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Automatic Parking of an Articulated Vehicle Using ANFIS

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Abstract:Parking is recognized as the most difficult task among the driving tasks. Through this topic Articulated vehicle parking problem is more difficult than passenger car, because under the aspect of control theory, the vehicle and environmental nonlonomic constraint, nonlinear and time varying kinematic equations of motion, they require a sophisticated handling. In this paper Automatic Parking of Articulated Vehicle will be considered when articulated vehicle intends to burden in Special Parking lot in two phases. First, Forward maneuver to put vehicle in suitable position and then backward maneuver to put the back of trailer in the parking slot without collision with parking wall. Because of the nonlinear and sophisticated kinematic motion of articulated vehicle and also successful application of Fuzzy logic and Artificial Neural Networks in Vehicle handling, in this research Adaptive-Network-based Fuzzy Inference System (ANFIS) approach was proposed to solve this problem. The simulation results based on the equation of kinematic motion of articulated vehicle along the strategy of proposed ANFIS Controller indicates good behavior in the parking maneuvers.

Key-Words:Automatic Parking, Kinematic Motion of Articulated Vehicle, ANFIS

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1 Introduction

Parking is recognized as the most difficult task among the driving tasks, because the driver requires finding and determining a place to park, do maneuvers back to put the car in considered location that is associated with crash possibilities [1].Vehicle driving for less experienced individuals, even with its daily use development, is a difficult task, especially when the subject is parking or moving backward [2]. Automatic park skill development is not easy, first the vehicle should be capable of sensing the environment and identifying obstacles to find parking space.Then it will automatically have the ability to plan for movement and eventually be able to track and follow the successive planned movements and be sure that the car is in the final position.Mainly all the existing solutions for automatic car parking use visual sensors data or active sensors such as ultrasonic to find local image for guidance.

This paper focuses on the problem of automatic car park in articulated vehicles that is a far more complex problem than passenger cars because based on reference [3] Articulated vehicles belong to the category of nonholonomous wheelersUnder the aspect of control theory they require a sophisticated handling, less experienced drivers often suffer many hardships to maneuver backwards for the trailer in a straight or curved line.Even according to the reference [4], moving backward and parking in articulated vehicles is difficult even for experienced drivers, because of the problems that were encountered in managing such a maneuver, along with several approaches based on control theory like optimal control and nonlinear control and combination of other controllers, Fuzzy logic and artificial neural network are approaches proposed to path generation, direct and control articulated vehicles, and today many efforts in this area have been made [3].

Researches have been working in this area to park articulated vehicles like Nicolaj and colleagues in reference [5] research on the problem of fuzzy rules of the decomposition technique about classical control of Reverse Park for articulated car. Zobel et al [6], explained issues related to minimum Parallel Park in articulated vehicle and extracted the basic equations of motion and derived the exact definition of minimum Parallel Parking, the successive stages of parks.Reference [7] after offering center articulated kinematic model, has proposed the control technique to follow the reference trajectory satisfying the geometric and non-geometric constraints and by Lyapunov method, stability analysis with the controller was studied. In [4] a control strategy is suggested that includes a controller for joint angle and the other to follow the path. The proposed controller has cascade layer structure, which means that the inner layer is responsible for motor control and vehicle dynamics are associated with the outer layer. Reference [8] studies on the car park backward in articulated car park with fixed and moving obstacles at different points. It should be noted that two fuzzy controllers have been used separately, one to find the path and the other to prevent crashing with obstacles.

As noted, the purpose here is Automatic Parking of articulated vehicles so that the car first moves forward from the different initial conditions into a suitable state and then moves backward maneuver, it is noteworthy that the backward maneuver occurs when articulated car must put its trailer back in loading place in the garage or parking lot for loading.

It has been assumed in this study that skilled driver information for garage parking maneuvering or reference path is availableand different positions of tractor, trailer and driver changes in steering angle can be measured.In other words, there are rule bases for writing fuzzy rules to design and implement a fuzzy controller and fuzzy neural hybrid algorithm. To fulfill this assumption, simulation has been made for parking maneuver of articulated vehicles, targeting the end of the trailer in loading area without colliding with walls and satisfying the initial and final conditions of the car, so there is no need to measure the states in the same actual environment and all the desired modes are available.

Section 2 derives the equations of kinematics of articulated vehicle's motion, before the controller design, to move the vehicle automatically in maneuver Park; it should find the position and orientation. The third section discusses briefly about parking sensors and detection. Section 4 is devoted to a discussion of the control system. Then, we have a brief description of ANFIS in the fuzzy logic, the computer simulation model of the controller is proposed in Section 5 and Section 6 is a closed loop system and finally we have the results of the controller in Section 7.

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2 The Articulated Vehicle Kinematic Model

Motion equations of articulated vehicles in parking maneuver is based on moving without slipping. In practice, this approach is coincidentwith the fact. Reference [9] has pointed out that car kinematic in park perspectives should be along with simplifications, meaning that vehicle speed is low in park, sliding does not happen in practice under tires and speed will be in tire direction, and hence the car motion can be considered just as a rigid body motion in plate. Local coordinate system fitted in Figure 1 and representationof speed directions in Figure 2 confirmedthis topic.Where f_t confirms tractor's front, r_t end of the tractor and r_s trailer's end.

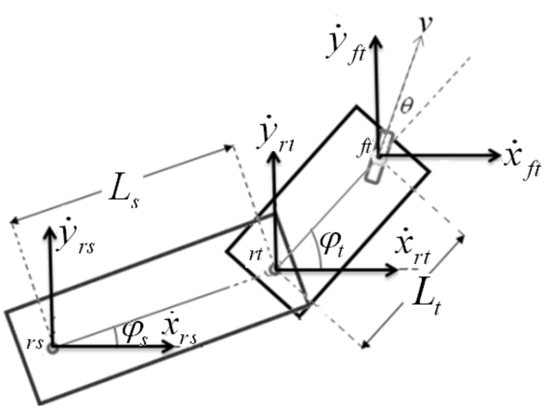

Fig.1 Articulated vehicle with local coordinate

The argument of motion without slipping, equations (1) and (2) indicates the speed of the ft, to compute a movement without a slippage in articulated car easily, the instantaneous center of rotation, that is shown in Figure 2, is used.

$$\dot{x}_{ft} = v\cos(\theta + \varphi_t) \tag{1}$$

$$\dot{y}_{ft} = v\sin(\theta + \varphi_t) \tag{2}$$

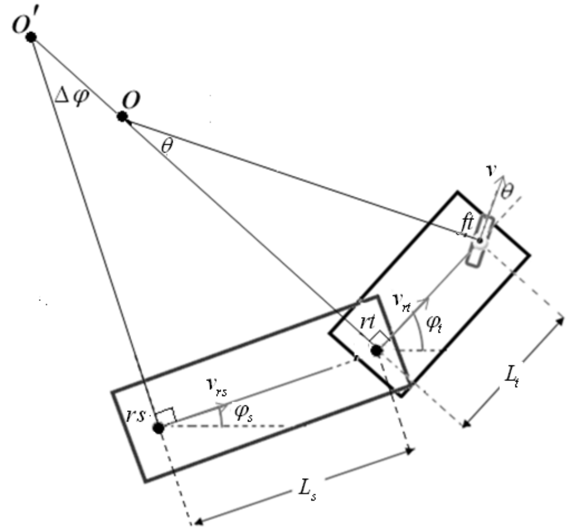

Fig.2 Instantaneous Center of Rotation Method

Where θ is steering angle and φ_t is tractor yaw angle and φ_s is trailer yaw angle. According to the geometrical relationship shown in Figure 2, we have the following intervals:

$$\overline{ft-o} = \frac{L_t}{\sin(\theta)} \tag{3}$$

$$\overline{rt-o} = \frac{L_t}{\tan(\theta)}$$

$$\overline{rt-o'} = \frac{L_s}{\sin(\Delta\varphi)}$$

$$\overline{rs-o'} = \frac{L_s}{\tan(\Delta\varphi)}$$

According to figure 2 by using Instantaneous Center of Rotation Method, relation (3) shows velocity in r_t position and relation (7) shows velocity in r_s position. r_t and r_s velocity in x and y direction according to local coordination shown in figure 1 respectively are exhibited in (4),(5),(8) and (9). Also (10), (11) and (12) are related to tractor yaw velocity and trailer yaw velocity and thedifference between them.

$$v_{rt} = v\cos(\theta) \tag{4}$$

$$\dot{x}_{rt} = v\cos(\theta)\cos(\varphi_t) \tag{5}$$

$$\dot{y}_{rt} = v\cos(\theta)\sin(\varphi_t) \tag{6}$$

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$$\Delta\varphi = \varphi_t - \varphi_s \tag{7}$$

$$v_{rs} = v_{rt}\cos(\Delta\varphi) \tag{8}$$

$$\dot{x}_{rs} = v\cos(\theta)\cos(\Delta\varphi)\cos(\varphi_s) \tag{9}$$

$$\dot{y}_{rs} = v\cos(\theta)\cos(\Delta\varphi)\sin(\varphi_s) \tag{10}$$

$$\dot{\varphi}_t = \frac{v}{L_t}\sin(\theta) \tag{11}$$

$$\dot{\varphi}_s = \frac{v}{L_s}\cos(\theta)\sin(\Delta\varphi) \tag{12}$$

$$\Delta\dot{\varphi} = \frac{v}{L_t}\sin(\theta) - \frac{v}{L_s}\cos(\theta)\sin(\Delta\varphi) \tag{13}$$

3 Sensors and Identify Parking Location

Before designing the controller, in order to move automatically in park maneuver, it needs to be informed of their exact position and orientation. Identifying the location of the vehicle should be according to the location of the park [10]. Therefore identifying environment is an important part of control decision-making for identification appropriate park place. Several approaches have been proposed for example in [11] used as a ring of ultrasonic sensors on the vehicle to determine the relative position between the vehicle and the surrounding environment. Reference [12] used a hybrid method, combining information from sensors, encoder, gyroscope, Differential Global Positioning System to determine the approximate location of the park. By video promotion and development of technology in the references [13], CCD1 camera is used to obtain a comprehensive picture of the park area. Reference [14] proposed a solution based on machine vision and ultrasonic sensors that is efficient in determining park location.

1Charge Couple Devised

4 Control System

The nature of fuzzy logic leads to robust control algorithm in spite of sensor, and ambient fluctuations of dynamical systems. In the definition of artificial neural networks, it can be defined as information processing model for which it is inspired by the structure of human brain [15].Computational intelligence tools such as artificial neural networks and fuzzy logic have been addressed for applications in a wide range of issues, and recently researchers tend to combine these two approaches [15, 10]. The control system proposed in this paper combines the two approaches of fuzzy and neural network scheme. Then, with a brief introduction of the structure of fuzzy controller, Adaptive-Network-based Fuzzy Inference System is described in the proposed adaptive closed-loop system with articulated vehicle.

4. 1 Structure of Fuzzy Controller

A classical fuzzy controller is composed of five main sections. Fuzzification, database, inference or decision-making section, rule base and de-fuzzification. Usually before and after fuzzy controller, pre-processor and post-processor are used respectively. It should be noted that because the input and output of fuzzy systems are real numbers, some interfaces should be created between fuzzy inference engine and environment, these intermediaries are the same fuzzification and de-fuzzification [16]. Figure 3 shows the structure of the classical fuzzy controller.

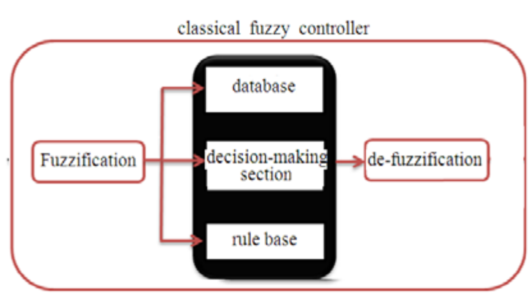

Fig.3 Classical Fuzzy Controller Structure[16]

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Artificial neural networks and fuzzy inference systems inspired the willingness of many researchers in various fields of science and engineering, this followed urgent need of adaptive intelligent systems to solve real-world problems such as vehicle control, pattern recognition, human-machine interaction, medical and economic issues, etc. [17]

Several constructs as Fuzzy neural network can be designed. One of these structures has been stated by Roger Jang [18]. Structure proposedby Jang in 1993 was named ANFIS. In this structure of fuzzy networks, fuzzy systems are modeled by fuzzy systems in different ways, and then this model is equivalent to the fuzzy neural network. Among the methods used in the design of the fuzzy model, we have "Takagi Sugeno and Kang", a practice in which fuzzy inputs and fuzzy outputs are indirect. In this approach the input and output variables are real values. For example, this fuzzy system uses the following rules: ***If the speed of the car (X) is high, then the force exerted on the gas pedal is Y = CX (C is a constant).***Comparison shows that a description of the linguistic values of the "then" part of fuzzy rule has become a simple mathematical relationship, makes it easier to change the composition of fuzzy rules. In fact, TSKfuzzy system is a weighted average of the values of rules. Furthermore, the proposed structure by Jang is presented as a summary of the reference [18].

4. 2 ANFIS Structure

For simplicity, we assume the fuzzy inference system under the consideration has two inputs x and y and one output f, as shown in figure 4.

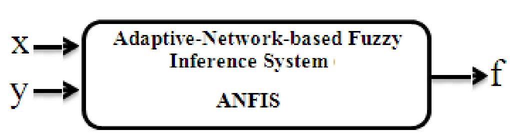

Fig.4 ANFIS with two input's and one output[18]

Which each one only has two membership functions, input x A_1 and A_2, input y has B_1 and B_2. Suppose that the rule basis contains two fuzzy if-then rules of Takagi sugeno's type:

$$if\ x\ is\ A_1\ AND\ y\ is\ B_1\ Then\quad f_1 = p_1 x + q_1 y + r_1 \tag{14}$$

$$if\ x\ is\ A_2\ AND\ y\ is\ B_2\ Then\quad f_2 = p_2 x + q_2 y + r_2$$

Fuzzy reasoning is illustrated in figure 5 where the output of each rule is a linear combination of input variables plus a constant term, and the final output is the weighted average of each rule's output.

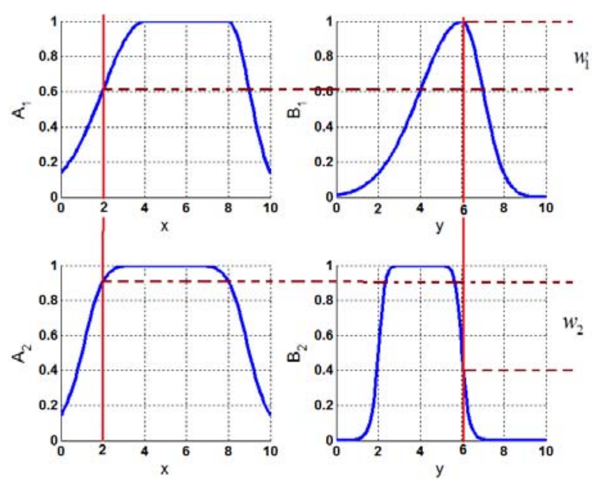

Fig.5 fuzzy reasoning[18]

$$f = \frac{w_1}{w_1 + w_2} f_1 + \frac{w_2}{w_1 + w_2} f_2 = \bar{w}_1 f_1 + \bar{w}_2 f_2 \tag{15}$$

Corresponding equivalent ANFISarchitecture is shown in figure 6.

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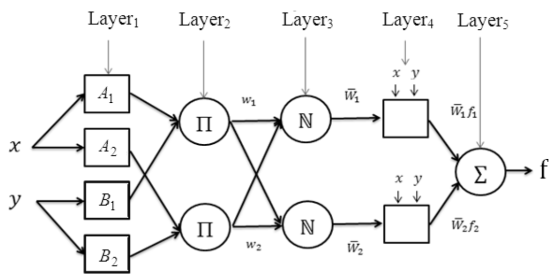

Fig.6 equivalent ANFIS [18]

Layer 1: This layer is adaptive; it means that parameters should modify. Every node *i* in this layer is a square node with a node function:

$$O_{1\,1} = \mu_{A_1}(x) \tag{16}$$

$$O_{1\,2} = \mu_{A_2}(x)$$

$$O_{13} = \mu_{B_1}(y)$$

$$O_{14} = \mu_{B_2}(y)$$

Where x and y are input's and A_1, A_2, B_1 and B_2 are linguistic label associated with this node function. In other word, the output of this layer is the membership function of linguistic labels and it specifies the degree in which the given x satisfies the quantifier A_1, B_1, A_2, B_2. For example membership function can be bell-shape with maximum equal to 1 and minimum equal to 0, such as

$$\mu_{A_1}(x) = \frac{1}{1+\left|\frac{x-c_1}{a_1}\right|^{2b_1}} \tag{17}$$

Where $\{a_i, b_i, c_i\}$ is the parameter set. As the values of these parameters change, the bell-shaped functions vary accordingly, thus exhibiting various forms of membership functions on linguistic label.

Layer 2: This layer is not adaptive; it is constant layer. Every node *i* in this layer is a circle node labeled which multiplies the incoming signals and sends the product out. For instance,

$$O_{2i} = w_i = \mu_{Ai}(x) * \mu_{Bi}(x)\ i = 1,2 \tag{18}$$

Each node output represents the firing strength of a rule. (In fact, other T-norm operators that performs generalized AND can be used as the node function in this layer.)

Layer 3: This layer is constant layer and every node is a circle node labeled N1 and N2. The i_{th} node calculation the ratio of the i_{th} rules firing strength to the sum of all rules firing strengths:

$$O_{3i} = \bar{w}_i = \frac{w_i}{w_1 + w_2}, i = 1,2 \tag{19}$$

Output of this layer will be called normalized firing strengths.

Layer 4: This layer is adaptive; every node *i* in this layer is a square node with a node function.

$$O_{4i} = \bar{w}_i f_i = \bar{w}_i (p_i x + q_i y + r_i), i = 1,2 \tag{20}$$

$\{p_i, q_i, r_i\}$ is the parameter set.

Layer 5: This layer is constant layer and the overall output as the summation of all incoming signals, i.e.,

$$f = \sum_{i=1}^{n} \bar{w}_i f_i \quad n = 2 \tag{21}$$

According to the explanation of ANFIS, in order to design controller by this method, neural networks should be trained with desired data.so, to generate such desired data, computer simulation MATLABis used.

5 Computer Simulation

Data Table 1 is according to reference [19] and using the experience of skilled drivers in the articulated car park, which is extracted by answers to thequestions asked orally or written by experimental basis. In Figure 8, the standard

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dimensions of car Refrigerated Semi-Trailer can be seen that in simulation of (9a) and (9b) this model is used.

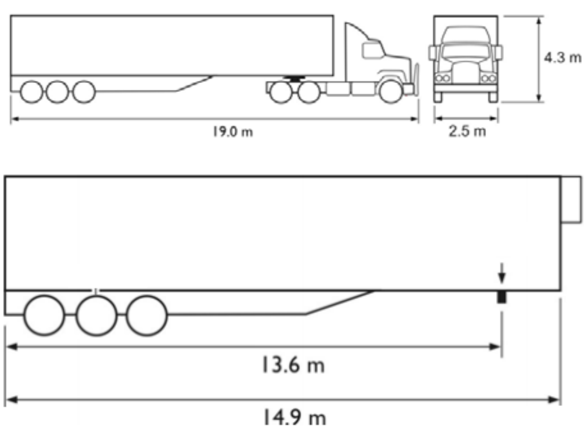


Fig.8 Refrigerated Semi-Trailer [19]

Table 1 Computer Simulation Data

5.4 (m)	Tractor Length
13.6 (m)	Trailer Length
2.5 (m)	Articulated Vehicle Width
7 (m)	Parking Opening Width
$\lvert\theta\rvert \le 30_{degree}$ $\lvert\Delta\varphi\rvert \le 90_{degree}$	Vehicle Kinematic Constraint
$+1_{(m/s)}$	Vehicle Speed-Forward Motion
$-1_{(m/s)}$	Vehicle Speed-Backward Motion
$\varphi_t = 0$ $\varphi_s = 0$	Initial Condition

The first phase of the motion is moving forward with an arbitrary initial condition and second phase is backward maneuver. It is noteworthy the first phase changes to the second phase when the expert driver feels a suitable distance from the back of trailer with respect to edge of the opening of parking area to put the trailer in parking lot without collision.It is notablethis issue from practical point of view by ultrasonic distance sensor will be verified.

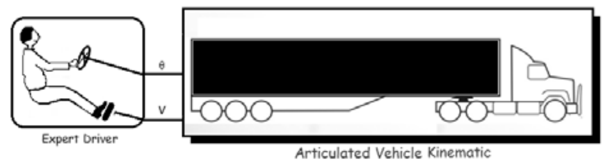
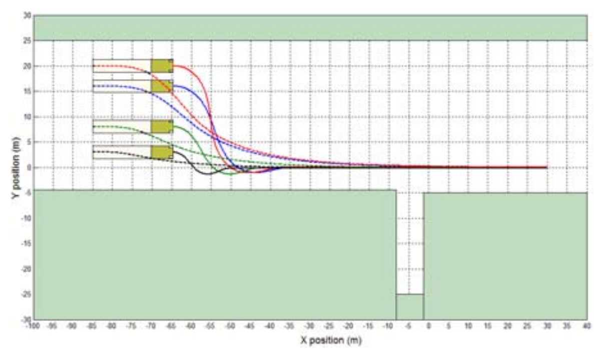
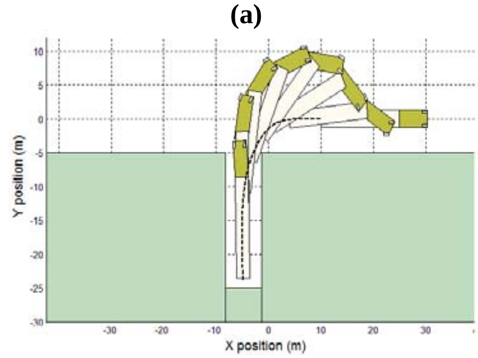


Fig.9 Computer Simulation of Articulated Vehicle

Number of desired paths by the expert driver's experience is extracted from answers in the questionnaire and the results of simulations are shown in (10a-) and (10b-). For example, in Figure (10a-) articulated vehicle moves in the first phase shows the initial conditions and (10b-) represents a moving articulated vehicle in Second phase.



(a)



(b)

Fig.10 Desired Path (a) first phase (b)second phase

To understand the vehicle behavior inautomatic parking maneuver, a flowchart is depicted in Figure 11. The phase-change maneuver is evident. Changing from the first phase to the second phase is

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by a signal that spans the distance from the edge of the trailer park, measures it and sends it to the control system, this change coincided with a change in velocity of the vehicle.

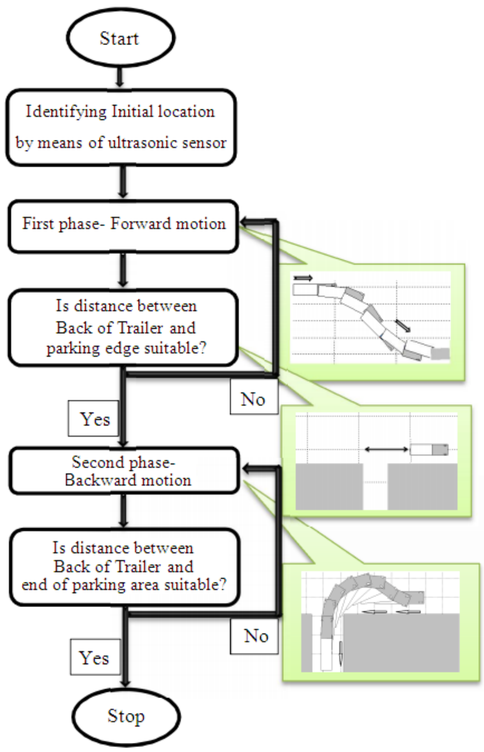

Fig.11Articulated Vehicle Behavior in Parking Maneuver

According to what was mentioned earlier, the phase shifting in parking maneuver verified by ultrasonic sensor. Section 6, is about controller design by given desired data based on the skilled driver's experience.

6 Closed-Loop Control System in Automatic Parking Maneuver

Figure (12a-) shows closed-loop control system as mentioned in the previous section, φ_s and φ_t and horizontal distance from the wall as input into the control system and the steering angle and speed are control system outputs. Two-phase maneuver will require the proposed control system in two parts, as shown in Figure (12-b), these two parts, one for forward maneuver and other ones backward maneuver.

Table 2

$-1.2 \le \varphi_t \le 0_{(phase_1)}$
$-0.86 \le \varphi_t \le 1.6_{(phase_2)}$
$-0.7 \le \varphi_s \le 0_{(phase_1)}$
$0 \le \varphi_s \le 1.6_{(phase_2)}$
$0 \le D \le 22.7$
$-30 \le \theta \le +30$

Figures (13) and (15) show input membership functions and Figures (14) and (16) represent the structure of the neural network controller in both phases. Simulation terminates when trailer's end distance with respect to end of parking lot be suitable.

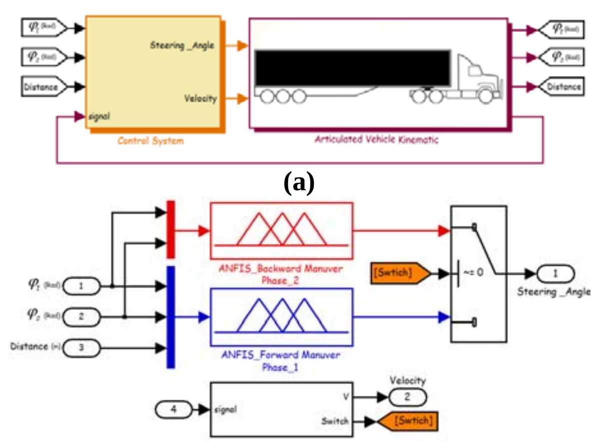

Fig.12Closed Loop Control in Articulated Vehicle in Automatic Parking

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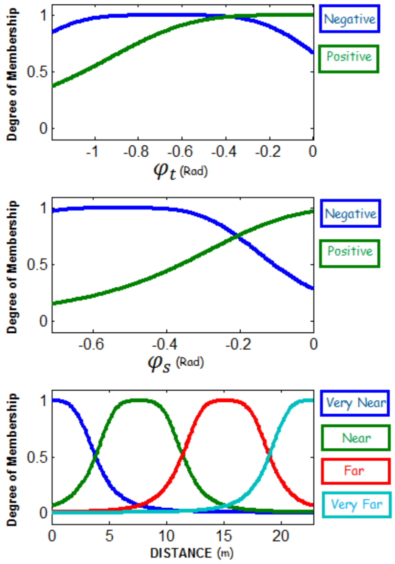


Fig.12Input membership function for Controller in first phase

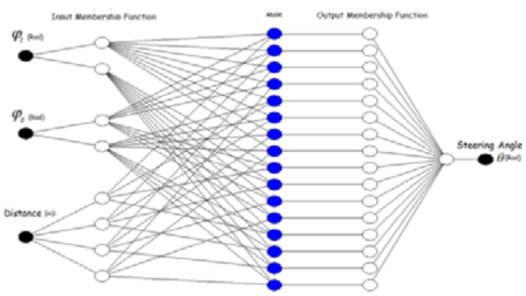


Fig.13Neural Networks for ANFIS Controller in first phase

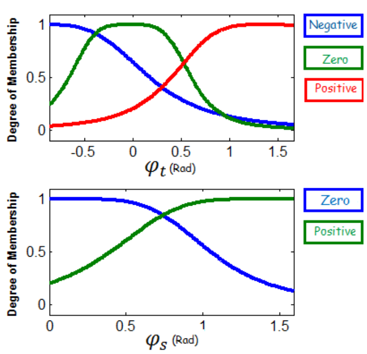


Fig.14Input membership function for Controller in second phase

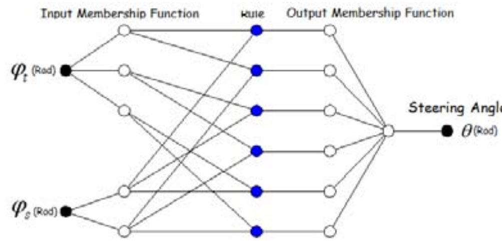
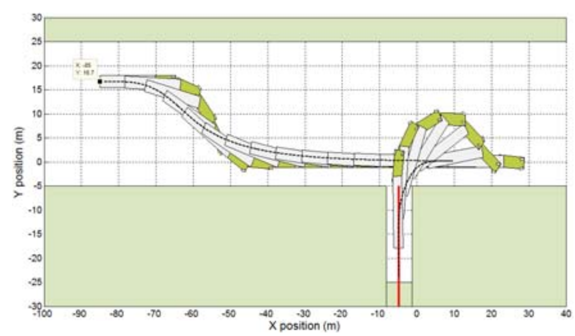


Fig.15Neural Networks for ANFIS Controller in first phase

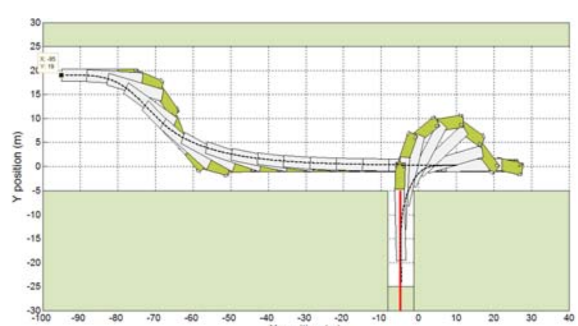
Table (3) and (4) represent fuzzy rules in each of the maneuver**s**, as shown in Table (3) of Law No. 1 it is interpreted according to equation (22).

7 Results of ANFIS controller

As shown in Figures (17a-) to (17c-), ANFIS controller works well with different initial conditions without colliding with walls, each of the two-phase maneuvers are successful implementations.



(a)



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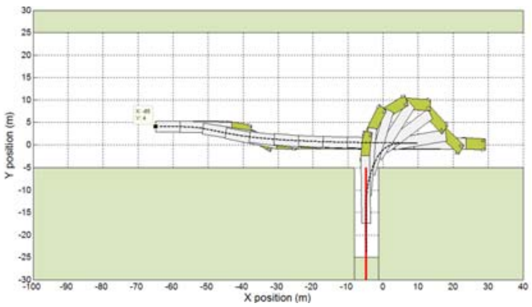
(b)



(c)

Fig.16 Automatic Parking Maneuver of Articulated Vehicle Initial Condition

(a) (x=-85m,y=16.7m),(b) (x=-95m,y=19m), (c) (x=-65m,y=4m)

Table.3 Fuzzy Rules in first phase

NO	φ_t(rad)	φ_s(rad)	Distance(m)	outMF
1	Negative	Negative	Very Near	192.6
2	Negative	Negative	Near	3.745
3	Negative	Negative	Far	1.042
4	Negative	Negative	Very Far	0.9004
5	Negative	Positive	Very Near	-47.23
6	Negative	Positive	Near	-6.599
7	Negative	Positive	Far	-4.434
8	Negative	Positive	Very Far	-3.838
9	Positive	Negative	Very Near	-129.5
10	Positive	Negative	Near	-2.541
11	Positive	Negative	Far	0.0378
12	Positive	Negative	Very Far	-0.645
13	Positive	Positive	Very Near	31.75
14	Positive	Positive	Near	4.439
15	Positive	Positive	Far	2.573
16	Positive	Positive	Very Far	2.461

Table.4Fuzzy Rules in second phase

NO	φ_t(rad)	φ_s(rad)	outMF
1	Negative	Zero	3.18
2	Negative	Positive	-7.38
3	Zero	Zero	-0.23
4	Zero	Positive	2.38
5	Positive	Zero	-4.44
6	Positive	Positive	0.69

7. 1Error Calculation

Relations (22) shows final values of back of the trailer and relations (23) and (24) respectively indicates the distance error with respect to desired final position and trailer yaw angle with respect to desired yaw angle, the relationship (25) shows the distance from the initial position to the final position of the end of the trailer. Final Error Calculation results, in fourteen maneuvers by different initial conditions are presented in Table 4.

$$x_{final} = -4.75_{(m)} \quad y_{final} = -24_{(m)} \quad \varphi_{final} = \frac{\pi}{2}_{(rad)} \tag{22}$$

$$D_{Error(m)} = \sqrt{\left(x_{final} - x_s\right)^2 + \left(y_{final} - y_s\right)^2} \tag{23}$$

$$\varphi_{s\_Error} = \varphi_s - \varphi_{final} \tag{24}$$

$$N_{(Ic_x, Ic_x)} = \sqrt{\left(x_{final} - Ic_x\right)^2 + \left(y_{final} - Ic_y\right)^2} \tag{25}$$

Table 5Automatic Parking Error with different Initial Condition

$Ic_{\varphi_s(\deg)}$	$Ic_{x(m)}$	$Ic_{y(m)}$	$N_{(Ic_x, Ic_x)}$	$D_{Error(m)}$	$\varphi_{s\_Error(\deg)}$
0	-65	4	66.4	o.14	2.21
0	-72	21	76.2	0.37	3.57
0	-74	18	80.9	0.69	5.01
0	-79	10	81.6	0.23	1.91
0	-80	11	82.9	0.22	1.97
0	-83	15	87.4	0.22	2.12
0	-85	16.7	89.9	0.15	2.45
0	-87	12.5	89.9	0.32	1.58
0	-88	14.5	91.7	0.29	1.73
0	-90	11	92.1	0.18	1.24
0	-90	14	93.3	0.43	1.54
0	-90	20	95.9	0.32	2.26
0	-92	16.5	96.2	0.24	1.66
0	-95	19	99.9	0.26	1.67
Mean Value of Error				$D_{Error(m)}$	$\varphi_{s\_Error(\deg)}$
				0.29	2.21

8Conclusion

In this study, the use of Adaptive-Network-based Fuzzy Inference algorithm (ANFIS) has been detailed in Automatic Parking of Articulated Vehicle. To create a network of routes for training ANFIS, detailed computer simulations to maneuver the car park was done in MATLAB. After learning and applying the proposed controller, the simulation results show the errors of complex kinematic behavior of the vehicle is very suitable automotive maneuvers park.

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