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Autonomous Parallel Parking Based on Dual Fuzzy Logic Controller from Any Initial Position

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Abstract— Nowadays, different daily life problems are solved by using autonomous mobile robots or unmanned ground vehicle (UGV). Similarly, autonomous parking is an area of great evolutionary interest. In a modern era, including of complex scenarios, autonomous parallel parking develops a great interest. In which the autonomous vehicle itself plans the path to its final parking destination. This article proposes an advanced evolutionary strategy based on the concept of the Dual Fuzzy Logic (DFL) controller mechanism, which solves the problem of autonomous parallel parking successfully, by using the information of local coordinates system. The first fuzzy controller brings the vehicle near to the target parking position, from its initial position autonomously, using the concept of path planning, where-as the second fuzzy controller parks the vehicle accurately to the target parking position. An additional flexible feature of obstacle avoidance is added in it, for parking maneuver. For the fuzzification of parameters, triangular and trapezoidal membership functions have been used. Mamdani inference engine is used for the rule mapping, corresponding to the inputs and their outputs. In the end, results have been shown for the proposed Dual Fuzzy Logic Controller strategy (DFL),which solved the autonomous parking problem in an accurate way.

***Index Terms*--**Robotic vision system; decoupling; stabilization control; frictional disturbance; gimbal system.

I. INTRODUCTION

THE advanced technology for an automatic parking system is introduced by different automotive companies, with a set of limited features. This is the leading part of technology nowadays in autonomous vehicles, which shows a strong interest in this parking mechanism. This area belongs to the field of robotics and different solutions are available in the market which is introduced by few of the automotive companies [1]. In the current scenario, automatic parking has achieved a peak of interest among the automobile companies for the advancement and correlation [9].

Parallel Parking is a new method of parking a vehicle, parallel to the roadside. The procedure of parallel parking is considered to be one of the most difficult parking maneuvers, which is generally performed by skillful drivers. The parameters of the driver's skills would be judged by environmental conditions and spatial perceptions. It is a common practice that a driver is performing forward and backward maneuvers in a tight space to fit the car into the parking lot. However, it is very difficult which might result in minor pressure or scratch to the body of the vehicle. The autonomous parking system is a safe and secure artificial intelligence-based mechanism, in which the safety of a vehicle and driver is the topmost priority during the autonomous parking maneuver.

There are some of the top-end cars, which include intelligent technology, in a routine environment that controls the movement of the steering wheel in the procedure of parking.

In spite of the fact that artificial intelligence is used, a driver is somehow responsible for the maneuver, braking and accelerator action. The concept of the fuzzy logic controller was successfully applied in mobile robot applications.

Many different applications relating to the vehicle are designed by the fuzzy logic controller, for example in Anti-Lock Braking System (ABS) [2], Airbags operation mechanism and active suspension system [3].

Recently, some research interest has been shown in an autonomous parallel parking mechanism. Currently, there are two different approaches that are being generally followed; planning approach [4] and skill-based approach [5]. In the Planning approach, the driver plans the waypoint of the vehicle and then the vehicle settles to the parking position.

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In the skill-based approach, a controller designed is itself intelligent and decides the path to the parking position. The parking problem has also been solved by computer vision technology in which the omnidirectional camera has been mounted on the top of a vehicle through which continuous image samples are taken and generates a path till the parking position using augmented reality-based approach [6].

Smart and intelligent based parking mechanism was implemented mostly in the Middle East, European countries and Japan [7]. In the current era, there is rapid progress in automotive cars with usage dependencies and it is difficult manually to select a parking lot and give proper directions to park the vehicle. So the current environment needs a system based on the automatic parking that reduces manual manpower and provides help in the careful parking of the vehicle [8].

From the aspect of control, the autonomous fuzzy-based parking system is a complex algorithm. As fuzzy control involves the making of a rule set for the decision of the output variable, it is dependent on the designer’s professional skill sets. The automatic parking mechanism consists of various steps, including two major steps, first in which the detection of the parking area is to be confirmed and second the artificial intelligence-based path planning technique. The Bayesian hierarchical scheme is developed for the detection of a parking lot [10]. Another concept was introduced in which the estimation of parallel lines was used to detect the parking slots [11]. The hierarchy of tree structure was to be used for the detection of parking slot marks in [12]. Mathematically, geometry also helps in the path planning and parking maneuver with respect to the traveled distance against the controller designed [9].

An optimized mechanism in which the membership functions were presented in [13], tuned by a genetic algorithm for the efficient parking trajectory. There is another method of automatic trajectory path planning which is realized by the self-organizable fuzzy system [14]. A preview fuzzy system is another method of automatic parking [15]. Automatic Parking System by fuzzy control is a method of parking with numerous advantages include robustness with respect to uncertainties and the nonlinear control strategy [16]. Later on, a new technique was proposed based on the sliding mode vehicle control (SMVC) and model predictive control (MPC) in order to follow the trajectory for the vehicle coordinated system [17]. Another researcher gives a smart parking technique based on a vision system, to find the empty slot for parking. This technique splits the parking block segments into small segments and then classifies the block status. It then intimates the driver about the slot status, whether it is free to park or not [18]. In contrast to it, there is also a hybrid technique of automatic parking system. Sliding mode control (SMC) is used as a trajectory planner near to the parking space and for the purpose of a parking maneuver mechanism fuzzy logic control was used in [19].

Flaws regarding parking maneuver and trajectory tracking were presented in different schemes along with certain environmental parking problems. For example, sliding mode control (SMC) is used in [19]. The chattering effect is produced by this, which added to the desired output response of the controller. Chattering effect in the sliding mode control produces certain harmonic vibrations, which results in the heating and shortage of electronic circuits. The presence of the unmodeled dynamics in the system results in the chattering effect. All the dynamics of the system can never be captured by the controller, so it is not possible to obtain 'chattering free' sliding mode control but alternative methods are there to reduce the effect of chattering. Among them, two are major methods. First is Integral Sliding Mode Control (ISMC) and the Second is Higher Order Sliding Mode (HOSM). Both are used to obtain continuous and 'smooth enough' control signal.

Generally using Model Predictive Control (MPC), in real-time data computation, a sluggish response was obtained along with feasibility issues. Two approaches were used to eliminate these difficulties, first is a minimal time approach and the second is a self-constraint approach [20].

This needs to be improved, that the path planning near to the parking position and further maneuver of parking is done in an accurate way. This paper proposes a Dual Fuzzy Logic controller (DFL), irrespective of the vehicle initial position. Dual Fuzzy Controllers are used for their complete automatic parking maneuvers. First 'Positioning controller' is used for the trajectory tracking near to the parking position and the second 'Parking Controller' is used for the parking maneuver into the parking lot.

II. PATH PLANNING ALGORITHM

The parking system based on artificial intelligence consists of several steps, which include planning of path, environmental perception, path following and Human Machine Interference (HMI). These four elements are responsible for the complete autonomous parking mechanism.

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Autonomous Parking Flow Representation

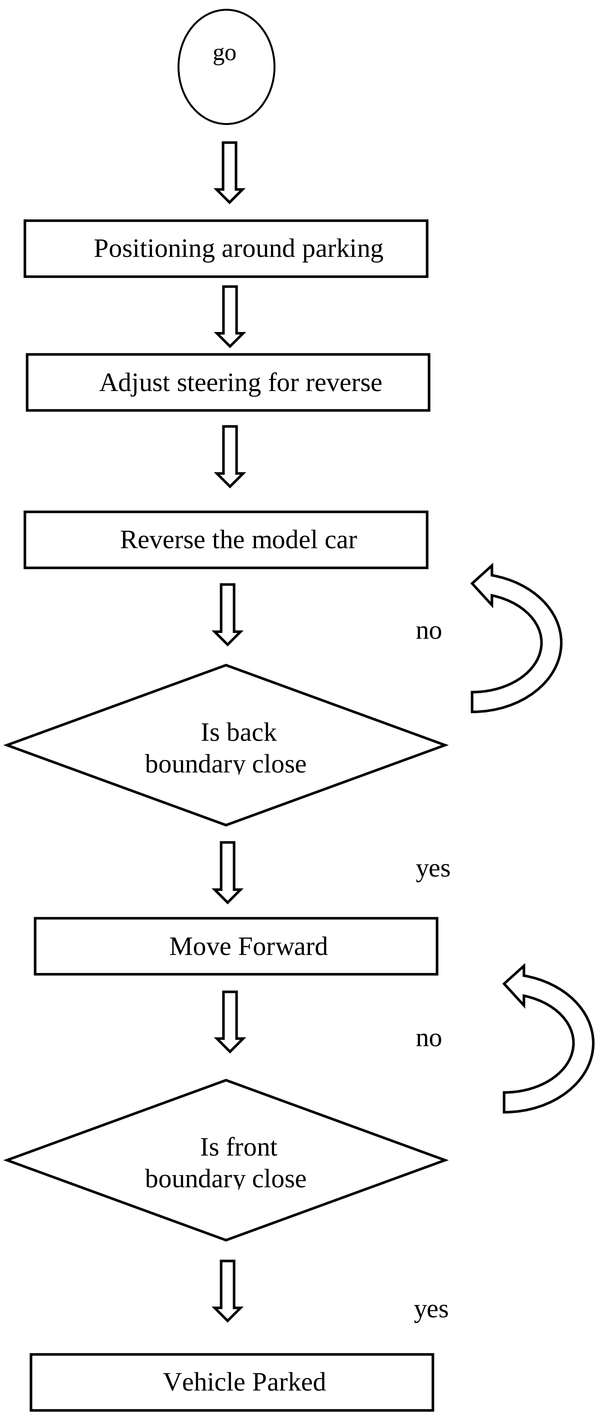

Fig.1: Autonomous Parking Procedure

The representation in *Fig. 1,* shows a complete autonomous parking flow scheme. The ideal target parking position is shown in the *Fig. 2*.

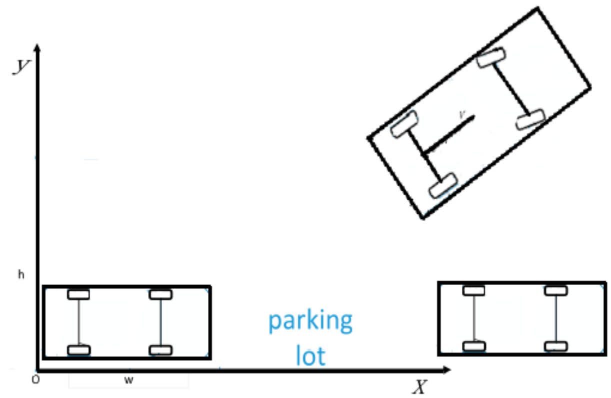

Fig. 2: Ideal Target Parking

III. MATHEMATICAL MODEL OF THE VEHICLE

Normally the vehicle velocity for parking mechanism is near about 15km/h, which means that the rear wheel slip is almost zero. The velocity in the direction of y-axis w.r.t the rear wheel is zero too and can be written as [21]:

$$y \cos\theta - x \cos\theta = 0 \tag{1}$$

Now considering the model of vehicle in a 2-D plane, according to the *Fig. 1*, front wheels of the vehicle are movable to left or right in direction, whereas the rear wheel is fixed apart to the body of the vehicle. Movement of the front wheels of a vehicle is always in a parallel direction.

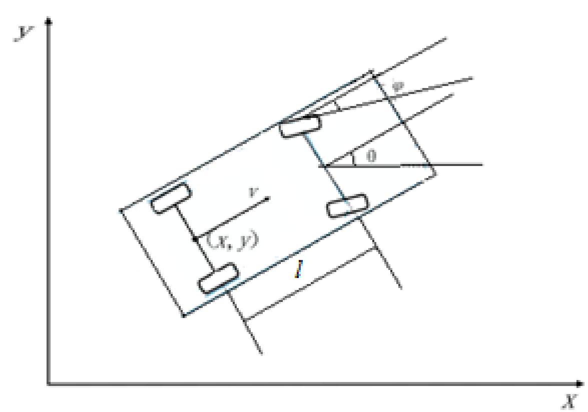

Fig. 3: Vehicle Dynamics

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In the 2-D plane coordinate system, θ is the positional angle of the vehicle, φ is the angle of the front wheel, wheelbase length is l and the vehicle speed is denoted by v. So, the vehicle dynamic equation can be written as [21]:

$$\dot{x} = v\cos(\theta + \varphi) = v\cos\theta\cos\varphi \tag{2}$$

$$\dot{y} = v\sin(\theta + \varphi) = v\sin\theta\cos\varphi \tag{3}$$

$$\dot{\theta} = \frac{v}{l}\sin\varphi \tag{4}$$

Now suppose if the front wheel angle φ is very small that cosφ is nearly equal to 1 & sinφ is nearly equal to tanφ so that the linear direction of motion will be [19]:

$$\dot{x} = v\cos\theta \tag{5}$$

$$\dot{y} = v\sin\theta \tag{6}$$

$$\dot{\theta} = \frac{v}{l}\tan\varphi = \omega \tag{7}$$

Now by integrating Eq. (2) and Eq. (3), we can obtain the estimated rear trajectory of the vehicular body [21]:

$$x_r(t) = l\cot\varphi\sin(\frac{v\sin\varphi}{l}t) \tag{8}$$

.

$$y_r(t) = -l\cot\varphi\cos(\frac{v\sin\varphi}{l}t) + l\cot\varphi \tag{9}$$

$$x^2 + (y_r - l\cot\varphi)^2 = (l\cot\varphi)^2 \tag{10}$$

A. Trajectory of the rear left wheel

Now by further solving Eq. (8), Eq. (9) and Eq. (10) by means of geometric relation, we can obtain the trajectory of each individual rear wheels. Trajectory equation of the rear left wheel is as follows [21]:

$$x_{rl}(t) = (l\cot\varphi - \frac{w}{2})\sin(\frac{v\sin\varphi}{l}t) \tag{11}$$

$$y_{rl}(t) = -(l\cot\varphi - \frac{w}{2})\cos(\frac{v\sin\varphi}{l}t) + l\cot\varphi \tag{12}$$

$${x_{rl}}^2 + (y_{rl} - l\cot\varphi)^2 = (l\cot\varphi - \frac{w}{2})^2 \tag{13}$$

B. Trajectory of the rear right wheel

Similarly, the trajectory equation of the rear right wheel would be obtained by the geometric configuration as follows [21]:

$$x_{rr}(t) = (l\cot\varphi + \frac{w}{2})\sin(\frac{v\sin\varphi}{l}t) \tag{14}$$

$$y_{rr}(t) = -(l\cot\varphi + \frac{w}{2})\cos(\frac{v\sin\varphi}{l}t) + l\cot\varphi \tag{15}$$

$${x_{rr}}^2 + (y_{rr} - l\cot\varphi)^2 = (l\cot\varphi + \frac{w}{2})^2 \tag{16}$$

C. Dynamic Equation in Matrix form

As Eq. (2), Eq. (3) and Eq. (4) represent the dynamic equations of vehicle, in matrix form there can be written as [19]:

$$\dot{p} = \begin{bmatrix}\dot{x}\\ \dot{y}\\ \dot{z}\end{bmatrix} = \begin{bmatrix}\cos\theta & 0\\ \sin\theta & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}v\\ w\end{bmatrix} \tag{17}$$

$$\dot{p} = \begin{bmatrix}\dot{x}\\ \dot{y}\\ \dot{z}\end{bmatrix} = Jq \tag{18}$$

In *Fig. 4*, shown below, the initial condition of the vehicle is represented as (x_c, y_c, θ_c) and after a certain motion of vehicle the coordinates of a vehicle will become (x_r, y_r, θ_r), including the error in the position (x_e, y_e, θ_e). Thus the relation between(x_c, y_c, θ_c) and (x_r, y_r, θ_r) in matrix form will become [19]:

$$P_e = \begin{bmatrix}x_e\\ y_e\\ \theta_e\end{bmatrix} = \begin{bmatrix}\cos\theta_c & \sin\theta_c & 0\\ -\sin\theta_c & \cos\theta_c & 0\\ 0 & 0 & 1\end{bmatrix}[P_r - P_c] \tag{19}$$

Here P_r and P_c are:

$$P_r = \begin{bmatrix}x_r\\ y_r\\ \theta_r\end{bmatrix}, P_c = \begin{bmatrix}x_c\\ y_c\\ \theta_c\end{bmatrix}$$

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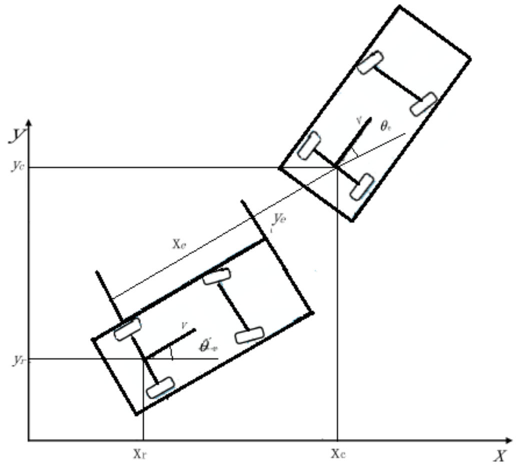

Fig.4. Movement of the vehicle

Now take the derivative of error equation, Eq. (19) and the dynamic equation, Eq. (5), Eq. (6) and Eq. (7), the error based a differential equation is obtain as [19]:

$$\dot{P}_e = \begin{bmatrix} \dot{x}_e \\ \dot{y}_e \\ \dot{\theta}_e \end{bmatrix} = \begin{bmatrix} y_c\omega_c - \gamma_{c+}\gamma_r \cos\theta_e \\ -x_e\omega_c + \gamma_r \sin\theta_e \\ \omega_r - \omega_c \end{bmatrix} \quad (20)$$

In Eq. (20) above, γ_r and ω_r are the ideal speed and ideal yaw rate whereas γ_c and ω_c are the current speed and current yaw rate.

IV. CONVENTIONAL FUZZY CONTROLLER

Fuzzy logic control is an advanced control strategy based on the principals of if "this" then "that" arguments for the complete process of control. Arguments are made by using simple English alphabets for negative, positive and zero values. Only on the bases of these arguments, complete control strategy can easily be designed. The advantage of using a fuzzy logic control system is that no mathematical model is required of the system, and it can cope with system nonlinearities by using a fuzzy logic control strategy. The flowchart of a typical fuzzy logic control system is shown in *Fig. 5*.

A. Dual Fuzzy Logic Controller (DFL)

The two fuzzy logic controllers are connected in a cascade formation so that the desired output is obtained from the system. The working philosophy of each controller itself is the same as taking the crisp inputs going through the fuzzification procedure and defuzzification mechanism, but the working of each controller is changed and is given below:

- Controller 1
  It turns on and only brings the vehicle from a random position, near to the parking space irrespective of the car's initial position and angle. This complete task of controller 1 is autonomous, by selecting the current coordinates of the car by the driver. On reaching near to the parking lot, it then turns off by giving the signal to controller 2.

- Controller 2
  Just after receiving the signal from controller 1, it turns on and moves the car autonomously from the position where controller 1 left the car, near to the parking space and parks the car into the parking lot.

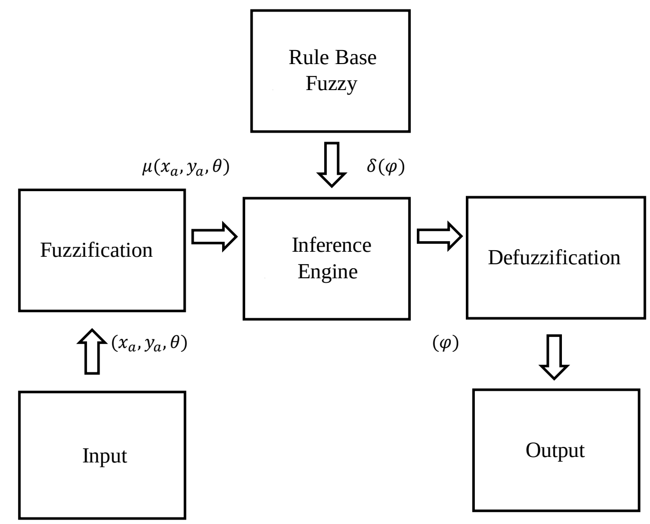

Fig.5: Methodological Flow Chart Scheme for Fuzzy Logic Control System

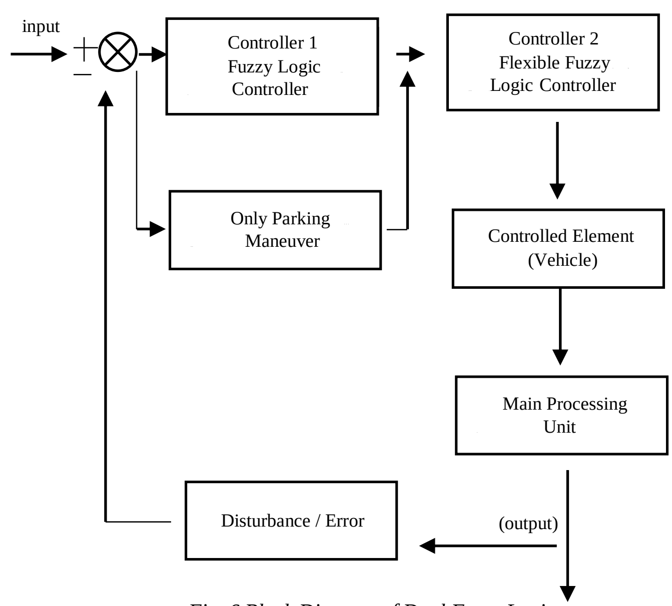

Fig..6 Block Diagram of Dual Fuzzy Logic Controller (DFL) Integration

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As there are two types of parking positions i.e., perpendicular parking and parallel parking. This research work focuses on parallel parking of a vehicle, so controller 2 is designed to perform a parallel parking maneuver in a reverse strategy.
In addition to it, obstacle avoidance feature is added into the controller 2, so that the autonomous vehicle does not collide with any other already parked vehicle. This makes controller 2 flexible in nature, named as a flexible fuzzy controller.
Fig. 6, shows a block that reads only the parking maneuver. This is a feature added in the mechanism when only simple car parking is required. The detail of this mechanism is described in Section 5.

B. Inputs of Fuzzy Controllers

The fuzzy controller uses "Position of x", "Position of y" and "Angle" as inputs. By using these inputs and calculating the difference between the parking points and initial setpoints, the car will move autonomously by minimizing the error/difference value up to the parking points. Both the controllers will work by considering these 3 components as their input values depending upon their desired tasks. The input ranges and the membership functions of both the controllers are shown below. *Fig. 7(a), Fig. 7 (b)*, and *Fig. 7(c)*, represent the input memberships function of controller 1 as θ, x & y.

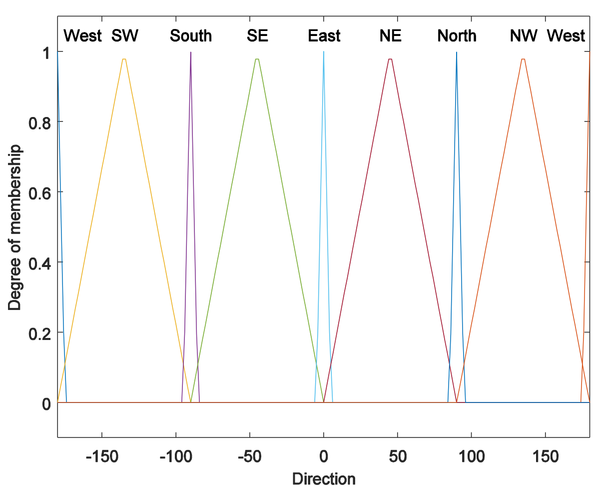

Fig. 7(a) Directional angle

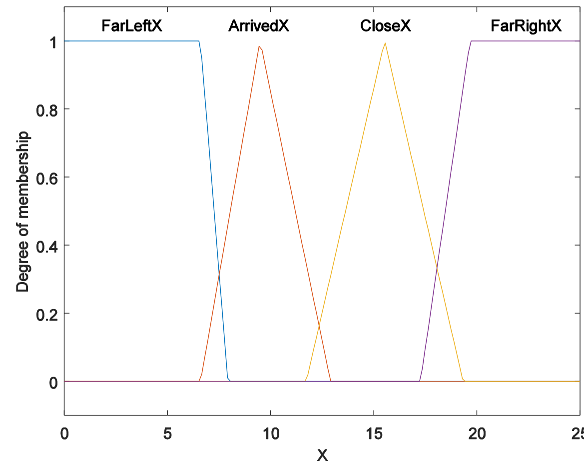

Fig. 7(b) X-axis Direction

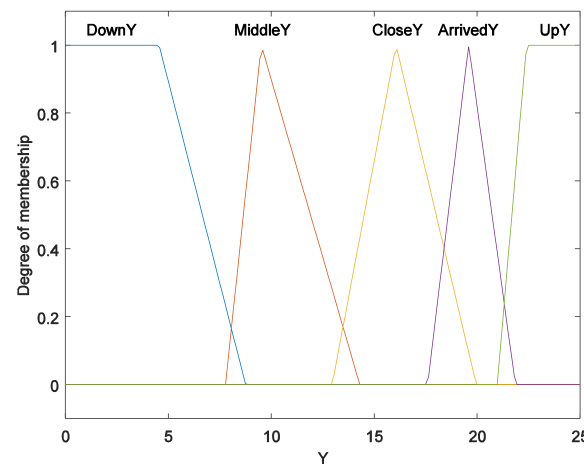

Fig. 7(c) Corrected Y- axes Direction

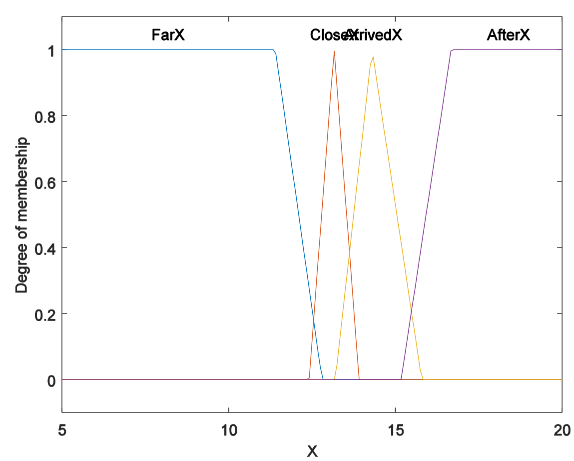

Fig. 8(a) X-axis Direction

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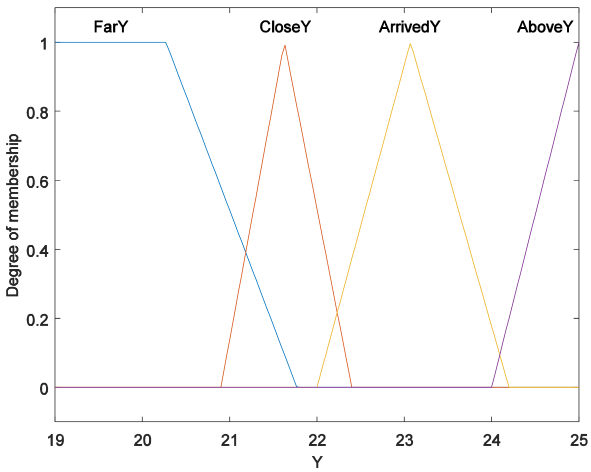

Fig. 8(b) Corrected "Y-Axis Direction"

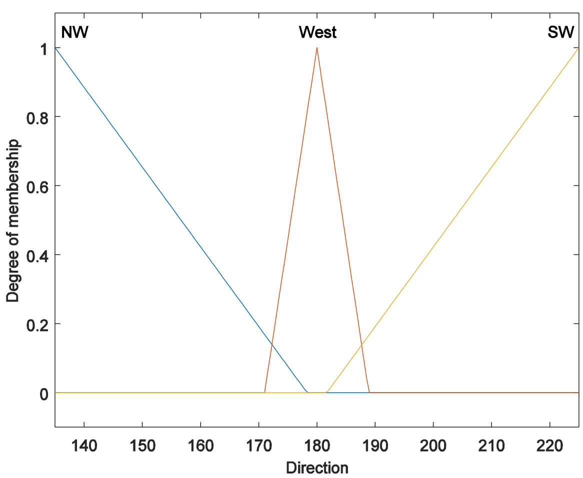

Fig. 8(c) Directional angle

Fig.7, and *Fig. 8*, are the membership functions of controller 2 *Fig. 8(a)*, *Fig.* 8(b), and *Fig.* 8(c), represent the input membership functions of controller 2 as x, y & θ.
Mamdani Fuzzy Inference Engine is used. Crisp results are obtained as a result of defuzzification. Fuzzy membership functions for both designed controllers are taken in triangular and trapezoidal in shape for the smooth and easy functionality.

C. *Rule Table*

Table I are the rules for controller 2 which are used to derive the output angle φ for an autonomous vehicle. In the same way, rules are generated for controller 1 for positioning a vehicle nearby to the target parking position from any random initial position.

TABLE I
RULES USED FOR AUTONOMOUS CAR PARKING

Rule	**Input**			**Output**
	X	***Y***	***θ***	***φ***
1	Far X	Far Y	SW	Right Big
2	Far X	Far Y	West	Right Big
3	Far X	Far Y	NW	Right Big
4	Close X	Far Y	SW	Right Big
5	Close X	Far Y	West	Right Big
6	Close X	Close Y	SW	Left Big
7	Close X	Close Y	West	Right Big
8	Close X	Arrived Y	SW	Left Big
9	Close X	Arrived Y	West	Left
10	Close X	Above Y	West	Zero
11	Arrived X	Far Y	West	Right Big
12	Arrived X	Far Y	SW	Left
13	Arrived X	Far Y	NW	Left Big
14	Arrived X	Close Y	NW	Right Big
15	Arrived X	Close Y	West	Zero
16	Arrived X	Close Y	SW	Left Big
17	Arrived X	Arrived Y	NW	Right Big
18	Arrived X	Arrived Y	West	Zero
19	Arrived X	Arrived Y	SW	Left Big
20	After X	Close Y	NW	Right Big
21	After X	Close Y	West	Zero
22	After X	Close Y	SW	Left Big
23	After X	Arrived Y	NW	Right Big
24	After X	Arrived Y	West	Zero
25	After X	Arrived Y	SW	Left
26	After X	Above Y	NW	Right Big
27	After X	Above Y	West	Zero
28	After X	Above Y	SW	Left Big

D. *Output of Fuzzy Controllers.*

The output of the fuzzy controllers is a continuously changing value according to the initial set point of the car. As the car is approaching the parking lot autonomously, so its output values are continuously changing. The vehicle is continuously minimizing the difference from an initial set point to the parking lot. The parameter of output used in the dual fuzzy controllers is angle "φ". As the input angle "θ" is continuously changing according to each point of parking, so Dual Fuzzy Controller automatically adjusts the value of output angle "φ" according to the initial set point. The vehicle will autonomously approach to the final parking position. The membership functions corresponding to each controller output are shown in *Fig. 9(a)*, & *Fig. 9(b)*.

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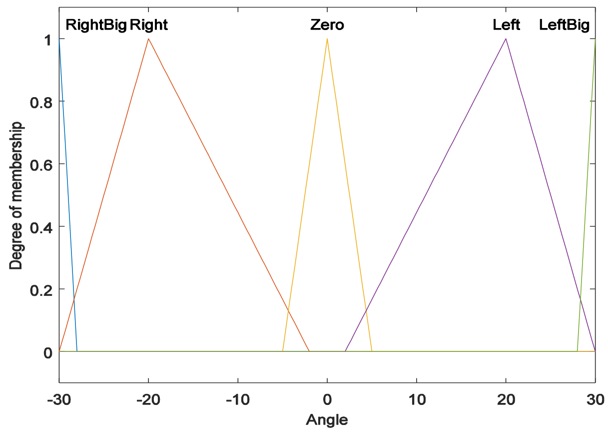

Fig. 9(a) Output directional angle φ of controller 1

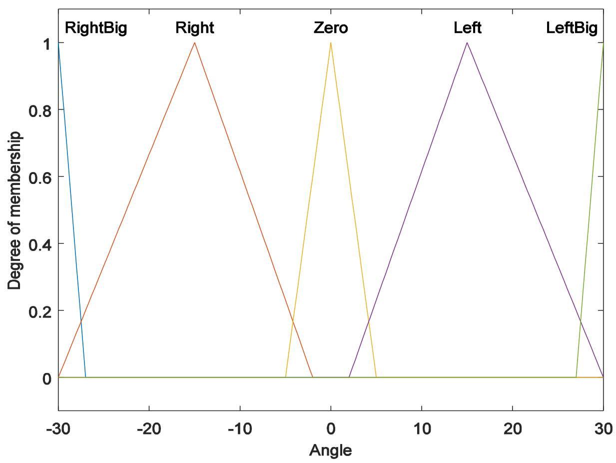

Fig. 9(b) Output directional angle φ of controller 2

V. FLEXIBILITY IN CONTROLLER WITH ONLY PARKING MANEUVER FUNCTIONALITY

This section discusses flexibility in Fuzzy Controller 2, which is required due to an additional feature introduced in the presented approach. As we have discussed earlier that our main aim is to park the vehicle to its target parking position from any random initial position by using the Dual Fuzzy Logic (DFL) controller, so an additional feature to be added is flexibility. That avoids collision with already other parked vehicles during the reverse maneuver procedure. Our autonomous vehicle is going to be parked in between already two parked vehicles parallel to the roadside. In spite of this, if the driver himself wants to find the parking space and park the vehicle near to the available space by his own decision. In this type of scenario, the working of controller 1 is to be minimized since this feature is performed by the driver. Now by pressing the special parking button from the dash console panel of car, autonomous parking system activates and directly jumps to the functionality of controller 2 for reverse parking maneuver procedure. The addition of this feature increases the comfortability of the driver.

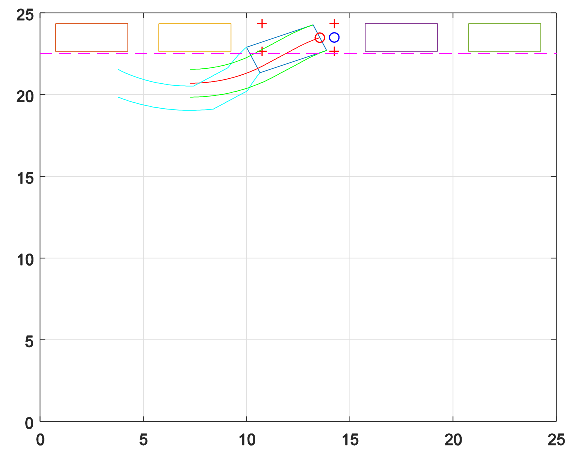

Fig. 10(a). Parking with flexibility performed

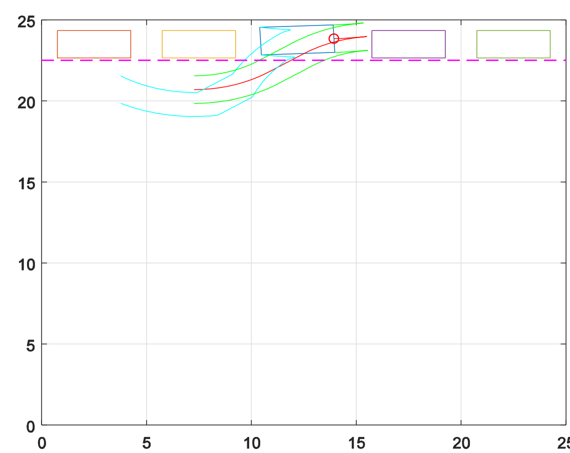

Fig. 10(b) Parking with flexibility performed

Fig. 10(a), & *Fig. 10(b)*, presents a MATLAB simulation that shows the successful performance of the reverse maneuver. This is dependent only on controller 2 in the context of the added functionality described above. *Fig. 10*, has two parts (a) & (b). In part (a) reverse procedure of autonomous car starts with the turning angle and depends on the direction of a vehicle. Part (b) shows when the autonomous vehicle stops as it approaches the already parked vehicle at the back of it. So for maintaining the aligned and balanced parking a little forward directional movement is required and performed in various situations.

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VI. SIMULATION

Simulations were performed in MATLAB, using the same points by Single Fuzzy Logic Controller and Dual Fuzzy Logic (DFL) Controller i.e. for example; *Fig. 10*, shows the graphical results of autonomous vehicle parking by using a single fuzzy logic controller. In part (a) the initial position of the vehicle is (x, y, θ) =(10,6,30). The vehicle autonomously moves to its final parking position, but unfortunately as seen in the results of *Fig. 11(a)*, the final parking position of the autonomous vehicle is not in the middle of a parking garage. The average turning angle of an autonomous vehicle is 20 degrees from the initial position to its final parking position but still accurate parking in the middle of the garage is not achieved by the single fuzzy logic controller. At the start, the controller decides the turning angle of the vehicle for approaching the parking lot would be nominal because the vehicle is near to the parking lot. But as long as it approaches the final position, the controller is unable to adjust its turning angle. The vehicle deviates from the middle of the parking lot. Similarly, in part (b), (c) & (d) the initial conditions were taken as (10,8,22) , (8,8,15) & (10,4,30). The average turning angle of an autonomous vehicle is 27 degrees, 29 degrees and 20 degrees. The steering turning angle of the vehicle is mainly concerned for the accurate car parking; all maneuvers are dependent on the steering turning angle of the vehicle.

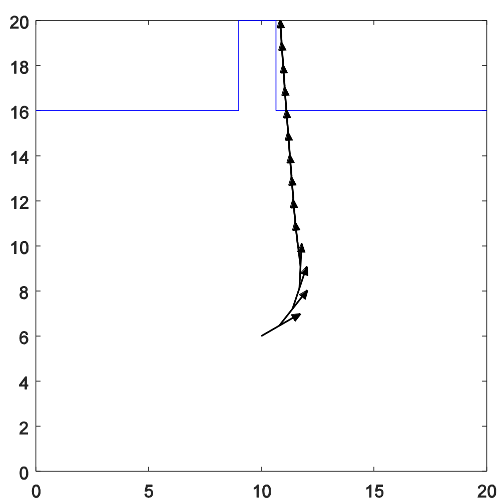

Fig. 11(a) Simulation Result by Single Fuzzy Controller

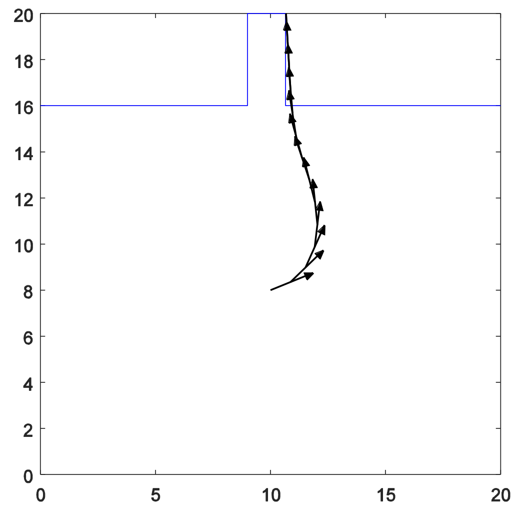

Fig. 11(b) Simulation Result by Single Fuzzy Controller

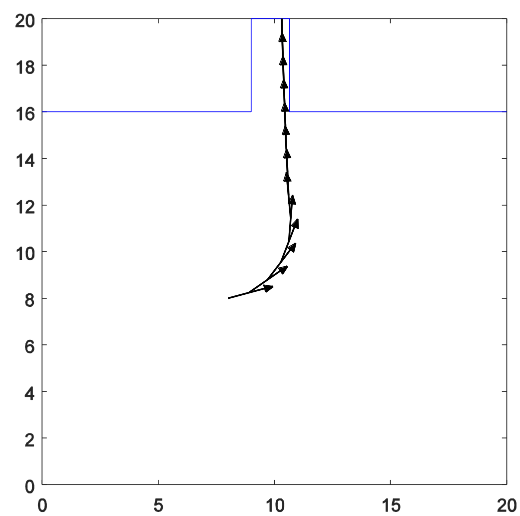

Fig. 11(c) Simulation Result by Single Fuzzy Controller

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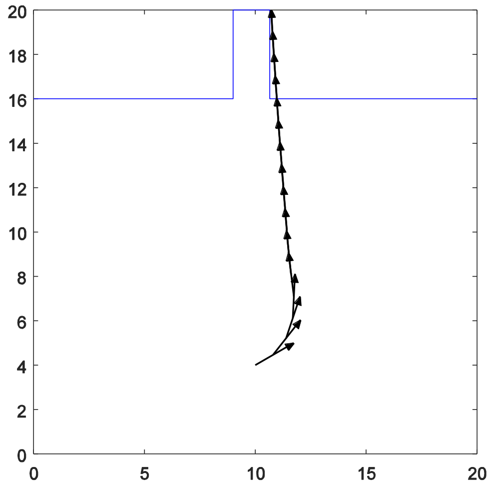

Fig. 11(d) Simulation Result by Single Fuzzy Controller

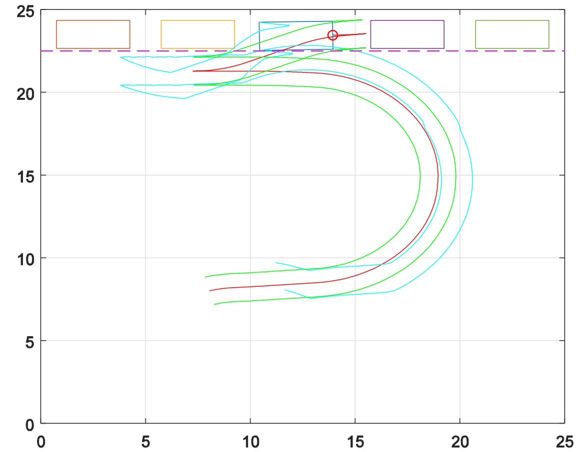

Fig. 12(c) Simulation Result by Dual Fuzzy Logic (DFL) Controller

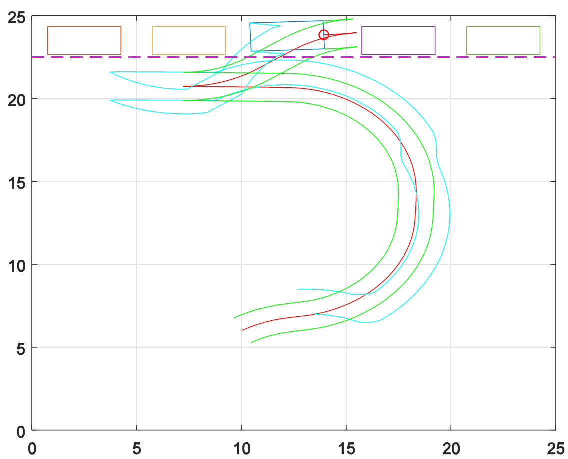

Fig. 12(a) Simulation Result by Dual Fuzzy Logic (DFL) Controller

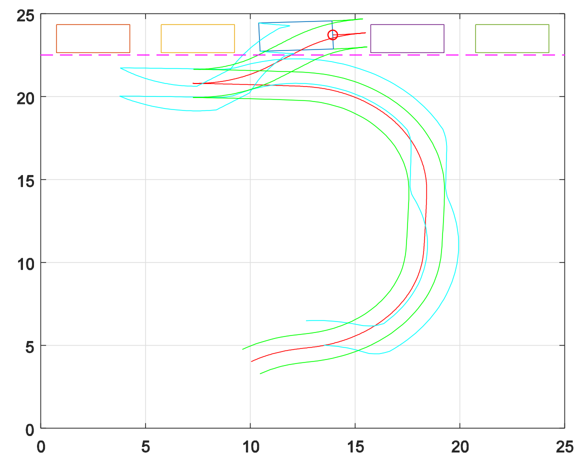

Fig. 12(d) Simulation Result by Dual Fuzzy Logic (DFL) Controller

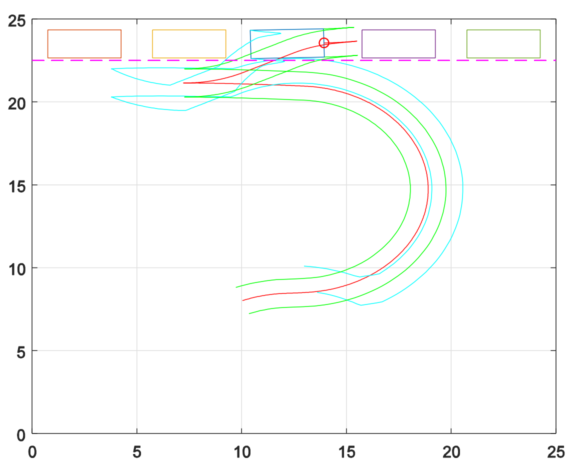

Fig. 12(b) Simulation Result by Dual Fuzzy Logic (DFL) Controller

In *Fig. 11*, part (b) and part (d) autonomous vehicle is completely going outside of the parking lot. This shows very inaccurate results for the parking maneuver by using a single fuzzy logic controller. Here controller needs to allow the vehicle to take a large turning angle so that the vehicle would get easily parked in the middle of a parking lot but unfortunately single fuzzy logic controller is unable to achieve the turning angle of the vehicle. Whereas in part (c), a large turning angle is taken by the autonomous vehicle with respect to the initial position of the vehicle, but the final parking position has not been maintained by the controller as seen.
These parking problems are easily solved by using the Dual Fuzzy Logic (DFL) Controller. In *Fig. 12*, we can see that car starts moving from initial position to parking position, 4 different color depicts the 4 wheels of car. By using the same

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initial conditions of the single fuzzy logic controller, the autonomous vehicle moves to the final parking lot comfortably by using two fuzzy controllers. And the final parking position of the autonomous vehicle is in the middle of the parking lot. The average turning angle in the dual fuzzy logic (DFL) controller is much less than the single fuzzy logic controller.

TABLE II
COMPARISON OF ERROR INDICES OF CONTROLLER

Points	**Single Fuzzy Logic Controller**		**Dual Fuzzy Logic Controller**	
	Average Angle	Mean Position	Average Angle	Mean Position
10,6,30	20.130°	Deviate	1.963°	Approach
10,8,22	27.498°	Deviate	1.711°	Approach
8,8,15	29.747°	Deviate	1.639°	Approach
10,4,30	20.130°	Deviate	1.863°	Approach
9,4,30	23.093°	Deviate	1.805°	Approach
10,8,15	28.430°	Deviate	1.642°	Approach
8.7,1.5,22	19.698°	Deviate	1.930°	Approach

Above shown comparison Table II is between the single fuzzy logic controller and the dual fuzzy logic controller technique. It shows that the average turning angle of an autonomous vehicle from initial to final parking position by using a single fuzzy logic controller is much greater, and the vehicle deviates from the mean position of a parking lot. In some of the scenarios, autonomous vehicle collides with the sidewall of the parking lot, which also damages the vehicle. Whereas by using the proposed technique of dual fuzzy logic controller, the average steering turning angle of the autonomous vehicle is much less as compared to the single fuzzy controller and the autonomous vehicle does not deviate from the mean position of the parking lot. This is helpful for the accurate and stable parking of a vehicle.

VII. CONCLUSION

Parking of autonomous vehicles by using a single fuzzy logic controller is not stable and results are deviating from the middle of the parking position. By comparing the results with the proposed technique of the Dual Fuzzy Logic (DFL) controller, it can be seen in simulations that; the vehicle correctly parks into the parking lot without any collision. Hence the most advantageous behavior of the Dual Fuzzy Logic (DFL) controller is that it correctly works when the parking area is very confined and congested. Whereas single fuzzy shows unwanted behavior. In addition to it, flexibility measure is added into the proposed Dual Fuzzy Logic (DFL) technique for obstacle avoidance. At the nearest settlement position of the vehicle, the controller helps in avoiding the collision with other already nearby parked vehicles as shown in *Fig. 9*. By using two fuzzy controllers, it becomes easy if the driver only wants to park the vehicle into the parking space rather than finding the parking position. By skipping the task of controller 1 and directly jumping to the strategy of controller 2 for the reverse parking maneuver. As compared to this, a single fuzzy logic controller cannot be able to handle this calibrated scenario. The results indicate that the parking of autonomous vehicles has become more advanced, reliable, efficacious and productive as compared to that achieved by a single fuzzy controller. Another advantage of opting for the Dual Fuzzy Logic (DFL) controller is their membership functions are distributed on both the controllers, as their working tasks are different. As compared to this, all the membership functions of a single fuzzy controller are developed on a single entity. The disadvantage of this is, it requires more time for the computational technique and the system response becomes sluggish. A larger processing unit is required for huge calculation, which makes the controlling system more expensive also. So, by using the proposed technique, it requires less computational time because their membership functions are divided into two different controllers and require a smaller processing element for data processing which in return makes the system's cost cheap.

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