

In order to simulate a real car parallel parking maneuver, a 1:10 scale prototype is set up and a micro-controller is mounted on it. This setup is later assumed as small mobile vehicle. It consists of several important parts which are robot mechanism, coding, sensor and other electronic parts. The automated parking maneuver for small mobile vehicle is explained by using some mathematical model (Fairus, M. A. *et al.* 2011). Generally, automatic parking can be divided into three parts which are sensory perception, path planning of path**,** and maneuver execution.

This paper aims to develop the automated parking movement of a small mobile vehicle using some mathematical model and circuit design of the prototype mobile vehicle. At first, a small mobile vehicle has implemented. Secondly ultrasonic sensor is used to accomplish environment detection and microcontroller for data processing. Finally, parking maneuver and coding algorithm was developed for successful parallel parking.

Parallel Parking System

Currently, there are cars which already equipped with parking assist system (PAS) whether in semi or fully autonomous such as in Ford Focus, Toyota Prius and Mercedes A45-AMG. Most of the available autonomous parallel parking system in a car integrates a set of sensors, visual image captured by the camera and microcontroller and also digital signal processor to detect the environment and act accordingly to complete the parking maneuver. Radio control servo controller is the one steering the front tires. Its input and output is PWM (pulse width modulation) signal. A built in speed controller is used for controlling direction and speed. Sensors are used to detect the available parking area and then the system will decide whether or not the parking space is enough. Only after that the parking maneuver is carried out.

Techniques that have been suggested for parallel parking can be divided into two categories. The first one uses conventional controllers to tackle the parallel parking problem. On the other hand, the second one uses intelligent control by taking the advantage of the merits of some tools of computational intelligence (Gowan, K. *et al*.). A sensor based maneuver (SBM) provides smooth and safe motion for the vehicle while undergoing the parking maneuver. It is initiated by using some predefined sensor modalities and controls. The vehicle will perform a specific type of maneuver in a reactive way. Besides that, it also involves three main phases which are detecting a parking space, retrieving an appropriate starting position for the vehicle, and executing the parallel parking maneuver (Moghri, M, P., Karami, R, M., Ghaderi, R., 2012).

Fuzzy logic theory and a sensor based navigation method are applied together to design a real-time execution program. Knowledge base on a FLC can be

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obtained from human experts or from a referential data set. It has been proven that these concepts can be applied successfully in autonomous mobile robot control applications (Tzuu, H., S., Li, 1997).

Prototype of Small Vehicle

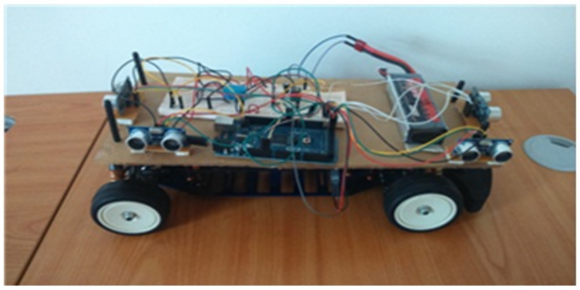

Figure-1. Prototype of small mobile vehicle.

Developed prototype of small mobile vehicle shown in Figure-1. The prototype is built on 1:10 scale RC car model's frame. It consist of several important parts which are DC geared motor, servo motor, Arduino MEGA 2560 microcontroller, ultrasonic sensor and a relay. Basically, in the circuit connections, all the echo and trigger pins of the sensors are connected to the digital pins on the microcontroller. This enables the output from the sensors in on and off or high or low state. In turn, it allows the user to use digital write coding for instructing the sensors to emit sound echo and then detecting it through the built in receiver. The duration of the travelling wave from being emitted and received is used for calculating the distance of the detected object. This is how the sensors being used to measure distance. Table-1 shows the specification of developed small car.

Table-1. Specification of RC car and electronic components.

Dimensions of RC car model	
Length	450mm
Height	138mm
Wheel base	260mm
Width	190mm
Track	16mm
Ground clearance	10mm
Gear ratio	5.01:1
Weight	961g
Electrical components	
DC geared motor	Cytron SPG30-60K
Servo motor	SKU S-01
Arduino board	MEGA 2560
Ultrasonic sensors	HC-SR04
Relay	Takamisawa RY5W-K

Servo motor relies on the 5V output of the board and its data wire is connected to the PWM pin 2. The servo control receives low power level signal and amplifies the power up to appropriate levels to move the servo motor. Geared motor is controlled digitally using 5V voltage output of the Arduino MEGA board, it is connected indirectly to PWM pin 3 from the resistor. This resistor receives the output voltage from voltage regulator. Relay is used as a switch for changing the rotational direction of this motor. In addition, a voltage regulator is built to convert the DC input voltage to a switched voltage applied to a power MOSFET. This setup helps in supplying a constant voltage to the DC geared motor. The path planning is further explained by using a referenced mathematical model.

Mathematical Model Used for the Parallel Parking System

Figure-2 shows the important consideration parameters for automated parallel parking. Ackerman steering angle is used as a reference for this mathematical model Minimum length of car circular motion (R_{min}) or turning radius is one of the important variables in the parking maneuver. This automatic parallel parking system will be designed base on the following mathematical model:

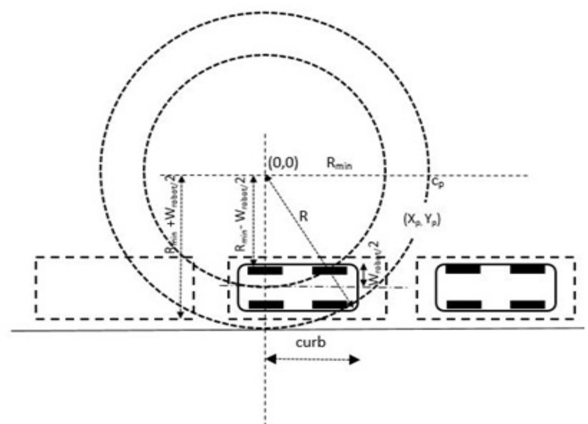

Figure-2. Automated car parking parameters.

Table-2. Parking parameters.

W_{park}	220 mm
W_{robot}	200 mm
m	30 mm
n	40 mm
L	260 mm
D	340 mm

As shown in Figure- 2, for circle C_P, general equation can be expressed as

$$x^2 + y^2 = \left(R_{min} + \frac{W_{robot}}{2}\right)^2 + D^2 \quad (1)$$

And,

$$y_p = R_{min} - \frac{W_{robot}}{2} \quad (2)$$

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W_{park}	Width of empty parking space
W_{robot}	Width of small mobile vehicle
m	Safe distance between the rear obstacle and the back of vehicle
n	Length from the center or rear axle to the rear of vehicle
R_{min}	Minimum radius for circular motion
L	Length between the vehicle rear and front axle
D	Length between the front bumper to rear axle of the vehicle
Δy	Measured distance between vehicle at start point to the side of the car in front of the empty parking space

Thus, x_p can be obtained as
#

$$x_p = \left(2W_{robot}R_{min} + D^2\right)^{\frac{1}{2}} \tag{3}$$

In order to execute safe parking maneuver, minimum distance, d_{min} from rear and front obstacles is obtained as

$$d_{min} = \left(2(20)(60) + 32^2\right)^{\frac{1}{2}} + 3 + 4 \approx 66cm \tag{4}$$

Second phase, the positioning phase will only is executed if the sensed parking slot is larger than d_{min}. In this phase, the small vehicle will move forward and backward to adjust to a suitable distance from the starting point to turn point before proceeding to the maneuvering phase.

It will execute reverse motion from the starting point to the turning point along the arc of a circle with radius R_{min}. This circle center is at (x_1, y_1). Algorithm used is as shown below:

$$a = \Delta y + \frac{W_{robot}}{2} \tag{5}$$

$$c = R_{min} - a - \frac{W_{park}}{2} \tag{6}$$

Thus, y_1 coordinate can be obtained from equation

$$y_1 = R_{min} + c = 2R_{min} - \left(\Delta y + \frac{W_{robot}}{2} + \frac{W_{park}}{2}\right) \tag{7}$$

θ value is calculated as

$$\theta = cos^{-1}\left(\frac{y_1}{2R_{min}}\right) \tag{8}$$

And x_1 coordinate is obtained as shown in equation below.

$$x_1 = 2R_{min}sin\theta \tag{9}$$

x_1 coordinate must be shifted forward to consider the safe distance. This is done to avoid collision with rear obstacle. Therefore,

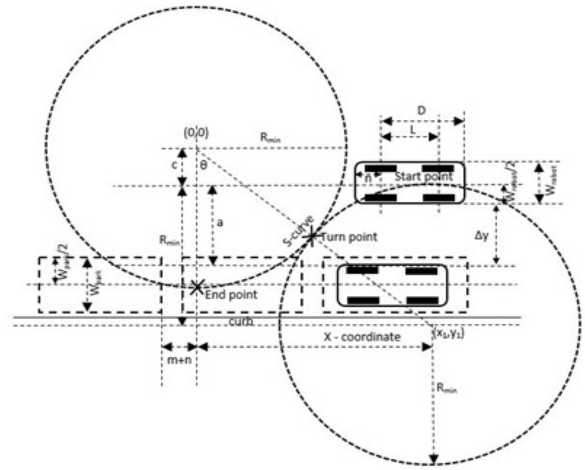

Figure-3. Path planning.

$$x_s = x_1 + m + n \tag{10}$$

x_s denotes the location of starting point. After the front wheels are steered to the right at its maximum, the mobile vehicle needs to reverse in this condition until the turning point on the arc length of a circle with a radius of R_{min}. Then, at the distance of S-curve, it needs to stop. This distance is calculated as

$$S_1 = R_{min}\theta \tag{11}$$

Then, the wheels are steered to the left at its maximum. Starting from the turning point, the vehicle continue to reverse in this condition until it reaches the end point at the distance of
#

$$S_1 = S_2 \tag{12}$$

Conceptual Design

In conceptual design, the first one is to define how the car senses the availability of parallel parking space. After being able to sense the parking space, the system will justify whether or not that particular space is long and wide enough to accommodate the mobile vehicle. Four sensors are placed at specific position on the vehicle and able to detect free space correctly.

Usually, in order for a driver to parallel park the car successfully, the following five basic steps are done

1) The car is driven pass the parking space and stops beside the car that fills the parking space in front of the empty one. (The driven car passes about half the length of the car beside it).
2) The drivers turn the car's wheels toward the curb and reverse the car into the parking space at 45°.
3) When the front wheels are in line with the rear wheels of the car in front, the wheels are straightened and reverse motion is continued.
4) While checking the rear view mirror to ensure the car is still within safe distance from the car behind, the wheels are turned away from the curb

to bring the front end of the car into the parking space.

This automated parking system should be able to do such maneuvers to guide the mobile vehicle into the parallel parking space.

Parking Maneuver and Coding Algorithm

The algorithm emulates Ackerman steering for completing the parallel parking maneuver. However, this is done without the application of front tire differentials for steering the wheels. The task for programming the motion of mobile vehicle had been broken down into several sections. This provides an effective way of modifying or correcting a portion of the programming without affecting the others.

Coding Algorithm

The coding is done using Arduino software. It started with the definition of servo, digital pins, long character and several integers of constant values. In void setup function, serial communication is established and the pin mode for sensors and motor are defined as output and input as required. Void loop function which is the main looping is created. Under this function, coding that includes all the conditions needed for the parking maneuver to be done is written. While loop is used as the main tool for creating the checking sequence of the crucial parameters. This is important in deciding whether certain movements need to be done or not. Mainly, the parameters involve are the distances from the RC car to the obstacles.

In almost every stage of the parking maneuver sequence, two functions which are outside the main looping function are called. The functions are read sensor and sensor save function. Read sensor function includes the coding for measuring the elapsed time from the time sound wave is emitted to the time sound wave is reflected by the detected object. Then, this elapsed time or duration as written in coding is converted into distance value by mathematical operation in sensor save function.

Based on the required distance values at every stage of the maneuver, the geared motor and servo motor response are determined. These responses are in term of the motor rotation and movement for the servo. In addition, at a specific stage of the maneuver, either both of them or one of the two motors need to be activated.

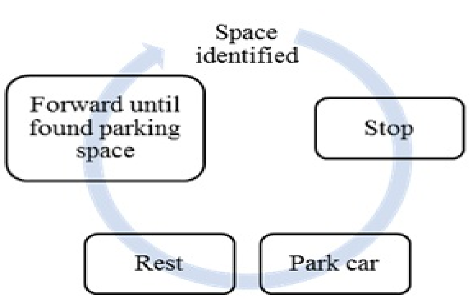

Figure-4. Automated parking sequence.

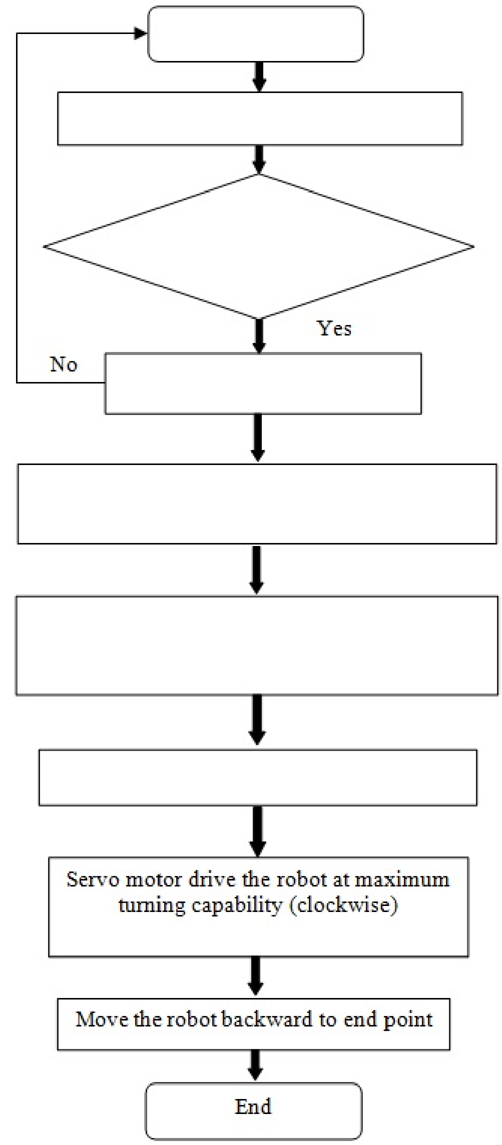

Figure-5. Flow of path planning algorithm.

RESULT AND DISCUSSIONS

The mobile vehicle was tested in order to determine whether the coding and system implemented able to do the required parking maneuver. The empty parking space is set to have a length of 600mm. the suitable width of the space is between 240 to 250mm. Firstly, the mobile vehicle moves past an open spot which is in between front and rear obstacle. During this motion, measurement of the length and width of the open spot is done by ultrasonic sensor. After that, if the microcontroller decides that the space is large enough for the mobile vehicle, it will stop at a position to execute the parking trajectory.

This trajectory is modeled closely on the arc that a full sized automotive follows as it parallel parks. In the middle of parking process, if the rear sensor sense that the rear bumper of the car is too close to rear obstacle, it will stop and make a simple adjustment so that the parking maneuver can still be completed. The adjustment made comprise of a series of forward and backward movement with an appropriate steering control.

When the car successfully enters the parking space, the rear and front sensor will detect the distance from the vehicle to the obstacles respectively. Then, the vehicle position is adjusted until the difference between the two distances is zero which means that the car is centered inside the parking space. Generally, during the parking maneuver, speed control is done in such a way that the vehicle accelerates to a desired speed and then remains at this speed for executing some part of the maneuver before it finally decelerate and stop when the vehicle has reached the desired position in the parking space.

There are other methods which is suitable for urban parking condition such as semi-automatic parking slot marking recognition. In this method, Rearview image is captured with camera fixed at the rear end of the vehicle. This image is displayed through human machine interface (HMI). Then, the target position is determined by the driver through finger pointing on the touch screen HMI. These two points are called seed points and around these regions, fisheye lens-related rectification and bird's eye view image construction are applied. This parking slot marking recognition method plan a path based on the coordinates of the target position. According to (Hélène, V.*et al.* 2015), by checking for junction pattern that match the parking slot pattern, the junction pattern is searched. It is check until the matching error is minimized. If two junction patterns are detectable, the entrance coordinate of the targeted slot is decided. In addition, there is an automated parallel parking system which proposes parking trajectory that has continuous-curvature path for the parking maneuver.

In a simpler way, this automated parallel parking system involves the detection of the suitable parking space using sensory perception that is the ultrasonic sensors. The small vehicle moves next to the parking space and scan it to obtain information about its length and width. Then comes the path planning stage which is a result of information accumulated through sensors and processed before making the decision whether or not to execute the parking maneuver. According to the results, simple developed system required just 1.33 time longer parking space than vehicle overall length. That is required less space than (Hsu, V.*et al.* 2008) which need 1.5 time required than vehicle overall length for parking space.

CONCLUSIONS

The small mobile vehicle has implemented and integrates technology using ultrasonic sensor to accomplish environment detection and microcontroller for data processing. The mobile vehicle is able to detect empty parking space and conduct the parallel parking maneuver. The front wheels of this prototype have the same turning angle and thus do not operate on the same condition to the Ackermann steering system. In actual condition, when a car makes a turn, geometry suggests that the outer wheel has to travel a greater distance than the inner wheel. Hence, automobile use the Ackermann steering system to turn the wheels at different angles to compensate the longer distance travelled by the front outer wheel. However, developed system required just 1.33 times longer parking space than vehicle overall length**.** Small mobile vehicles successfully able to manage the parallel park itself without hitting or touching front and rear obstacles in this development.

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