FUZZY Based Design of Parallel Park Assist SystemControlStrategy

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***Abstract*—The automatic parking is one of the growing topics that claim to enhance the comfort and safety of driving. It can help drivers automatically drive the vehicle in constrained environments where much attention and experience is required. The parking strategy is completed by means of coordinated control of the steering angle and taking into account the actual situation in the environment to ensure collision-free motion within the available space. This paper presents a fuzzy logic controller designed for automatic parallel parking system. The proposed system receives information about the parking environment from ultrasonic distance sensor HC-SR04 and then generates the velocity and steering angle for parking. The servomotor are used for steering angle control of the model car. In order to ensure the performance of proposed system a prototype of four wheel robot, equipped with Arduino Uno R3 board has been developed. The control law is designed in Simulink and executed in real time using the dSPACE DS1104 DSP board**.

***Index Terms*—Arduino Uno, Fuzzy Logic, Sensor, Servomotor,ultrasonic.**

I. INTRODUCTION

Currently, an increasing amount of the robotic researches has focused on increasing the autonomy of the vehicle. For this many researchers have developed different algorithms [1-10].

In the paper [1] infrared sensors where used for finding the vehicle velocity and direction. For path tracking Paromtchik and Laugier [3,4] proposed a parallel parking approach for a nonholonomic vehicle. A parking space is scanned before the vehicle reverses into the parking bay.

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The vehicle then follows a sinusoidal path in backward motion that is the control commands (steering angle and velocity) are generated such that the corresponding (x, y) path is sinusoidal. To keep the vehicle from colliding with the front left corner of the parking bay, a collision-free start position is obtained from an off-line lookup table according to the length of the parking bay and the lateral distance of the vehicle to the front left corner of the parking bay Jiang and Seneviratne [5] also studiedsensor guided autonomous parking where the process consists of three phases: scanning, positioning and maneuvering. The path in the maneuvering phase is constructed by two circular arcs of minimum radius tangentially linked to each other. Adaptive cruise control (ACC) widely used in automotive application. An Adaptive Cruise Control (ACC) is an automobile system whichpurpose is control the velocity of the vehicle with regards to the surrounding environment. Corona, D. and De Schutter, B [6] proposed an ACC system for a Smart car. Here they have designed a smart car as a benchmark setup for several model predictive control methods for nonlinear and piecewise affine systems. They have discussed different techniques to design ACC with common benchmark and these methods are compared with each other, the comparison results are tabulated. The lane departure system is another type of ADAS system which warns the driver of drifting off the lane inattentively. Sukhan Lee and Yongin [7] proposed vision based lane departure warning system which warns the driver of drifting off the lane inattentively. An estimation algorithm is derived to obtain the vehicle pose and lane geometry data so as to detect an unintended lane departure. Their system consists of lane departure alarm that is triggered by a warning algorithm which makes decisions on giving an alarm based on the data from the estimation algorithm. The performance criteria of the lane departure warning system are defined as false alarm rate and alarm triggering time.

Changing lanes while having no information about the blind spot area can be dangerous. Blind spot detection is ADAS system used in such cases which monitors the vehicle in blind spot area. Bin-Feng Lin and Yi-Ming Chan [8] proposed a vision based system to detect possible vehicles in the blind-spot area. They have proposed a method to combine two kinds of part-based features that are related to the characteristics of the vehicle, and we build multiple models based on different viewpoints of a vehicle. The location information of each feature is incorporated to help construct the detector and estimate the reasonable position of the presence of the vehicle.

II. DESIGN METHODOLOGY

In this section we have discussed the fundamentals of Parallel park assist system currently used in the industry. We have also briefly discussed about the different materials used for the design of the model car of our system.

Fundamentals of Parallel Parking System

In order to make driving task safer and more comfortable considerable resources are being directed to developing systems for communication, information handling and automatic controls. Traffic information, obstacle detection, in-vehicle warning systems, integrated telephones and motorist information are examples of systems available and under development. There has also been an increasing interest in automatic parallel parking. Parallel parking in narrow spaces is often considered a tedious and annoying task by many drivers. The situation has become even harder when visibility behind the vehicle has decreased because of aerodynamic design. Thus, there is a demand for systems that perform the parking maneuver automatically. The overview of parallel parking is shown in the figure 1.

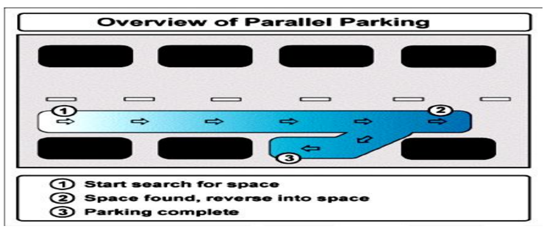

Figure 1: The Parallel Parking Process.

III. HARDWARE

In this section we have discussed different types sensors, actuators and controller boards are used for our purpose.

Ultrasonic sensor (HC - SR04)

The sensor utilized for parallel park assist system is ultrasonic distance sensor HC-SR04. Two HC-SR04 sensors are used reverse maneuvering and obstacles avoidance. These two sensors are located on the front and back of the model car. The model of the sensor is shown below figure 2

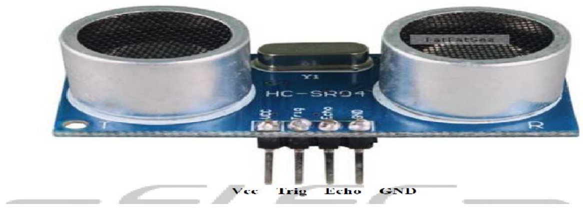

Figure 2: Image of the sensor HC-SR04

The principal of operation of the sensor are presented in Figure 3

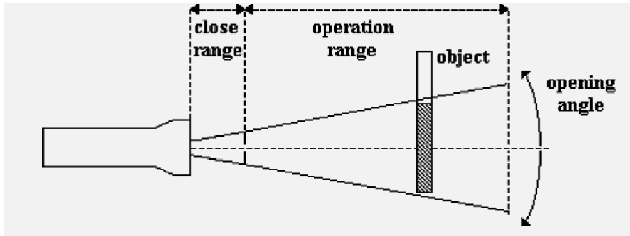

Figure 3: Principal of operation of ultrasonic sensor.

Ultrasonic ranging module HC - SR04 provides 2cm - 400cm non-contact measurement function, the ranging accuracy can reach to 3mm. The modules includes ultrasonic transmitters, receiver and control circuit.

Test distance =(high level time × velocity of sound (340M/S) / 2.

This sensor is a transducer that operates with piezo ceramics as sound transmitter and receiver. During operation, a packet of sonic pulses is transmitted and the echo pulse is converted into voltage by the integrated controller of thesensor and the distance is computed from the echo time and the velocity of sound. The transmitted pulse duration and the decay time of the sonic transducer result in a blind zone in which the ultrasonic sensor cannot detect an object. During this time the receiver is disabled in order to prevent the self-excitation of the receiver by the generated sonic pulse instead of echo. The needed signal waveforms for interfacing this sensor are presented in Figure 4.

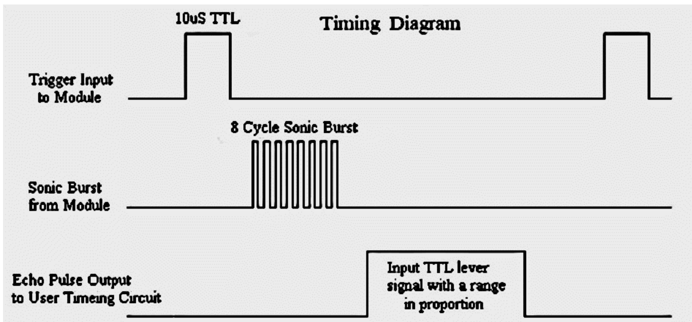

Figure 4: Ultrasonic sensor interfacing waveforms.

Here we need to supply a short 10uS pulse to the trigger input to start the ranging, and then the module will send out an 8 cycle burst of ultrasound at 40 kHz and raise its echo. The Echo is a distance object that is pulse width and the range in proportion .You can calculate the range through the time interval between sending trigger signal and receiving echo signal. Formula: uS / 58 = centimeters or uS / 148 =inch; or: the range = high level time * velocity (340M/S) / 2.

dSPACE DS 1104 R&D Controller Board

The DS1104 R&D Controller Board is a standard board that can be plugged into a PCI slot of a PC. The DS1104 is specifically designed for the development of high-speed multivariable digital controllers and real-time simulations in various fields. It is a complete real time control system based on a 603 PowerPC floating-point processor running at 250MHz. For advanced I/O purposes, the board includes a slave-DSP subsystem based on the TMS320F240DSP microcontroller. For purpose of rapid control prototyping, DAC, encoder interface 3.7.4, dSPACE's experiment software, provides all the functions to control, monitor and automate experiments and makes the development of controllers more effective. The graphical user interfaces to control manually the real time simulation. Many well-structured layouts enable the user to gain full control over the system. ControlDesk allows users to generate convenient, graphical user interfaces (layouts) with a great variety of control elements, from simple GUI elements (push-buttons, displays, radio buttons, etc.) to complex plotters You can configure all I/O graphically, insert the blocks into a Simulink block diagram, and generate the model code via Real-Time Workshop minimum. The DS1104 controller board photograph is shown in figure 5.

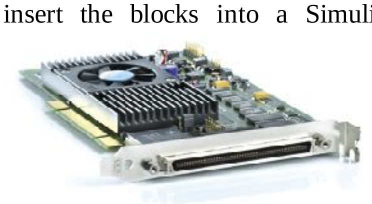

Figure 5: Photograph of DS 1104 controller board.

Using Real-Time Interface

With Real-Time Interface (RTI), you can easily run your function models on the DS1104 R&D Controller Board.

IV. SOFTWARE

Stateflow

Stateflow is a graphical design and development tool for control and supervisory logic used in conjunction with Simulink. It provides clear, concise descriptions of complex system behavior using finite state machine theory, flow diagram notations, and state-transition diagrams all in the same Stateflow diagram.

Stateflow is a product that is part of Simulink. In Simulink, Stateflow blocks are referred to as Stateflow Chart blocks. The following diagram shows a simple Simulink model that has a Stateflow Chart block in it:

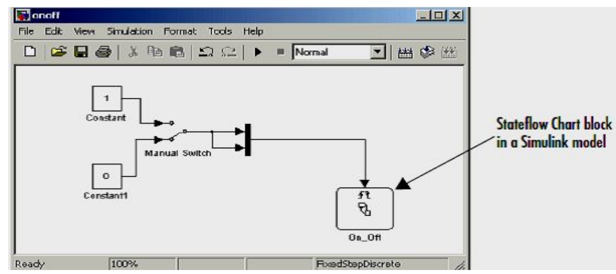

Figure 6: The Stateflow example.

Fuzzy control strategy

Overall structure of the problem and its solution should be created before developing a fuzzy control strategy. The definition should be made as simply and clearly as possible. The detected space can be described as shown in Figure 8. The size of the rectangular space is defined as $h_p \times l_p$, and BK, FT and SE represent the "back", "front" and "side" of the space, respectively. The origin of the local coordinate system is chosen as the intersection of BK and SE. The reverse-motion maneuvering algorithm developed here corresponds to the parallel parking procedure of an experienced human driver.

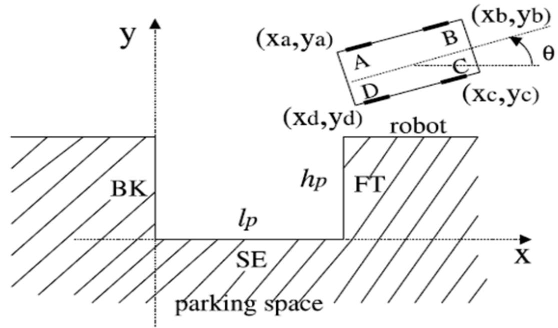

Figure 7: Maneuvering space and the local Coordinate system.

The reverse maneuvering into the parking space requires a more complex fuzzy logic controller. As shown in Figure 8, the coordinate of the left rear corner of the vehicle in the local coordinate system is defined as $(x_{a,}, y_a)$, and the coordinate of the right rear corner of the vehicle is defined as $(x_{d,}, y_d)$. Two new variables, x_{a1} andy_{d1}, are defined by$x_{a1} = x_a/l_p$and

$y_{d1} = h_p/l_p$; they represent the relative position of the rear of the vehicle with respect to the origin of the space. The fuzzy logic controller for this step has three inputs x_{a1}, y_{d1} and the orientation angle θ. The output is the steering angle $\emptyset$. Figures 9, 10, 11 and12 shows the utilized membership functions, where S, B, VB represent small, big and very big respectively. The three dimensional fuzzy rules are shown in Table 1 and its surface view in figure8.

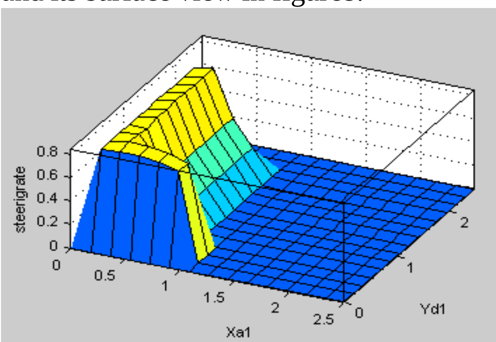

Figure 8: Surface view of Fuzzy rule base

There are a total of 18 rules. Empty rules in Table 1 mean the corresponding combination of inputs is invalid (i.e., they imply that either the vehicle is moving away from the parking space or it has entered one of the shaded regions in Figure 7). The rationale behind several of the rules is presented here.

If $\theta$is negative and x_{a1} is small and y_{d1} is small, then $\emptyset$ is positive big, i.e., when the vehicle is very close to both of the boundaries, and its orientation angle is negative, the steering angleshould be a big positive number to make the orientation angle positive.

If $\theta$is zero and x_{a1} is very big and y_{d1} is very big, then $\emptyset$ is zero, i.e., when the vehicle is parallel to the parking space, and the vehicle is outside the parking space, the vehicle should continue to reverse in the same direction.

If $\theta$is positive and x_{a1} is big and y_{d1} is big, then $\emptyset$ is zero, i.e., when the vehicle is in the middle of the parking space, and the orientation angle is positive, the vehicle should keep the same steering angle.

Table 1: Fuzzy Rules for the Backing up Step

	$x_{a1}\backslash y_{d1}$	S	B	VB
$\theta=N$	S	PB	PB	
	B	PM	PB	PB
	VB			PM
$\theta=Z$	S	Z	Z	
	B	Z	PB	PB
	VB			Z
$\theta=P$	S	NB	Z	
	B	NM	Z	PM
	VB			NB

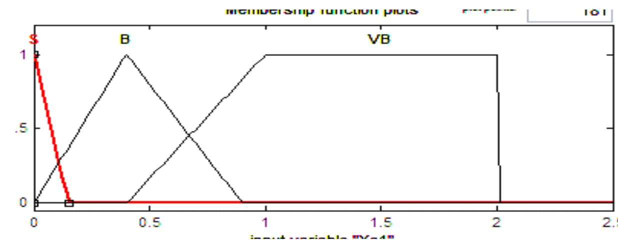

Figure 9: Membership Functions for the Backing up (input xa1).

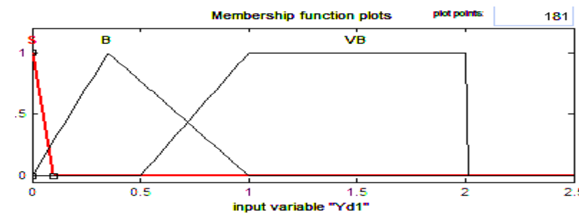

Figure 10: Membership Functions for the Backing up (input yd1).

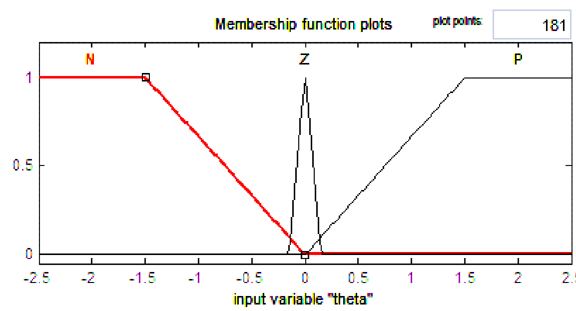

Figure 11: Membership Functions for the Reverse Maneuver (inputθ).

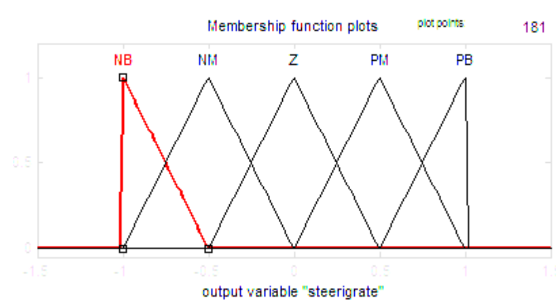

Figure 12: Membership Functions for the Reverse Maneuver (output $\emptyset$).

V. DESIGN IMPLEMENTATION

Kinematics of the car

Four wheeled front wheel steered car-like vehicle has complex kinematics. The route of the car is dependent on the steering angle, dimensions and speed of the car. Increasing speed increases the turning radius at a fixed steering angle for an under steer vehicle. This is due to the slip of the front wheels that causes a force for turning the car body during the maneuvers. Parking action of a car occurs at low speeds, so the effect of the speed can be ignored for the estimation of the route of the car during parking maneuvers. This kind of an approach significantly decreases the complexity of the problem and governing equations of the kinematics of the car can be expressed using simple trigonometric relations**.** The kinematic model of the car is shown below in the figure 13.

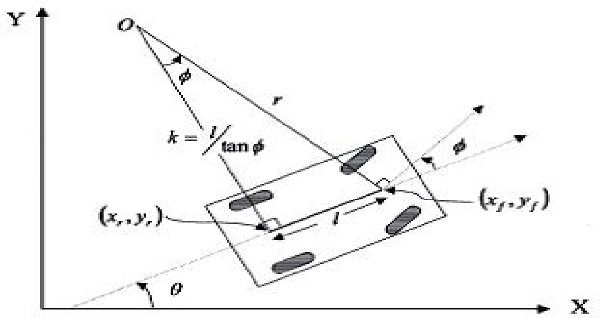

Figure 13: Kinematic model of the car.

Consider a kinematic model of the CLMR shown in Figure 13 where the rear wheels are fixed parallel to car body and allowed to roll or spin but not slip. The front wheels can turn to left or right, but the left and right front wheels must be parallel. All the corresponding parameters of the CLMR depicted in Figure 8 are defined as follows.

(x_f,y_f) = position of the front wheel center of CLMR;
(x_r,y_r) = position of the rear wheel center of CLMR;
Φ = orientation of the steering-wheels with respect to the frame of CLMR;
ϴ = angle between vehicle frame orientation and X-axis;
l = wheel-base of CLMR;
O = center of curvature;
r = distance from point O to point (x_f,y_f);
k = curvature of the fifth-order polynomial.

The rear wheel is always tangent to the orientation of the vehicle. The no-slipping condition mentioned previously requires that the CLMR travels in the direction of its wheels. Thus, we have,

$$\dot{y}_r \cos\theta + \dot{x}_r \sin\theta = 0 \qquad (1)$$

This is the so-called nonholonomic constraint. The front of the CLMR is fixed relative to the rear, thus the coordinate (x_r,y_r) is related to (x_f, y_f).

$$\begin{aligned} x_r &= x_f - l\cos\theta \\ y_r &= y_f - l\sin\theta \end{aligned} \qquad (2)$$

Thus, differentiating (2) with respect to time gives,

$$\begin{aligned} \dot{x}_r &= \dot{x}_f - \dot{\theta} l \sin\theta \\ \dot{y}_r &= \dot{y}_f - \dot{\theta} l \cos\theta \end{aligned} \qquad (3)$$

Substituting Equations (3) to (1), we can get,

$$\dot{x}_f \sin\theta - \dot{y}_f \cos\theta + \dot{\theta} l = 0 \qquad (4)$$

From Figure. 8, we have,

$$\begin{aligned} \dot{x}_f &= v.\cos(\theta + \varphi) \\ \dot{y}_f &= v.\sin(\theta + \varphi) \end{aligned} \qquad (5)$$

Substituting equations (5) to (4), we can derive,

$$\dot{\theta} = v.\frac{\sin\varphi}{l} \qquad (6)$$

Equations (5) and (6) are the kinematic equations of CLMR with respect to the axle center of the front wheels. We rewrite them in the following:

$$\begin{aligned} \dot{x}_f &= v.\cos(\theta + \varphi) \\ \dot{y}_f &= v.\sin(\theta + \varphi) \\ \dot{\theta} &= v.\frac{\sin\varphi}{l} \end{aligned} \qquad (7)$$

Equations (7) are used to generate the next forward state position of the vehicle when the present states and control input are given. Following these equations describing the motion kinematics, we can easily obtain the kinematic equations of the vehicle motion described by the position of the front wheel center (x_r,y_r) , then we can apply equation (3) to (7), the kinematics of CLMR with respect to the axle center of the rear wheels will be described as,

$$\begin{aligned} \dot{x}_r &= v.\cos\theta\cos\varphi \\ \dot{y}_r &= v.\sin\theta\cos\varphi \\ \dot{\theta} &= v.\frac{\sin\varphi}{l} \end{aligned} \qquad (8)$$

Equations (8) are used to generate the next backward state position of the vehicle when the present state and control input are given. By referring the above kinetic model car is designed. The model car is tested for the park assist by sing both DS1104 controller board and Arduino Uno R3.

Block Diagram of the system

In the process of identification of parking space the sensor plays major role. The block diagram shows the detail process of parallel parking. It starts with sensor positioning to the vehicle. Normally distance sensors are fixed in right side of the prototype of the model car for parking space measurement and the other distance sensors are placed in front and rear bumpers for reverse maneuvering and obstacle avoidance. Then the suitable signal conditioning circuit will be used for sensor output acquisition and analysis on the MATLAB/Simulink environment. After the analysis of right sensor's output variable d (measured space), the decision making process (compare d=2L, where L is the length of the vehicle) will takes place in the same stage. It gives the identification of the parking space along with the size specification. In the meantime it gives the position and orientation of the vehicle. The obtained sensor data and previous stage analyzed output will be given to state machine to reverse the car into the space. State machine acquires the information from front and back sensor as a variables S_f and S_b and generates a target steering-wheel turning command ϴ. The same state machine is used to control the traction of the vehicle by using H Bridge L293dne. The finally output is analyzed for different initial position.

Block diagram of the Parallel Park Assist System is shown in figure 14.

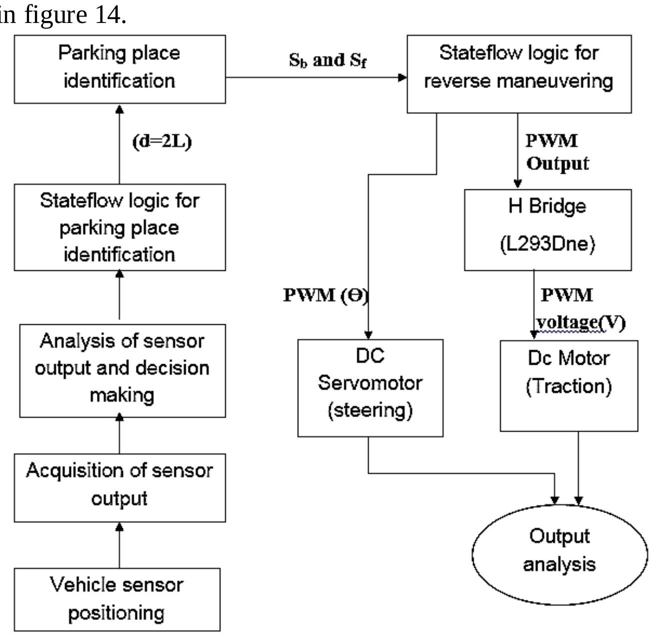

Figure 14: Block diagram of the system.

Flow chart of the system

First model car is placed in the initial position. The model car searches whether there is enough parking place. If parking place is not available model car stops there only. If there is enough parking place then it adjusts its orientation according to the state flow logic. Then model car reverses the parking area and it will check the back distance sensor for the threshold. When back sensor value is 2 cm threshold then model car changes its steering angle as well as direction. While going forward model car checks front distance sensor value for the threshold, when the front sensor values is 2 cm threshold model car stops there itself. The final position is reached depending on the front sensor value which we discussed in simulation results. The complete flow chart of our Parallel Park Assist System is shown in the figure 15.

VI. SIMULATION RESULTS

The experimental set up to test the proposed algorithm consists of model car which is controlled by DC servo motor for steering angle control and geared DC motor for traction control system and the distance sensors to complete the parking process. All these components are modeled in MATLAB/Simulink platform. The Servo motor and DC motor are controlled by PWM signals and these signals are generated in MATLAB/Simulink environment. Simulation is tested for two cases they are,

1. Parking space is available.
2. Parking space is not available.

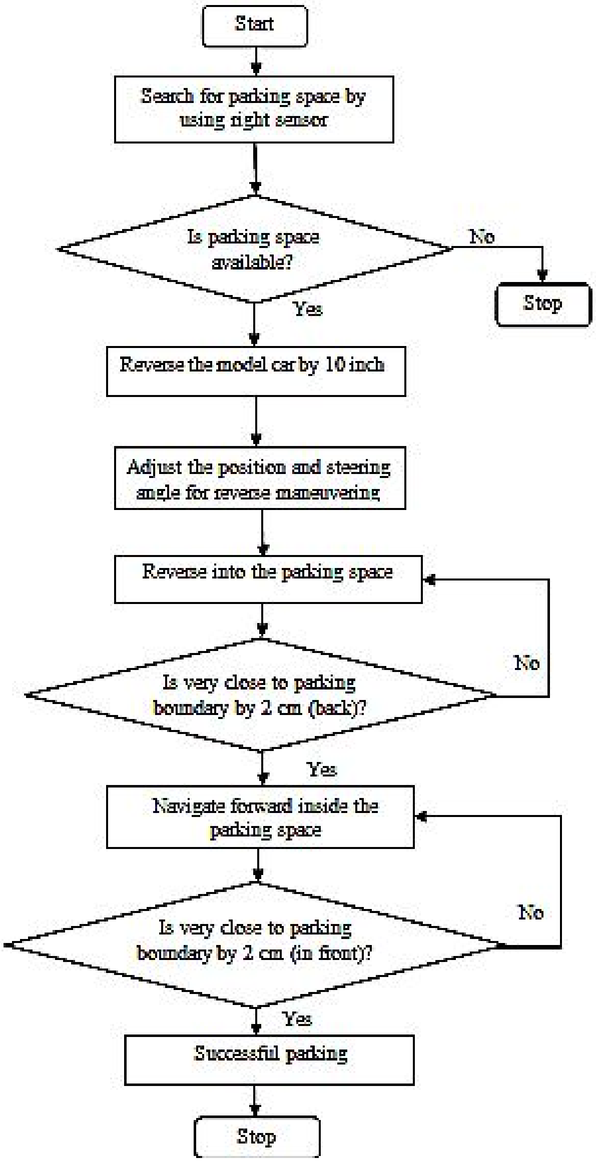

Figure 15 Flowchart of the complete system.

Parking space is available

When there is enough parking space, model car detects the space and completes parallel parking procedure. Figure 16 shows the PWM signals for both Servo motor and DC motor. Simulation result also shows the measured space through the right sensor. Whenever PWM signal inputs the motor corresponding motor will be actuated depending on the Stateflow logic of the MATLAB. While reversing at the end model car changes its motion depending on the back sensor value and also while forwarding at the end it will stop depending on front sensor value as shown in figure 16. The snapshot of the model car is shown below in figure 17 when it completes parking procedure successfully. The figure also shows the final position of the model car after finishing the parking procedure successfully.

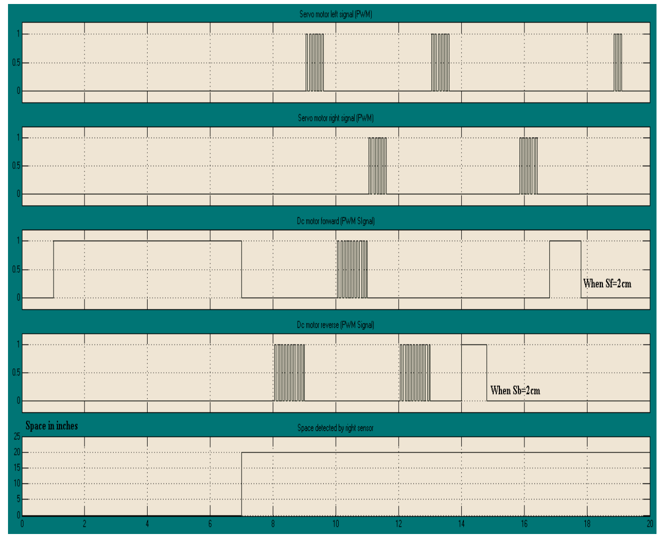

Figure 16: PWM Signal for the Servo and DC motor when space is available.

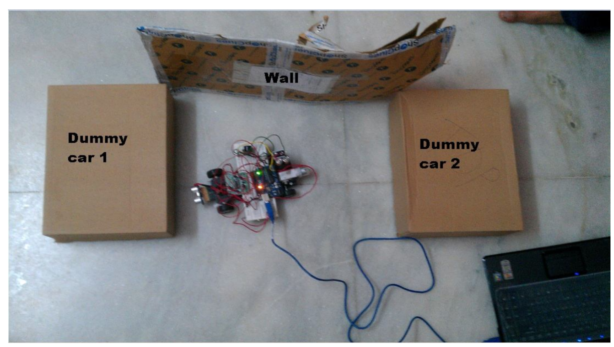

Figure 17: position of the model car after parking when space is available.

In the above figure two boxes are used to model the dummy cars. These boxes are labeled as dummy car 1 and dummy car 2. We have also used pad to model the wall of the parking bay which is labeled as wall. The figure shows final position and orientation of the model after finishing the parallel parking.

The model car calculates the parking space using stateflow logic, if the measured space is not enough then it stops there itself. Figure 18 shows the simulation result when there is no enough space. From the figure measured space is 10 inches which is less than two tomes the length (20 inches) of the model car. To stop the car all the PWM signals generated by stateflow logic is zero as shown in Figure 18.

The position of the model car is shown below in figure 19 when there is no enough parking place. The final position of the car if there is no enough parking space is shown in the figure.

When parking space is not available

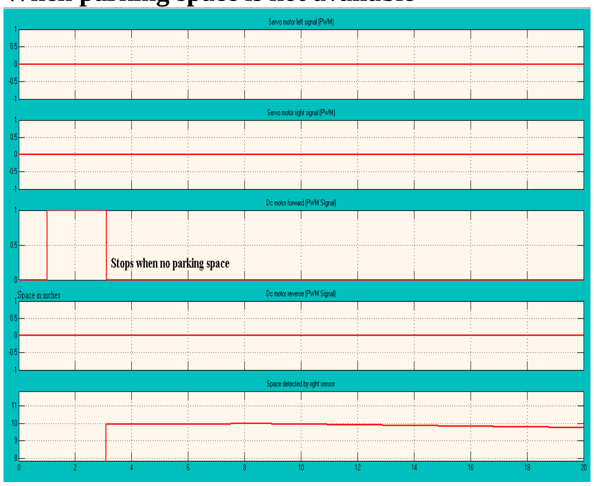

Figure 18: PWM Signal for the Servo and DC motor when space is not available.

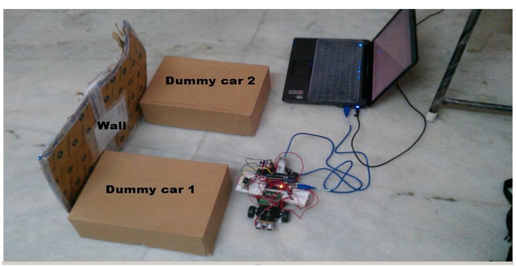

Figure 19: position of the model car when there is no enough parking space.

The path of the model car is also traced in the MATLAB environment as shown in figure 20.

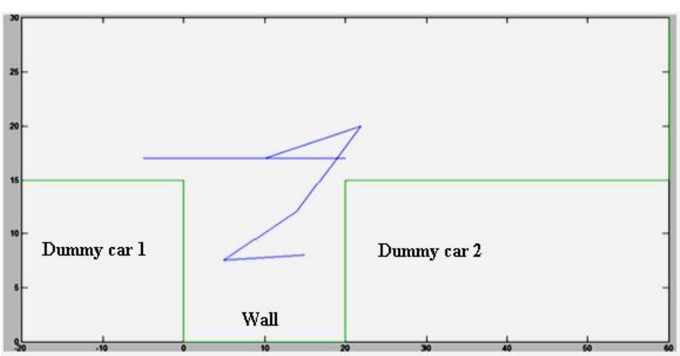

Figure 20: Path of the model after parking.

The simulated results are verified successfully in both the boards.

VII. Conclusion:

The work done in the previous section is satisfactory with the results obtained during the simulation. Technology have been implemented for the prototype model in a better manner and simulated with variety of the parameters. Electro-mechanical assemblies for front and rear alignments and dealing with small voltages and currents were challenging. The DS1104 R and D controller board from dSPACE shows good performance for the Park Assist System. Arduino Uno an onboard microcontroller was the heart of implemented module and it showed the best performance by giving the better results with high accuracy and time delay. Utilization of ultrasonic sensors and H-bridge was very challenging and finally which have been done it successfully.

VIII. Future Work:

Major scope for the future is to go with real time and for real four wheel vehicles with BLDC motors, characteristically described as follows…

1. Random parking space selection
2. Inclusion of neural network in addition to fuzzy logic.
3. Time saving methodologies.
4. Higher end implementation with enhanced motors.
5. Improvement in steering angle.
6. Artificial intelligence.
7. With use of more ultrasonic sensors we can improve the efficiency.
8. Use of vision based system for parking place identification will minimize the parking space measurement error.

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