Intelligent Parking Method for Trailers in Presence of Fixed and Moving Obstacles Randomly

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***Abstract*—a Fuzzy approach to backward movement control for trailers in a dynamic environment is presented in this paper. The approach is then extended and employed for conditions where obstacles are placed on the trailer pathway. In the first case, obstacles are assumed to be fixed, while the second condition includes moving obstacles through which the trailer should be directed toward the parking dock. The method is designed in a way to be used in conditions with infinite number of obstacles at arbitrary places. In any case, to find the parking dock, the trailer movement must be adapted to that of obstacles. In the present paper, two separate fuzzy controllers are used for directing the trailer: one for finding the target, and the other for avoiding the obstacles. While there is no obstacle around, the target finder controller is in use; and in the cases where the trailer gets close to obstacles the obstacle avoider controller is activated. The proposed method is employed for parking a trailer model through fixed and moving obstacles.**

***Index Terms*—Fuzzy control, avoiding obstacles trailer parking, routing, fixed and moving obstacles**

I. Introduction

In 1990, Nguyen and Widrow [1] applied a self-learning neural network to the trailer backer-upper problem. The latter has become an acknowledged benchmark in non-linear control since and numerous other techniques have been tried, including genetic programming [2] neurogenetics [3], simplified neural network solution through problem decomposition [4], etc.1. Computational overhead is usually very high in such applications, e.g. in [5] it is shown that about 20000 of back-up cycles are needed before neural network learns and even then, the back propagation algorithm may not converge for some sets of training samples[17].

A simplified version of the control problem (consisting of the cab part only), on the other hand, has been heavily exploited in the field of fuzzy control [7]-[14]. Apparently, it seems to be one of these cases where the traditional application area of fuzzy logic - knowledge-based control - would be an appropriate solution. Ability to drive a car is a very common skill among people thus it should not be too difficult to find an expert whose verbal instructions would then constitute the core of the control system. Car driving skill,however, is usually learned to a degree where it rarely intrudes on consciousness (the occasions when it does are unusual circumstances like a potential accident or a situation the driver is not used to (i.e. he/she has not yet learnt it). Consequently, it is difficult to extract appropriate rules from the expert because of one's inability to explain how the action behind the steering wheel is exactly related to car positioning and further difficulties in putting it down in terms of fuzzy logic. The design of knowledge based controller therefore becomes much more difficult than was assumed in the first place. Though the computational load is low, controller design procedure is ill-defined and plagued with the curse of dimensionality that often leads to subpar performance.

In [15] is shown how the decomposition of the control problem can make controller design very natural and substantially simplify expert knowledge acquisition. In the decomposed view we focus on information concerning car optimal orientation in two-dimensional space (much easier to explain and understand than the minute actions on the steering wheel), which ultimately leads to the efficient solution of the problem. The decomposition principle, according to [16], also helps to tackle the trailer and trailer problem[17].

II. Problem Definition

Designing an optimal pathway for backward movement of a trailer through a number of fixed and moving obstacles is among most complicated problems in engineering. Factors such as type, shape, and rate of movement as well as time limitations for achieving the target dock may introduce further complication into the problem.

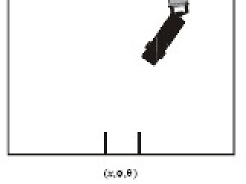

Fig. 1. A schematic of the trailer and parking dock; the position of the trailer is determined by the three state variables *x, y,* and *φ*

Backward movement of a trailer on a dock is a nonlinear control problem. Using the conventional control methods, a mathematical model for the system can be obtained, and then nonlinear control theory may be employed to design of the controller. An alternative to this is to design a controller which simulates human behavior. The latter is used in the present paper. We assume that an experience trailer driver is available; in addition, we can measure different positions of the trailer and corresponding driver's actions to move the

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trailer backward. Fig. 1 shows the trailer and the loading (parking) dock.

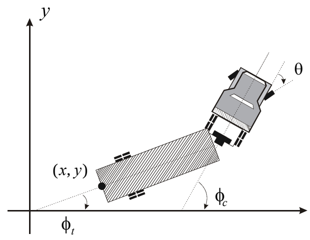
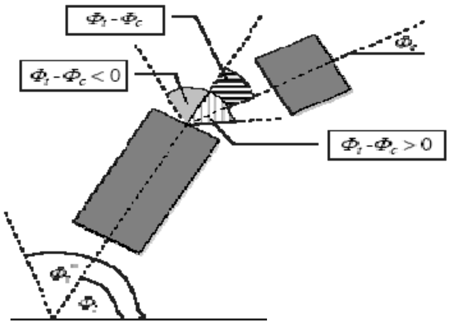


Fig. 2. State variables involved in intelligent backward movement of the trailer

The trailer is controlled by changing θ. Only backward movement is allowed here. In each step, the trailer moves backward with a constant change in position.

We assume that a sufficient space is present between the trailer and parking spot, and therefore, the vertical position y is not required as a state variable for our purpose.

Details of Plant			
State	x, y		Coordinates of the center rear of the trailer
	Φ_t		Angle of trailer with x-axis
	Φ_c		Angle of the cab with x-axis
Control	θ		Steering angle of the front wheels relative to cab orientation
Constraints	$x > 0$		The loading dock is at $x = 0$
	$\lvert\Phi_t - \Phi_s\rvert \le 90$		The angle between the cab and trailer can't exceed 90°
	$-70 \le \theta \le 70$		Limit of steering of the front wheel
Equations of Motion	$A = r \times \cos(\theta)$ $B = A \times \cos(\Phi_c[t] - \Phi_t[t])$ $x[t+1] = x[t] - B \times \cos(\Phi_t[t])$ $y[t+1] = y[t] - B \times \sin(\Phi_t[t])$ $\Phi_c[t+1] = \Phi_c[t] + \arcsin(\frac{r \times \sin(\theta)}{L_s + L_c})$ $\Phi_t[t+1] = \Phi_t[t] - \arcsin(\frac{A \times \sin(\Phi_c[t] - \Phi_t[t])}{L_s})$		
	$\Phi_c[t+1]$		Is then adjusted to respect the constraint on $\Phi_t - \Phi_s$
Parameters	r	3m	distance front wheel moves per time step
	L_s	14m	length of the trailer, from rear to pivot



Relationship between truck and trailer angles

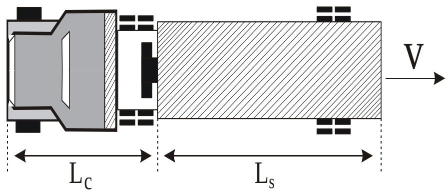


Fig. 3. Constraints of the trailer parking problem

A. Problem Constraints

- The trailer has a constant velocity of V.
- The length of the trailer is $L_c + L_s$

III. Defining the Fuzzy Sets

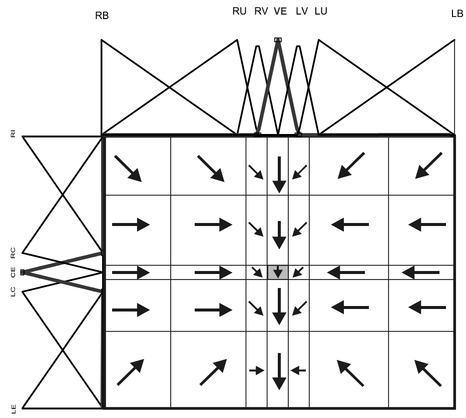


Fig. 4. Rule base of the two-input fuzzy supervisor.

TABLE I: Fuzzy Rules Defined for the Control Problem

Φ_c		Φ_t		x		θ	
NE	Negative	RB	Right below	LE	Left	NB	Negative Big
ZR	Zero	RU	Right Upper	LC	Left Center	NM	Negative Medium
PO	positive	RV	Right Vertical	CE	Center	NS	Negative Small
		VE	Vertical	RC	Right Center	ZE	Zero
		LV	Left Vertical	RI	Right	PS	Positive Small
		LU	Left Upper			PM	Positive Medium
		LB	Left Below			PB	Positive Big

Fig. 5. Through 8 shows the membership functions defined in MATLAB:

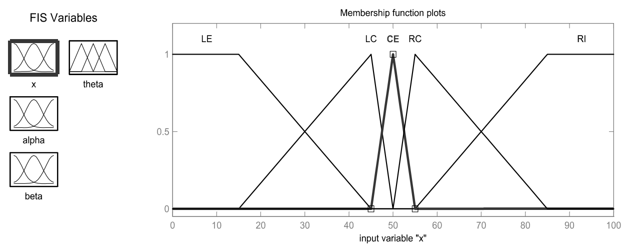


Fig. 5.membership functions for position of the trailer

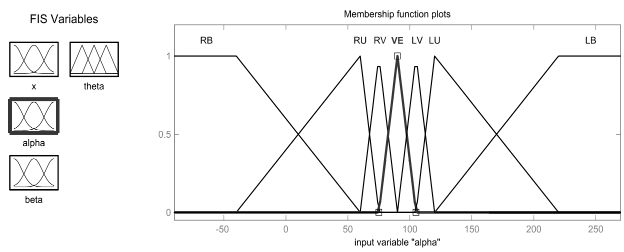


Fig. 6. membership functions for the angle $\alpha = \Phi_t$ (degrees)

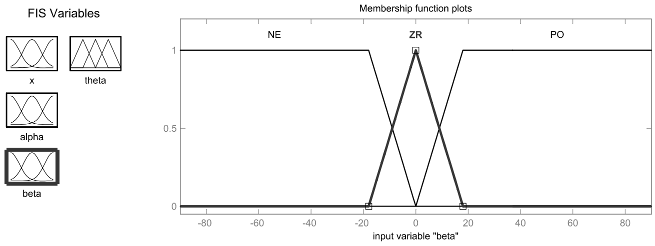


Fig. 7. Membership functions for the angle $\beta = \Phi_c$

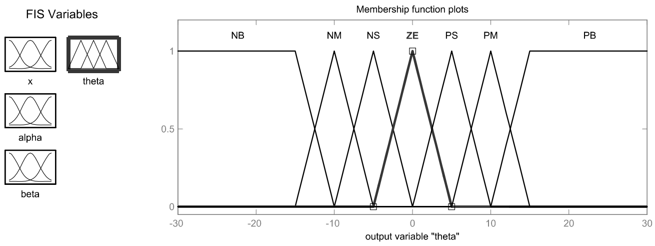


Fig. 8. Membership functions for the angle θ

Overall,105 fuzzy rules are defined as follows:

$x = LE$		Φ_t						
		RB	RU	RV	VE	LV	LU	LB
Φ_c	NE	PS	PS	PS	PS	PS	PB	PB
	ZR	PS	NS	NS	NS	NM	NM	NM
	PO	NS	NS	NM	NM	NB	NB	NB

$x = LC$		Φ_t						
		RB	RU	RV	VE	LV	LU	LB
Φ_c	NE	PM	PS	PS	PS	PS	PS	PS
	ZR	PM	ZE	NS	NM	NM	NB	NB
	PO	NS	NS	NS	NM	NM	NB	NB

$x = CE$		Φ_t						
		RB	RU	RV	VE	LV	LU	LB
Φ_c	NE	PM	PM	PS	ZE	PS	PS	PS
	ZR	PM	PM	PS	ZE	NS	NM	NM
	PO	NS	NS	NS	ZE	NS	NM	NM

$x = RC$		Φ_t						
		RB	RU	RV	VE	LV	LU	LB
Φ_c	NE	PB	PB	PM	PM	PS	PS	PS
	ZR	PB	PB	PM	PM	PS	ZE	NM
	PO	NS	NS	NS	NS	NS	NS	NM

$x = RI$		Φ_t						
		RB	RU	RV	VE	LV	LU	LB
Φ_c	NE	PB	PB	PB	PM	PM	PS	PS
	ZR	PM	PM	PM	PS	PS	PS	NS
	PO	NB	NB	NS	NS	NS	NS	NS

Fig. 9. Fuzzy rules defined for the control problem

The program will run until the trailer is parked at the desired dock or hits the walls in which case the program will stop running.

The105 fuzzy rules provided here successfully generate a trajectory for trailer movement from any initial state to the final state. The followings are the output of the program for some arbitrary initial states:

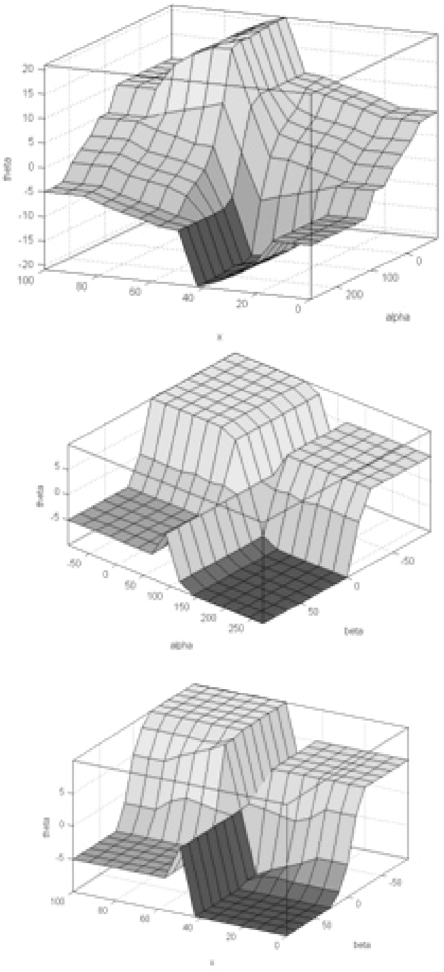


Fig. 10. Control surfaces for the fuzzy controller

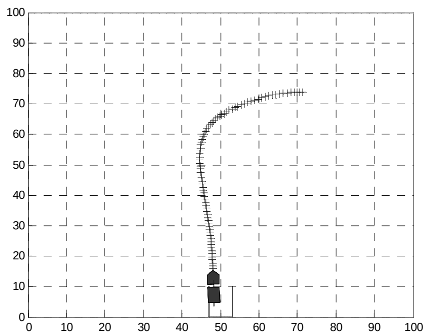


Fig. 11. Trajectories determined by fuzzy controller for different initial states.

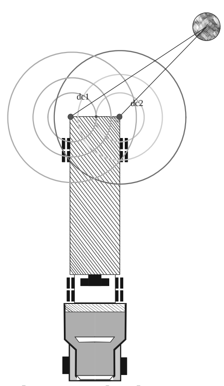


Fig. 12. Position sensors for detecting the distance and position of obstacles relative to the trailer position

IV. Design of Fuzzy Controller for Backward Movement Through Moving And Fixed Obstacles

The procedure used to detect the obstacles is explained in this section. Suppose that two position sensors are installed at the back of the trailer as shown in the figure below. The green circles represent the field of view for these sensors.

Left and right sensors are used to detect the position of obstacles relative to the trailer position.

Fig. 11 shows the procedure used for obstacle detection.

As shown in Fig. 11:

dc1<dc2 means the obstacle is seen at the left side if the trailer by the driver, and dc1>dc2 shows an obstacle at the right side (as seen by the driver).

The sensors are able to detect any obstacle on their field of view. In practice, sensors for distance measurement are used for such purpose.

The two sensors can detect the relative position of the obstacles (e.g. whether the obstacle is placed at the right side or left side). For improving the accuracy, in fact, 8 sensors are installed on the vehicle. Fig. 12 shows the position of these sensors [17]:

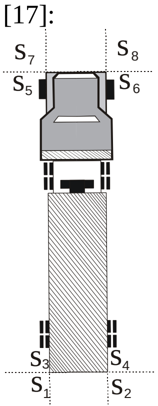


Fig. 13. Sensor positions on the trailer

In practice, only four sensors are activated in each step based on the relative position of the obstacle (e.g. four sensors are activated for right obstacles and four for left ones).

Let us denote the sensors as follows. S_1-S_2: back sensors placed at right and left side, respectively; S_3-S_4-S_5-S_6: sensors placed at the right and left sides of the trailer; and finally, S_7-S_8: sensors installed on the front of the trailer at right and left, respectively. These sensors measure the distances d_1 to d_8, respectively

V. Trailer Backward Movement Through Fixed and Moving Obstacles

If fixed obstacles are placed at the backward pathway of the trailer, the trailer must adapt itself with the constraints in order to reach the parking spot.

What happens in practical cases, however, is that moving obstacles are also present on the pathway and the trailer is required to take appropriate action while facing the obstacles whether fixed or moving.

In the automatic parking mode, the trailer not only should be able to identify the environment, but also should avoid the obstacle. In a dynamic model, moving obstacles (such as people or other objects) change the environment. In order to follow an identified path, the trailer should be equipped with some type of real time identification of its surrounding environment in order to meet the requests received from navigation system.

An intelligent method is proposed here for navigating the trailer in a dynamic environment using fuzzy logic. Such system also enables the trailer to avoid obstacles. In [17] a controller was used for finding the path through fixed obstacles; here, two separate fuzzy controllers are used as "target finder" and "obstacle avoider" which enable the trailer to avoid moving obstacles as well. While no obstacle is close to the trailer, the target finder determines the path toward the target (parking spot). As soon as an obstacle is detected, the obstacle avoider comes to act. In the proposed method, when an obstacle is faced (a situation which is called "emergency" here), the high-level controller determines the path in order to avoid obstacles. When the trailer is far enough from obstacle, the control action is reduced to low level. This procedure repeats until the trailer reaches the target. The overall procedure is based on the algorithm used for fixed obstacle case; however, few changes are made in the avoiding procedure.

Unlike other methods [17], in the method proposed here the single controller is replaced by two controllers at two levels: one controller acts at high-level as the supervisor, while the other controls the system at low level. In normal case, the low-level control generates the command signal and the supervisor has no role in the control process. However, the latter is activated in emergency, causing the former going back to inactive state. When the conditions are back to the normal state, the low-level controller becomes activated and the supervisor is inactive. Fig.13 shows the block diagram for the proposed control method.

Here, the target finder is defined as low-level controller, while the obstacle avoider acts as high-level controller or supervisor. As a result, when no obstacle is detected (normal conditions), the low-level controller directs the trailer toward the target.

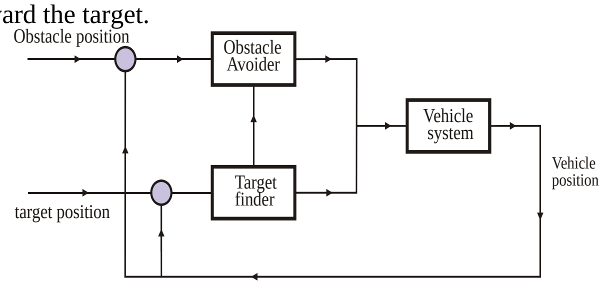


Fig. 14. Block diagram for the proposed control method

As soon as an obstacle is detected (emergency), the obstacle avoider comes to act in order to avoid collision with the obstacles. When the trailer is far enough from obstacle, the control action is reduced to low level. This procedure repeats until the trailer reaches the target.

A. Constraints

There are several constraints present in the problem facing which the trailer should adopt the appropriate decision in order to find the path toward parking spot.

1) Obstacle size

The size of obstacles on the pathway could be different:

- The obstacle may be big enough to cover the whole pathway toward the target and given the initial state, it is not possible to avoid the obstacle. In this case, the trailer must be stopped.

- The obstacle may be small enough to allow the trailer to run it over! In this case, controller must direct the trailer to run over the obstacle.
- The size of obstacle may be in a range that allows the trailer to pass it by changes in the direction and to make its way toward the parking spot.

2) *Position of obstacles*

The position of obstacles on the pathway is also of great importance, since the obstacles can:

- Be placed on the pathway in a way that do not provide the space enough for the passage of the trailer; in this case, it is not possible to avoid the obstacles.
- Be placed on the pathway in a way that allows the trailer to pass through them by changing its direction and to reach the target.

VI. Low-Level Control

As mentioned earlier, "target finder" is defined as low-level controller. The low-level controller is the same as the fuzzy controller used for parking in the normal conditions. Two mamdani fuzzy systems with two inputs and one output are employed as shown in Fig. 14. The first input is horizontal displacement, while the second input is the angle φ. The output is the angle θ.

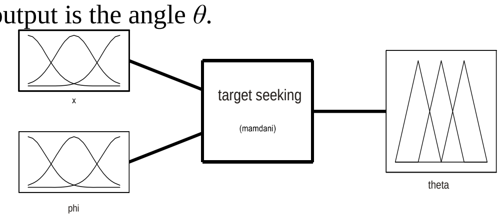


Fig. 15. fuzzy structure for low-level controller

The structure described above was studied in details.

VII. High-Level Controller (Supervisor)

The obstacle avoider is designed based on a three-input two-output mamdani fuzzy system. The inputs are direct distance between the trailer and the nearest obstacle, the angle formed by the sensor installed on the trailer front and the nearest obstacle, and the speed of the nearest obstacle relative to the trailer speed. The outputs are rotation angle with respect to the trailer axel and the trailer speed. Fig. 15 through 20 show the fuzzy structure, and input and output membership functions for the high-level controller.

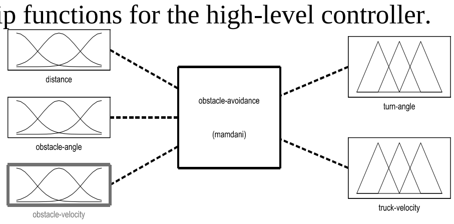


Fig. 16. High-level fuzzy system

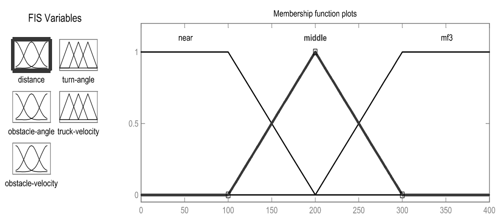


Fig. 17. The distance between the trailer and the nearest obstacle

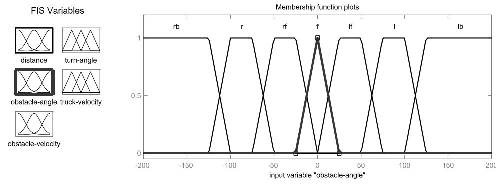


Fig. 18. The angle formed between the trailer and the nearest obstacle

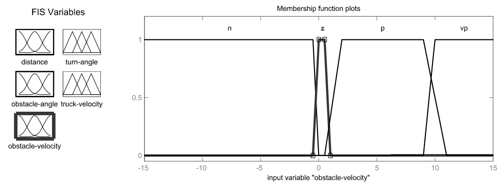


Fig. 19. Relative speed of the nearest obstacle with respect to the trailer

As shown in the figures above, membership functions are defined as follows:

Three membership functions *near, middle,* and *far* are defined for the first input to the fuzzy system (the distance between the trailer and the nearest obstacle) over the range [0 m, 6 m]

Seven membership functions *right –back (rb)*, *right (r), right-front (rf), front (f), left-front (lf), left (l),* and *left – back (lb)* for the second input to the fuzzy system (the angle formed between the trailer and the nearest obstacle), over the range [-180˚, 180˚]

Four membership functions *negative (n)* (for the case where the trailer moves away from obstacle), *zero (z)*, *positive (p)* (for the case where the trailer moves toward obstacle), and *very positive (vp)* for the third input to the fuzzy controller (the speed of obstacle relative to trailer speed).

And for supervisor's outputs:

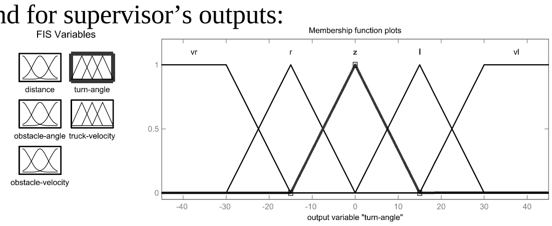


Fig. 20. The trailer rotation angle

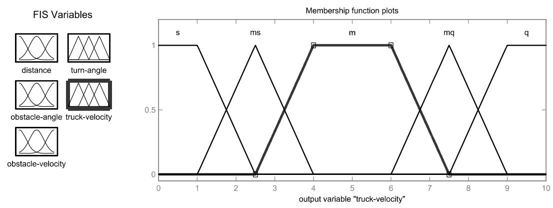


Fig. 21. Trailer speed

Five membership functions *very right (vr), right (r), straight (z),* left *(l),* and *very left (vl)* for the first output from the fuzzy system (trailer rotation angle) over the range [-45˚, 45˚]

Five membership functions *slow (s), middle slow (ms), middle (m),* middle *quick (mq),* and *quick (q)* for the second output from the controller (trailer speed) over the range [0 cm/s, 10 cm/s]

If the trailer is *far* from the nearest obstacle in front of the trailer (farther than 6 m), or the trailer is *very near* to the target (nearer than 1m), the trailer will be controlled by the low-level controller. Otherwise, when the trailer is *near* to obstacle, the supervisor comes to act to avoid the obstacles, change the direction, and reduce the speed to pass the obstacle. Once the obstacle is passed by, the speed increases again.

Fig. 21 describes the angle and distance between the trailer and the obstacle.

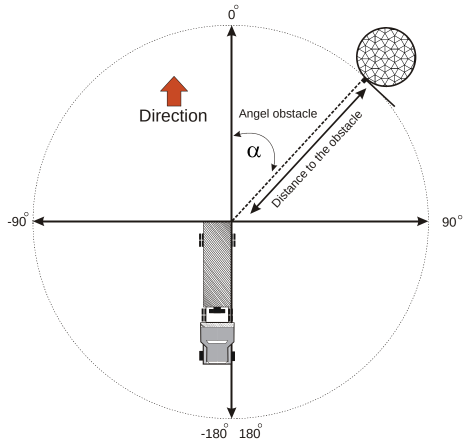


Fig. 22. Description of the angle and distance between the trailer and the obstacle

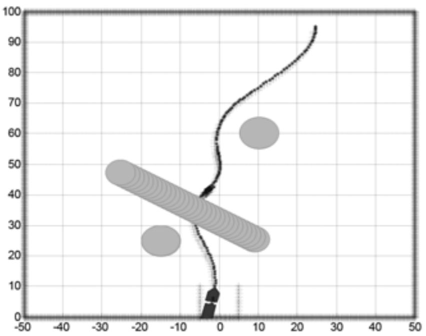


Fig. 23. Trailer movement through two fixed obstacles with different normal sizes and one moving obstacle

VIII. Simulation and Results

To test the proposed navigation method, simulation is performed using MATLAB in different conditions for the position of the trailer and moving and fixed obstacles. We tried to improve the trailer movement through changing or weighting the fuzzy rules.

Due to the low noise in the installed sensors in comparison to the minimum range of control inputs (maximum of 1 to 2 cm compared to 1 m), there is no need to consider the measurement noise while modeling the controller.

In the following lines, the movement of the trailer while facing obstacles moving with constant velocity is reviewed. The sign (*) is used to denote the movement and speed of the trailer. The space between the stars represents the changes in the trailer speed.

The proposed algorithm is applied for a situation consisting of two fixed obstacles and one moving with constant speed (however, there is no limitation on the number of fixed and moving obstacles).

The algorithm may be applied for a greater number of obstacles moving with different velocities.

As it can be seen, the fuzzy controller operates well in variety of conditions.

The following shows the program results for different conditions. Number of moving and fixed can be increased in the simulation.

Fig. 23 shows the results obtained from MATLAB simulation.

IX. Conclusion

Using search table method, an appropriate fuzzy controller was designed to find a trajectory for parking a trailer on a pathway with no obstacle. Then, a number of fixed and moving obstacles were added on the path. Based on its adaptive performance, the fuzzy controller finds an appropriate movement path through the fixed and moving obstacles.

Simulations show a desired smooth movement of the trailer. It may be suggested then that if the system inputs are measured with small errors and applied to the fuzzy controller, the proposed method can be applied in practice.

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