Behavior Integration via MS-ANFIS for Realistic Navigation of Multisensor Autonomous Vehicle

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Abstract-In the recent works either the obstacle avoidance of robot in the 2-D unconstrained environment or the wall following behavior of mobile robot in constrained motion has been discussed. In some of them target alignment behavior has been discussed. Also the integration of some but not sufficient behaviors have been discussed in some research works. But all of the behaviors have not yet been integrated. So the problem of designing the optimal controller to perform on all conditions has been a major attraction for the designers and scientists. In this paper the effort has been made to take into account various types of factors like the limitations of suspension system and the physics laws like friction, motion, momentum, centrifugal and centripetal force, Tilting avoidance due to turning Traffic rules, Traffic congestion, signals, overtaking, passing high speed vehicle, speed breakers, single lane road and varying width road, final target alignment in no-road or broad area, limited time to reach the target etc. during the design of the controller. Designing the optimal controller with all the behaviors integrated for proper motion planning in all types of environments needs much treatment. This work mainly deals with designing of the unified controller for optimal navigation of a multisensor mobile robot in real-environment by applying fuzzy rule simplification technique (FRST) via multi-stage adaptive neuro-fuzzy inference system (MS-ANFIS).The Proportional and Derivative (PD) control has also been used in connection with some ANFIS stages for this work.

Index Terms- FRST, Fuzzy Rule Simplification Technique, MS-ANFIS, Multistage ANFIS, Multisensor Mobile Robot Optimal Navigation

INTRODUCTION

Modern research in robotics aims to build a self decisive, autonomous and intelligent robot, which can plan its motion in a dynamic environment. A successful use of an autonomous mobile robot depends on its controller. Thus, to generate optimal collision-free path within two side boundaries of a car-like robot during its navigation among several moving obstacles, it should have proper motion planning as well as obstacle avoidance schemes. The obstacle avoidance in unconstrained two dimensional grounds [1],[5],[6],[7] has the drawback that it does not consider the both sides of road because it is necessary to take into account the real environment. The wall following behavior [2], [3] describes the navigation of robotic vehicle in constrained environment only. In this paper we have made effort to design the optimal controller which integrates many behaviors related with real road environment. These behaviors are target alignment, Lane speed, traffic signals, variation of the width of the road, speed breaker, obstacle avoidance, tilting due to excessive turning, wall (divider) following, limited time to reach the target, traffic rules. In this paper various image processing methods have been implemented to sense the sides of roads and the distance of both sides with respect to left and right ends of the robotic vehicle. The concept of template matching has been used to sense the colors of the traffic signal lights. The height of the breaker is also found by processing of the camera image. Based on the concept of multistage fuzzy controller [9] we have introduced here Multistage Adaptive Neuro Fuzzy Inference System (MS-ANFIS) which will have the trainable nature and characteristics like MSFC. For fuzzy rule base reduction (FRST) for step by step getting a number of outputs depending on large no of inputs with reduced complexity due to huge rule base. In the present work the efforts have been done to solve the problem of navigation of a mobile robot within boundaries and real environment in the optimal collision-free path by using multistage adaptive neurofuzzy inference system. An initial effort for this approach (MSANFIS) has been discussed in [16].

FUZZY RULE SIMPLIFICATION TECHNIQUE

We have taken the following assumptions for the basis of Fuzzy Rule Simplification Technique to be used in robotic navigation.

1. In the Robotic vehicles the sensors are incorporated for angle and velocity control.
2. The projections of all the oblique sensors in the direction normal to the moving axis of the robot and sensors in the direction normal to the moving axis of the robot will effect on the angle.
3. The effect of left side sensors will be opposed by the effect of the right side sensors.
4. The projections of all the sensors in the moving axis will effect on the velocity.
5. The sensors in the back side will oppose the effect due to the front side sensors.

6. The effect of all the factors responsible for speed will be taken separately and then the optimal speed will be the minimum of all the speeds.
7. The optimal angle will be found only after the effects of all the behaviors like target alignment, tilting avoidance due to turning obstacle avoidance, wall (divider) following, overtaking, passing, opposite side vehicle collision avoidance have been taken into account for angle.

Till now we have been well introduced by the various types of methods. We have studied about the rule reduction with simple pivoted QR(P-QR) decomposition [8], singular value decomposition (SVD) [10], similarity driven rule base simplification [11], SVD-QR [12]. Linear fuzzy rule interpolation proposed in [13], linear matrix inversion [14]. Now we discuss the procedure Fuzzy Rule Simplification by successive extraction of identical MFs of any input (to be fed in next stage) for the simplification of rule base.

A. First arrange the fuzzy rules with ***n*** input variables with ***m*** linguistic terms each in which the MF being extracted for the next stage contains the same linguistic terms.
B. Then arrange the combination of ***n-1*** inputs for each linguistic term of the extractive input.
C. There will be a common set of combination of **n-1** inputs for particular linguistic term of the output variable if decision space is continuous and non empty.
D. Define an intermediate output ***I***.
E. For each combination of ***n-1*** inputs assign a specific linguistic value of intermediate output. Let there are 4 MFs in intermediate output. Assume that,
F. Now define the combination of particular linguistic values of intermediate output and the extracted output with a particular linguistic term of the output variable.
G. In this way we get two stages for the Rule base: ***n***th and ***n-1***th stage. In ***n***th stage the result of interaction of ***n***th and intermediate output is found and another stage.
H. We repeat the algorithm 1 to 6 until we get all stages with two input and one output

Now because the intermediate output has defuzzified value so we can fuzzify intermediate output in any number of linguistic terms (MF) during feeding it to the next stage according to our convenience. So we see that we can reduce one stage with huge rule base to several stages of reduced rule base as above.

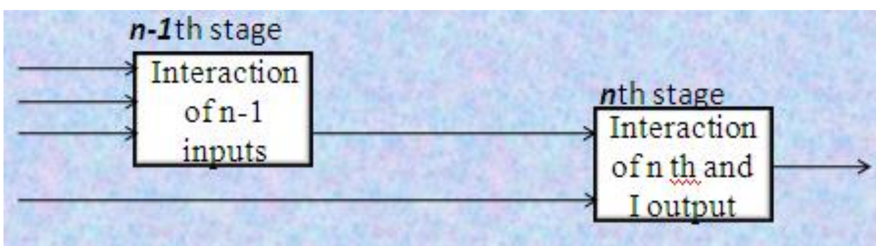


Figure4.1 Conversion of one stage with complex rule base with the two successive stages having reduced complexity

The final output is same value as found from the previous rule base. Though the intermediate output can also be taken as output for control purpose. In this way we will be able to successively reduce the huge rule base complexity and treating each factor separately and then comparing with other factor will turn into ease of designing the optimal controller which will be able perform in all types environment. By this point the necessity of introducing the concept of MSANFIS becomes of much importance. The MS-ANFIS performs the process of fuzzy rule base simplification via extraction of rules with identical MFs of input to be separated for the next stage.

MS-ANFIS

A. Structure of MS-ANFIS

In commonplace fuzzy controllers, usually the error and its derivative are frequently used as inputs to the rule base. There is a rule base (may be several) that produces control signals based on logical algorithms. In these methods, number of error inputs increases considerably if the system has more than one output. Together with above, the inclusion of large number of sensors for excellent control and for precision control inclusion of large no of membership functions per sensor oftentimes leads to a very large and huge rule base which is undesirable for controlling tasks particularly in real time applications. Not only this, but also any modification or readjustment of such a rule base will be really a tiresome and time consuming task. To remedy this problem, an innovative method had been established [9] that while it uses all error signals for control, dimension increment and related problems are subdued well.

Conformity on human's experience and reasonable structure of multistage control technique has motivated some researchers to devise and implement controllers based this algorithm [15].Based on Multistage fuzzy controllers [9] we have designed the Multistage Adaptive neurofuzzy controller. MSANFIS is different from MANFIS [24].In contrast with usual controllers that produce control signals in one stage, they produce the control signals in several stages together with the capability of learning as a neural network because of adaptive behavior of weights and the inference mechanism like FIS. Multistage Adaptive Neuro Fuzzy control is comprised of many stages of ANFIS has two renowned structures named skew-tree andternary-tree.Figure.2 and 3 schematically represent these structures.

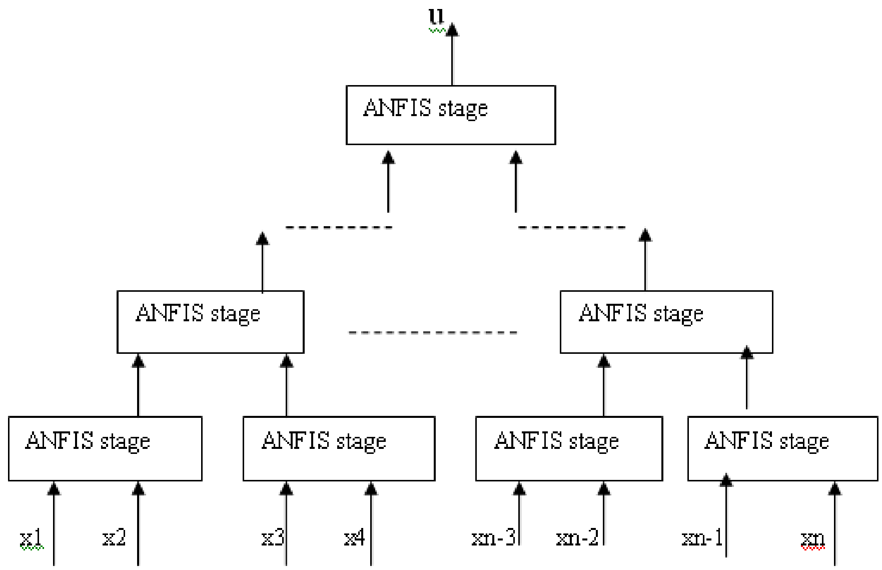


Figure 2: Skew-tree structure of MS-ANFIS

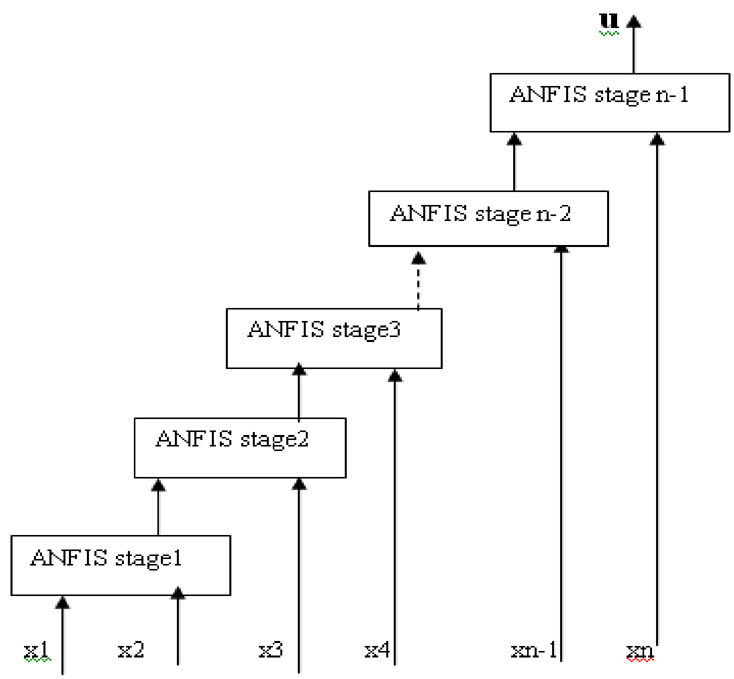


Figure 3: ternary-tree structure of MS-ANFIS

The number of rules and stages are equal in two structures, but logic of producing control signals is thoroughly different. There is a parallel mood in the ternary-tree structure; it means, some stages can be done and computed concurrently. In contrast, in skew-tree structure, each stage is dependent to outputs of former stages, so parallel calculation is not possible. While it seems that the ternary-tree structure is faster than the skew-tree structure, in most cases, skew-tree structure has more conformity on human's knowledge and experiences in sense of control [9]. Which structure is used is determined based on the underlying system and controlling goals. Next section presents the proposed adaptive neuro fuzzy controller using this structure and human's experiences together with the learning capability like neurons in human brain.

Based on skew-tree structure and considering two inputs for every stage, number of the stage, should be such that the total inputs equal the inputs required in the conventional fuzzy controllers, and the number of parallel output stages should be such that total out puts including one output per combination (one for speed control and other for angle control) is equal to the total outputs.

In the technique for fuzzy rule simplification we first make an ANFIS stage having two inputs and the output due to the first two inputs is calculated using fuzzification, inference and defuzzification depending on the input membership function and membership grades. This intermediate output is then given as input in the next ANFIS stage and depending on the value of intermediate output and the value of third input; the next intermediate output is obtained. May be any of the intermediate outputs can be used as one of final outputs. let the output 1 depends on the inputs 1,2,3 and 4 and also the output 2 depends on the input 1,2 and 3 then there will be two set of parallel ternary structures. In each set one of the outputs are calculated.

B. Behavior of MS-ANFIS

The behavior of the MS-ANFIS used as desirable component in FRST is like the humanoid thinking characteristics. Let the driver is driving the vehicle then he will lower the speed for the condition when the obstacles have come near. The human acts more for the factor which is more effective for example one obstacle at left is at 2m and another in right at 5m then he will take the speed lowering action for taking into mind the nearer obstacle i.e. at 2m. Now take the angle, the driver at first avoids the left obstacle and then he moving forward turns left to avoid right obstacle. His action is in two stages. So it contains two stage behaviors. The number of sensors and number of behaviors to be incorporated increases the number of stages. Generally the operator or driver does not know that exactly in how distance what the speed should be and angle value should be, but he knows that if the vehicle is collapsing at left then turns to right and if collapsing at right then turn to left if to if he turns both to avoid collapse but the collapse is further near to happen then he lowers the speed. This type of behavior is contained by MS-ANFIS. Multistage ANFIS has flexibility to design the controller with large number of sensors and large number of behaviors to be included for optimal control in real environment with considerably reduced complexity in designing the controller. Including all above the MSANFIS is also having the trainable behavior. Any of the stages can be trained to give desired performance. If there is some discrepancy in the desired (practical) performance then we can further adjust the scaling factors of the related FIS stage.

ASSUMPTION IN PRESENT WORK

In our work the following assumptions have been taken into account as seen happening in the real environment.

1. The speed limit has been taken maximum 60 km/hr. This is safe navigation speed.
2. Laser sensors are used for obstacles having shape. The maximum sensing ranges of the laser sensors 30 meters. For other the camera is used like for road side sensing.
3. The FIS range for sensor distance is taken 60 meters to avoid error due to overloading. The sensing range of Laser sensors is taken to be 30 meter.
4. Maximum steering turn angle is -45 to +45 degree.
5. The vehicle has no overhang after the rear wheel. The vehicle width is taken 1.5m, while the mirror projections are 0.25m both sides.
6. The standard clearance crosswise is desired at 0.75m from surfaces of both sides. The clearance less than 0.75 will reduce the speed. At 0.25 the speed will be zero. The absolute clearance of 0.5m is desired to make safe all the outwards projecting accessories like mirrors etc.
7. The front distance (also axial projection of oblique sensors) will reduce the speed if it is less than 30 meters and be zero at the distance of 1.25 m. further reduction of front clearance will reverse the speed (-ve) and max negative speed is -7 km/hr when the clearance is 0.5 m.. The acceleration of starting and retardation at stopping is taken $4.63 m/sec^2$.
8. The vehicles are following the traffic rules always but even in case of some randomness also this controller will perform satisfactorily.
9. The target distance is the distance by the road, not by the distance given by Radio Frequency Sensor. RFS distance and RFS angle are the absolute distance and angle of the
10. Until all the obstacles have not been crossed the speed remains within safe limit and as soon as the obstacles clearance increases the speed itself increases if target is distant.
11. When the target has been reached the controller reduces speed to zero and after this, the distance travelled is zero.
12. The vehicle will make effort towards turning to the target side but its turning will be reduced by the positions of obstacles in proximity.
13. According to the Indian Traffic Rules the vehicle will always follow the left lane and overtake from right side, will pass to the right side and remain left to the divider and give the side from right side to the vehicle coming from front.
14. The robotic vehicle will run on fixed speed at fixed distance from divider. If speed is lowered it will turn to left limited by obstacles at left. If speed is increased then the vehicle will start to move towards the divider.
15. It is not necessary that everywhere in the road the masonry dividers or Zebra dividers are present. So we have used the camera

sensors which will find the width of the road and the location of divider based on the gray level. The image from camera will be subject to further image processing for edge detection of the road (presently based on vanishing point detection[17]) and then these will be fed to wall following (or divider following subsystem)

16. Various other factors have been introduced for development of controller breaker flatness factor, target alignment factor, wall following factor.

The figure below depicts the sensor locations for optimal navigation. M means middle 30 means 30 degree, 0 means zero degree. F means front, B means back, C means camera, L means left, R means right, for example FR90 means the sensor at left 90 degree in the front side.

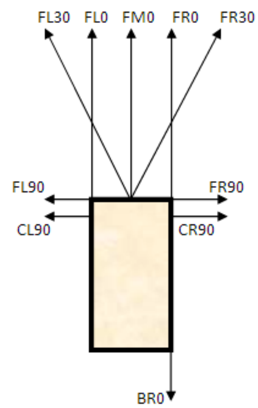


Figure 4.the sensor locations in the robotic vehicle

CONTROLLER DESIGN

During the design of controller we havedesigned the following controller structure for simulation for integrating the behaviors for speed and angle

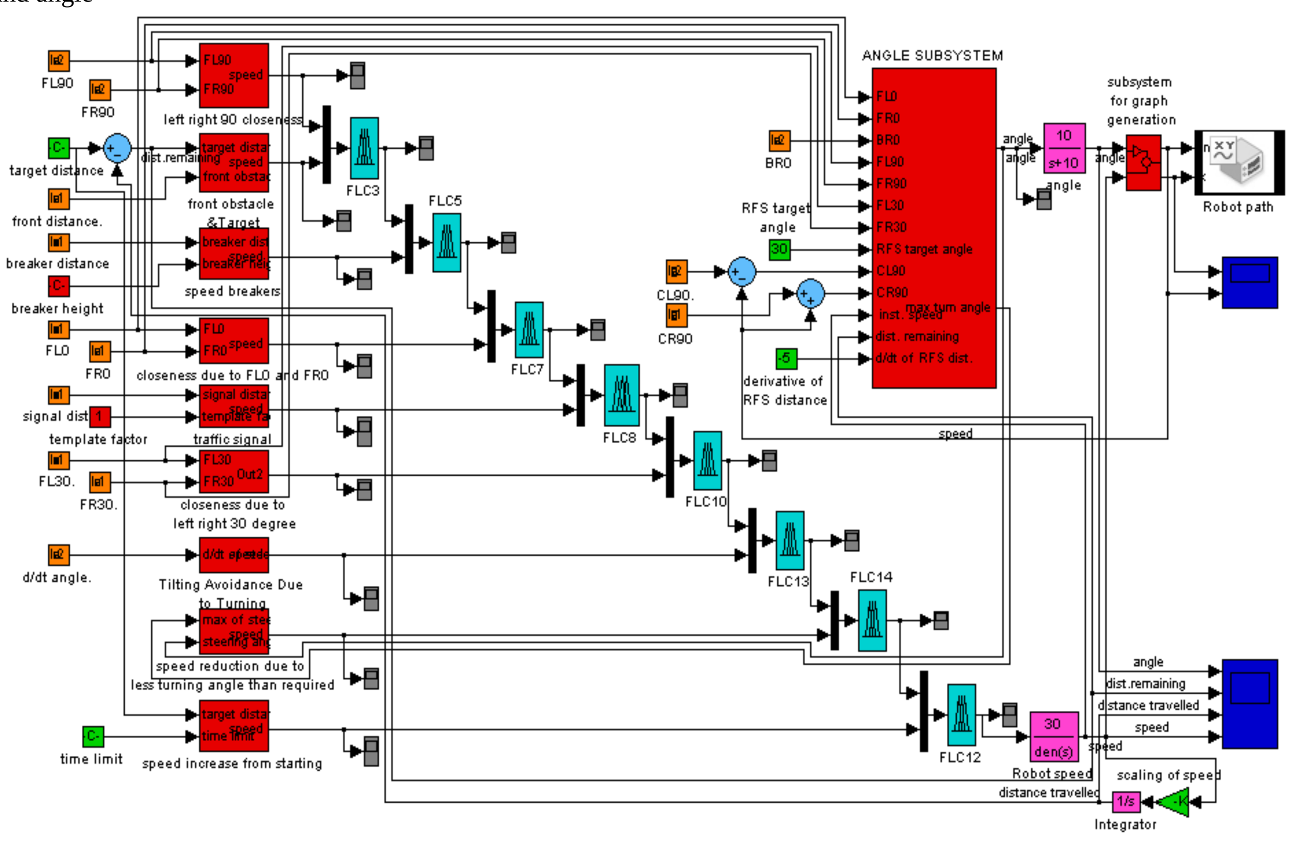


Figure5. The controller design

The angle subsystem shown inside the above controller is shown in the figure below.

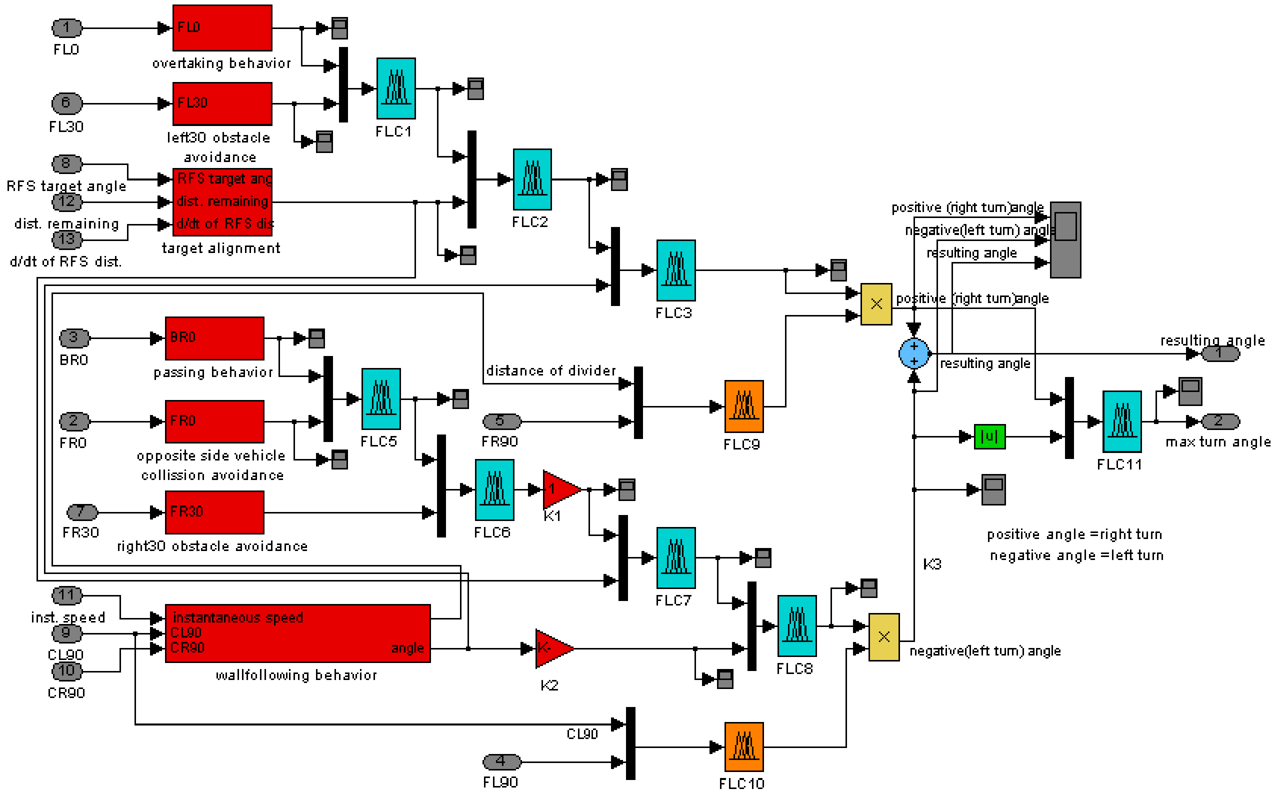


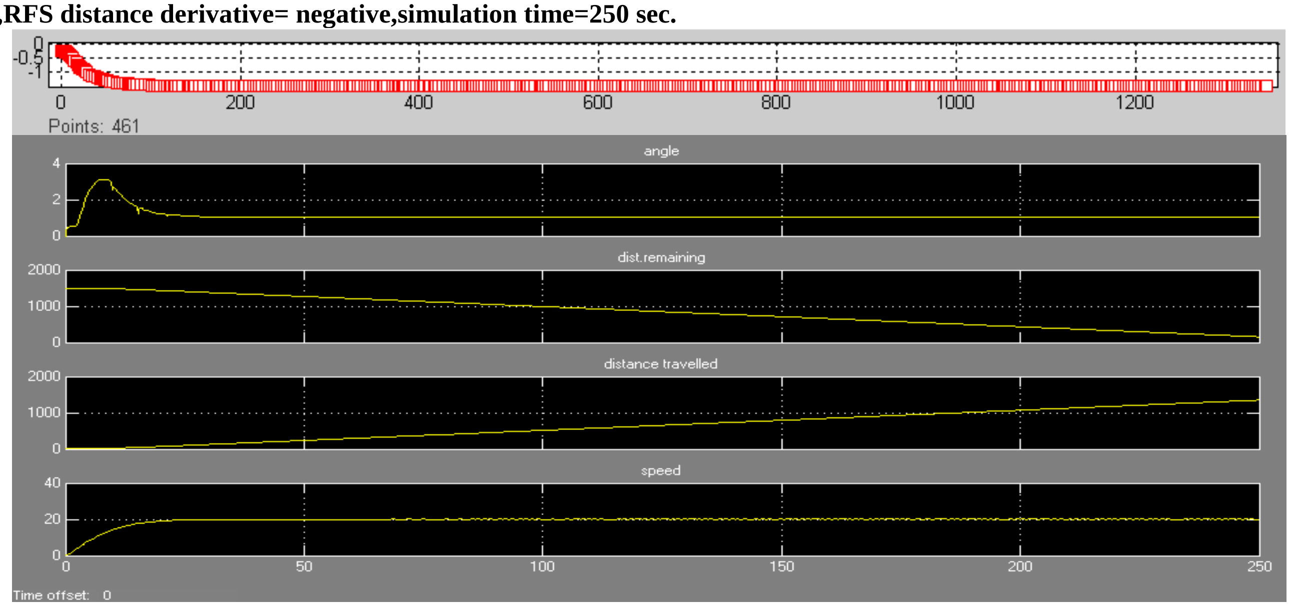
Figure 6. Angle subsystem of the complete controller

It is clear from above figures that the controller structure uses the MSANFIS containing mostly the ternary-tree structure, though at some places the skew–tree or the combination of both structures have been used.

SIMULATION RESULTS

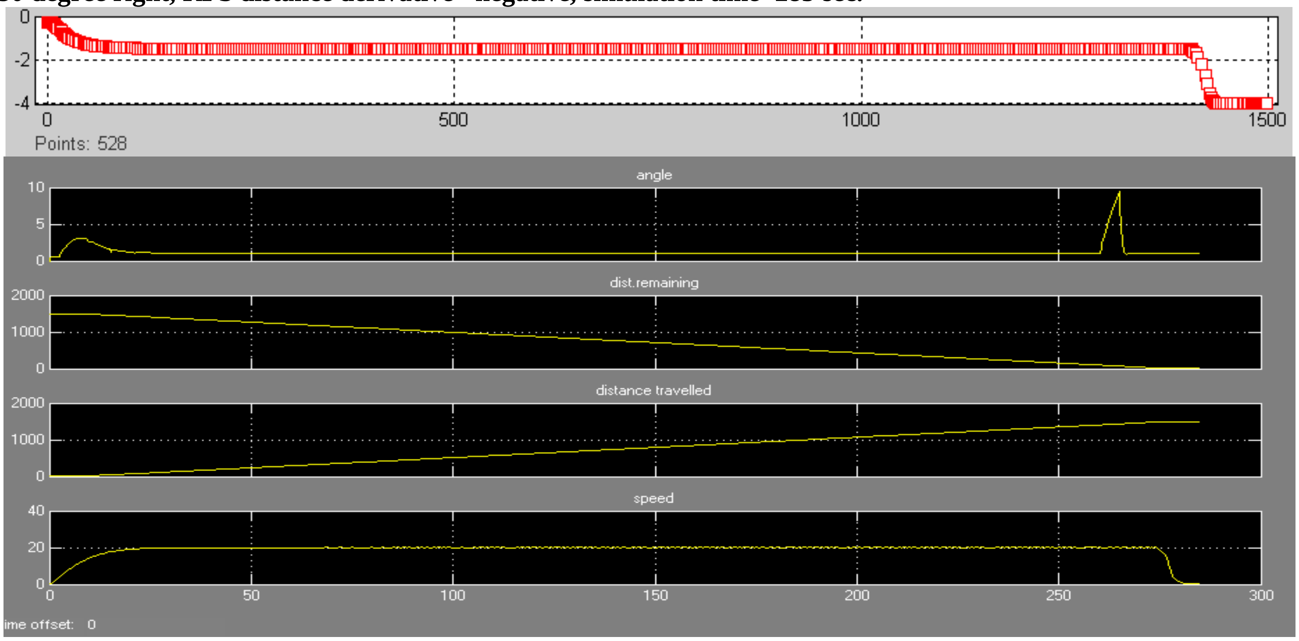
The simulation has been run on a MATLAB 7.6.0 (R2008) and PC with Microsoft XP, Pentium dual core CPU, E5400@ 2.70 GHz, 0.99 GB RAM for various conditions .

CASE 1: when no other factors are present, speed =20km/hr,road width =10 meter,target distance=1500 meter,target angle=0 degree,RFS distance derivative= negative,simulation time=250 sec.



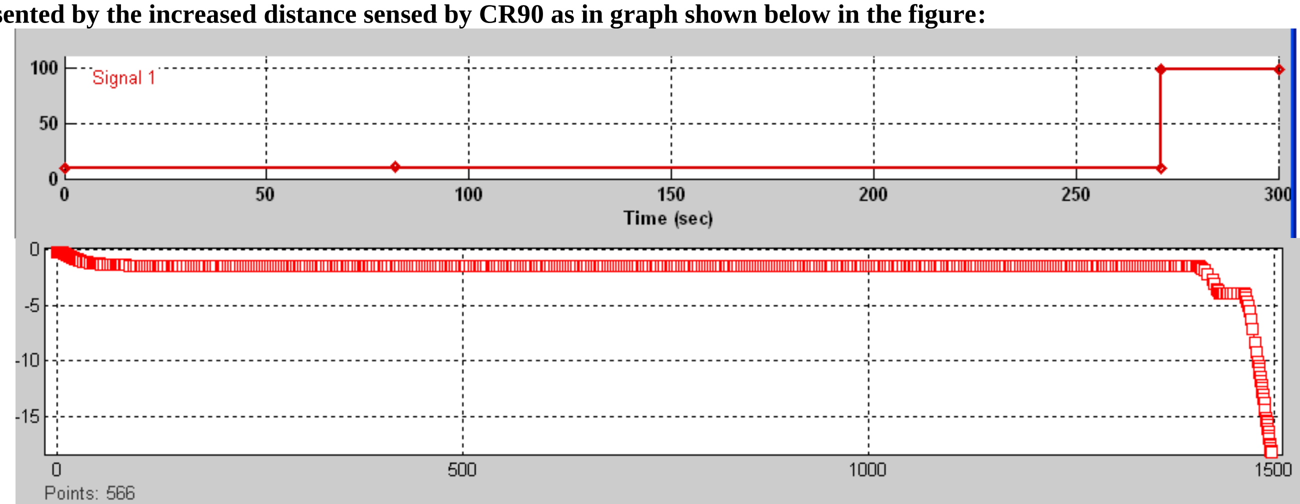
Explanation 1: This represents that the speed is increasing from starting and at speed of 20km/hr it takes a distance of 1.5 meter from left side of road after travelling 150 meter.

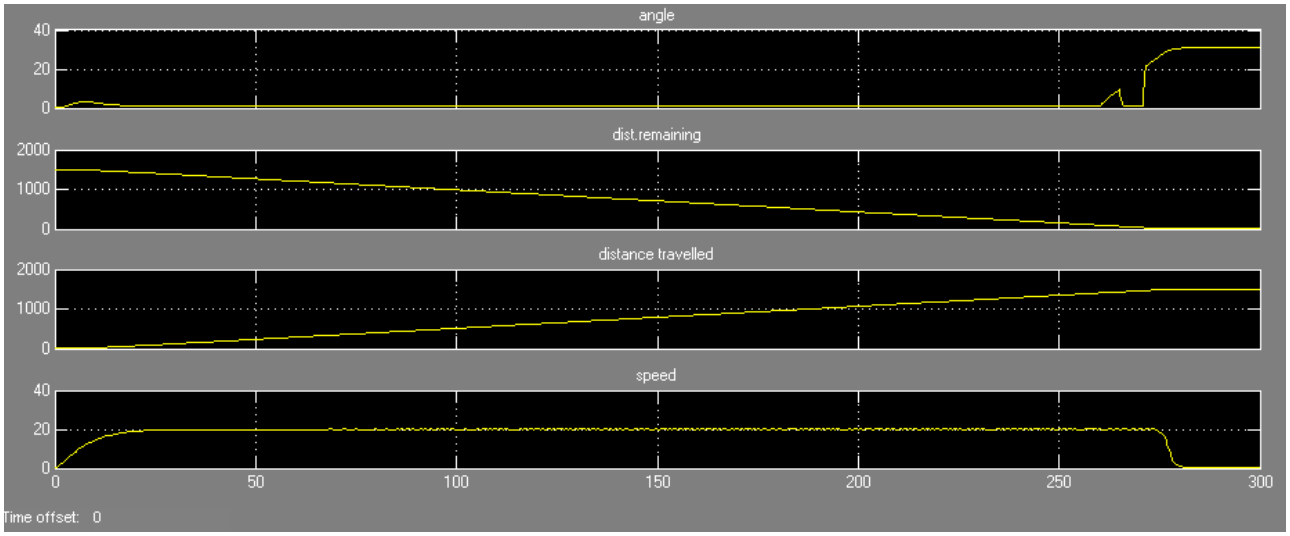
CASE 2: when no other factors are present, input speed =20km/hr,road width =10 meter,target distance=1500 meter,target angle=30 degree right, RFS distance derivative= negative, simulation time=285 sec.



Explanation 2: The vehicle starts to align towards right when reaching within 100 meters from target but due to presence of the divider it could only travel towards target in right 30 degree until the divider is close in right to the vehicle. When the divider is close the vehicle starts moving parallel to the divider but speed is decreased to zero. Had the square or right turning road been present the vehicle would have moved further towards target. This we will see in next result.

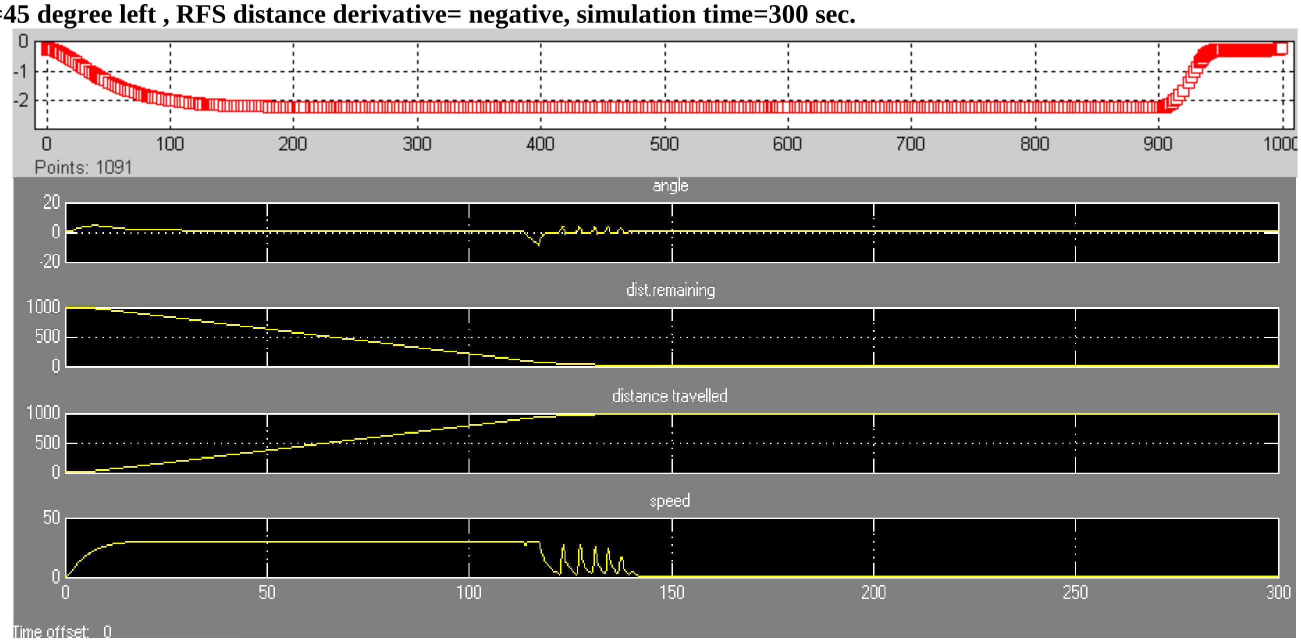
CASE 3: Square present near the target , input speed =20km/hr.,road width =10 meter,target distance=1500 meter,target angle= 30 degree right , RFS distance derivative= negative, simulation time=300 sec. The square (absence of divider) is represented by the increased distance sensed by CR90 as in graph shown below in the figure:





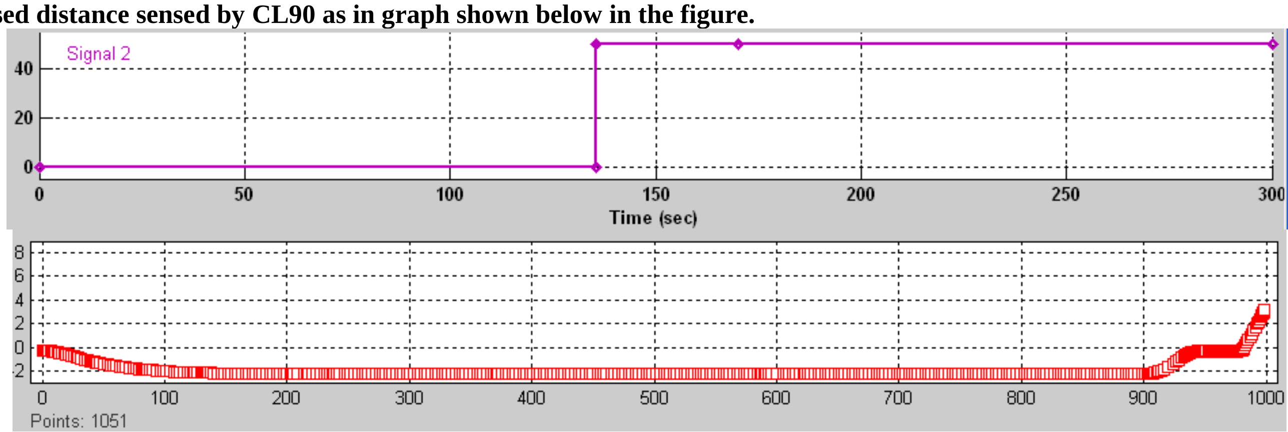
Explanation 3: this result describes that the vehicle has aligned towards the target until the divider is close. When the divider is close then the vehicle moves parallel to the divider. As soon as the square is reached the vehicle aligns target very fast.

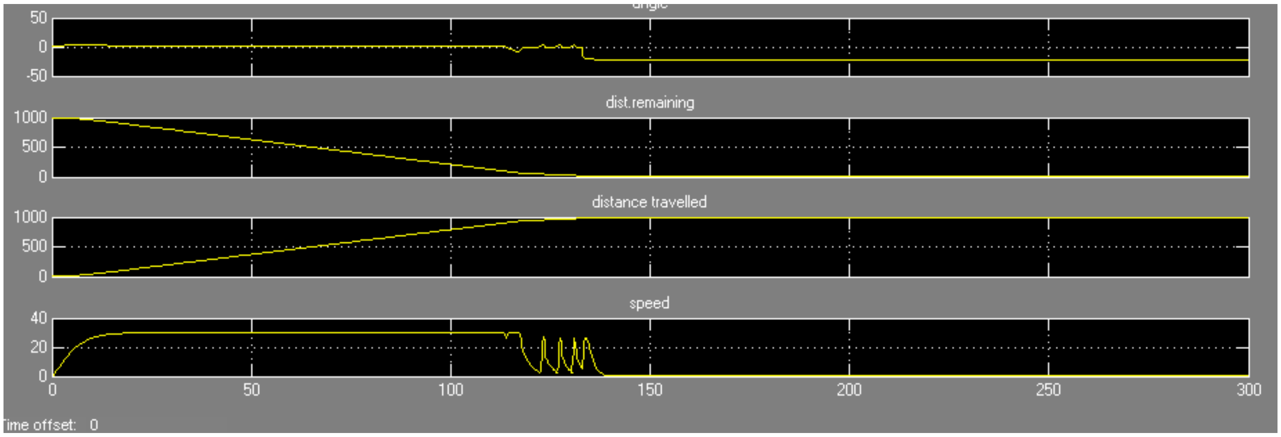
CASE 4: when no other factors are present , input speed =30km/hr.,road width =10 meter,target distance=1000 meter,target angle=45 degree left , RFS distance derivative= negative, simulation time=300 sec.



Explanation 4: this result describes that the vehicle has aligned towards the target at 45 degree left until the left side of the road is close. When the side is close, the vehicle moves parallel to the side. The speed is very low due to closeness of side.

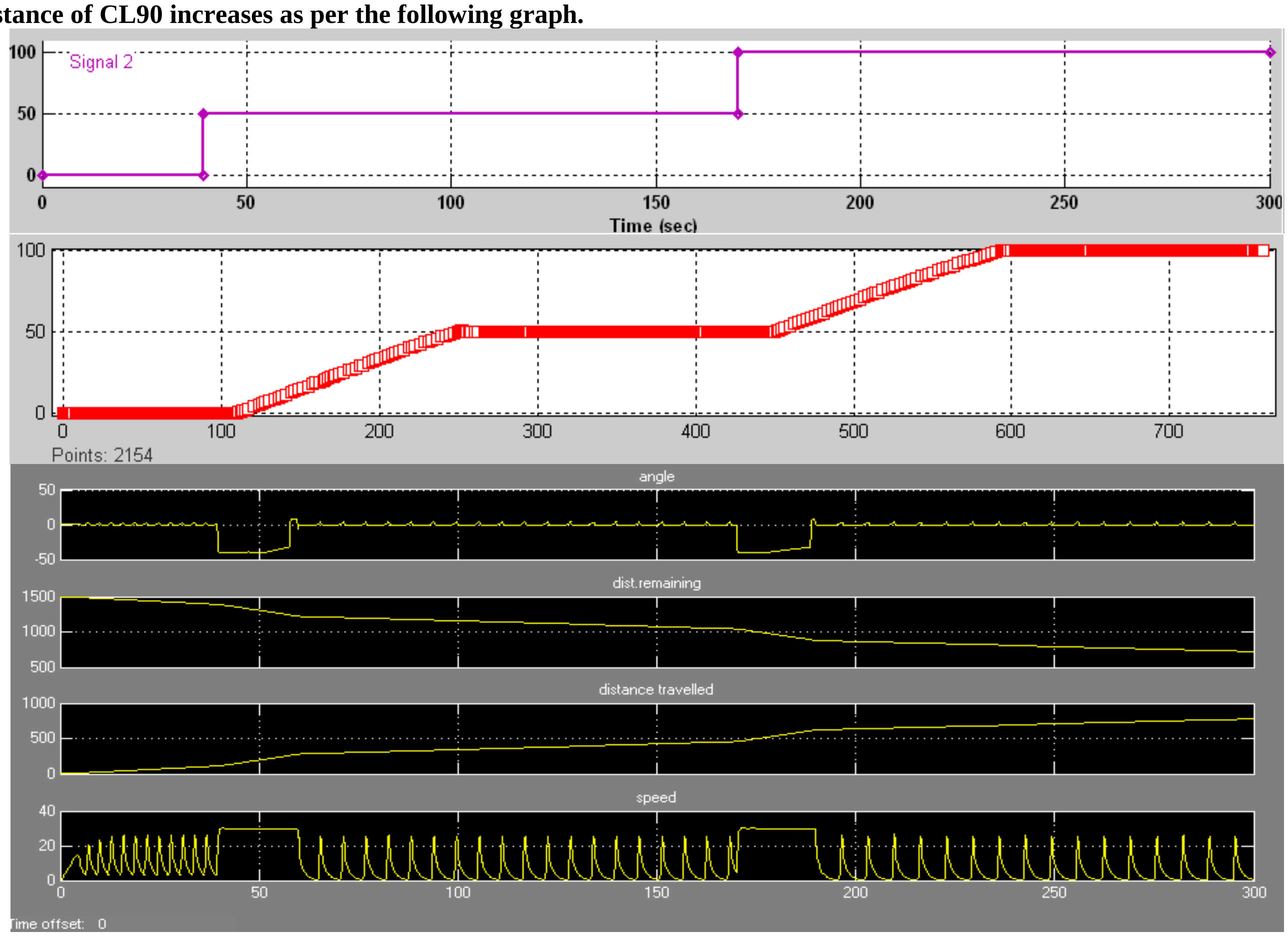
CASE 5: Square present near target , input speed =30km/hr.,road width =10 meter,target distance=1000 meter,target angle=45 degree left , RFS distance derivative= negative, simulation time=300 sec. The square (absence of left side) is represented by the increased distance sensed by CL90 as in graph shown below in the figure.





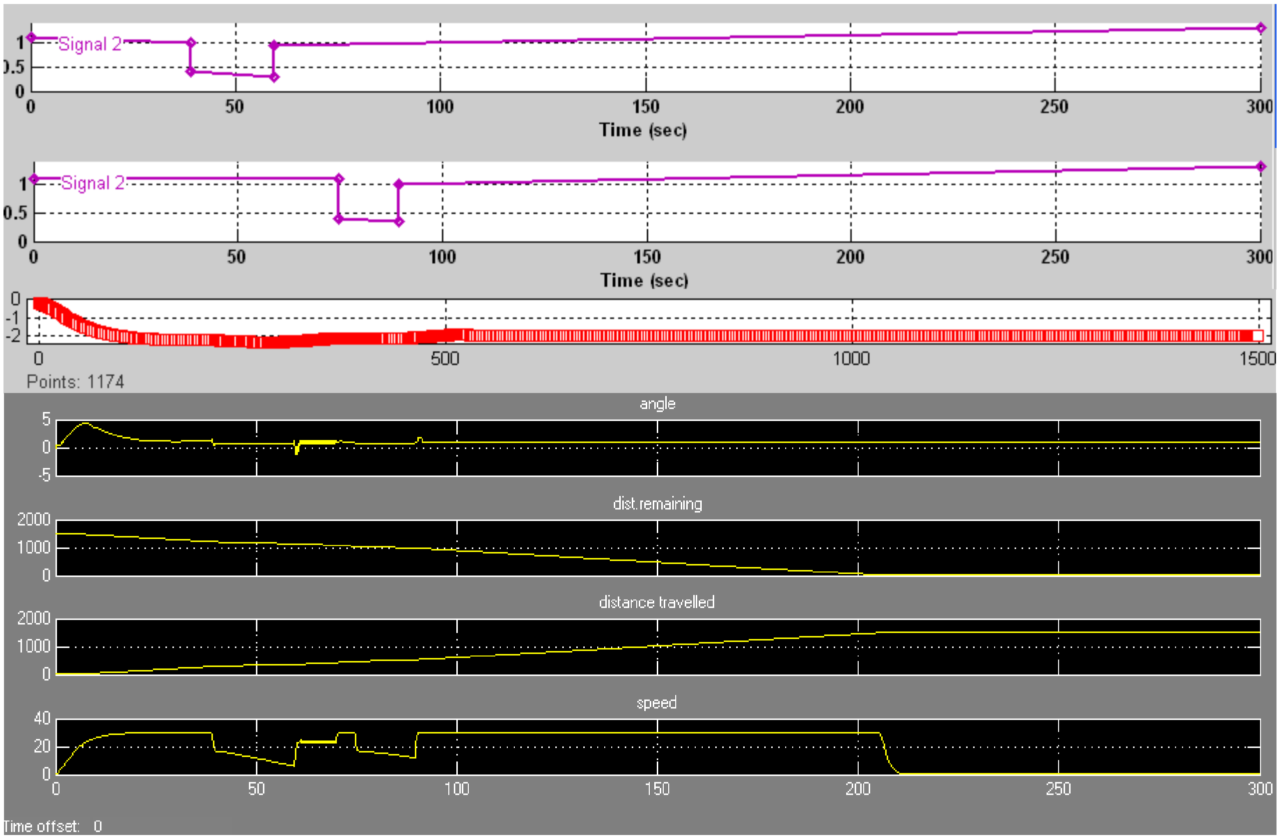
Explanation 5: this result describes that the vehicle has aligned towards the target when it is at 45 degree left and within 100 m distance. It aligns until the left side of the road is close. When the side is close, the vehicle moves parallel to the side. The speed is very low due to closeness of side. As soon as the square is reached the vehicle aligns target very fast.

CASE 6: Space to turn left available after a small distance of travel target , input speed =30km/hr.,road width =10 meter initially ,target distance=1500 meter,target angle=40 degree left , RFS distance derivative= Positive, simulation time=300 sec. The distance of CL90 increases as per the following graph.



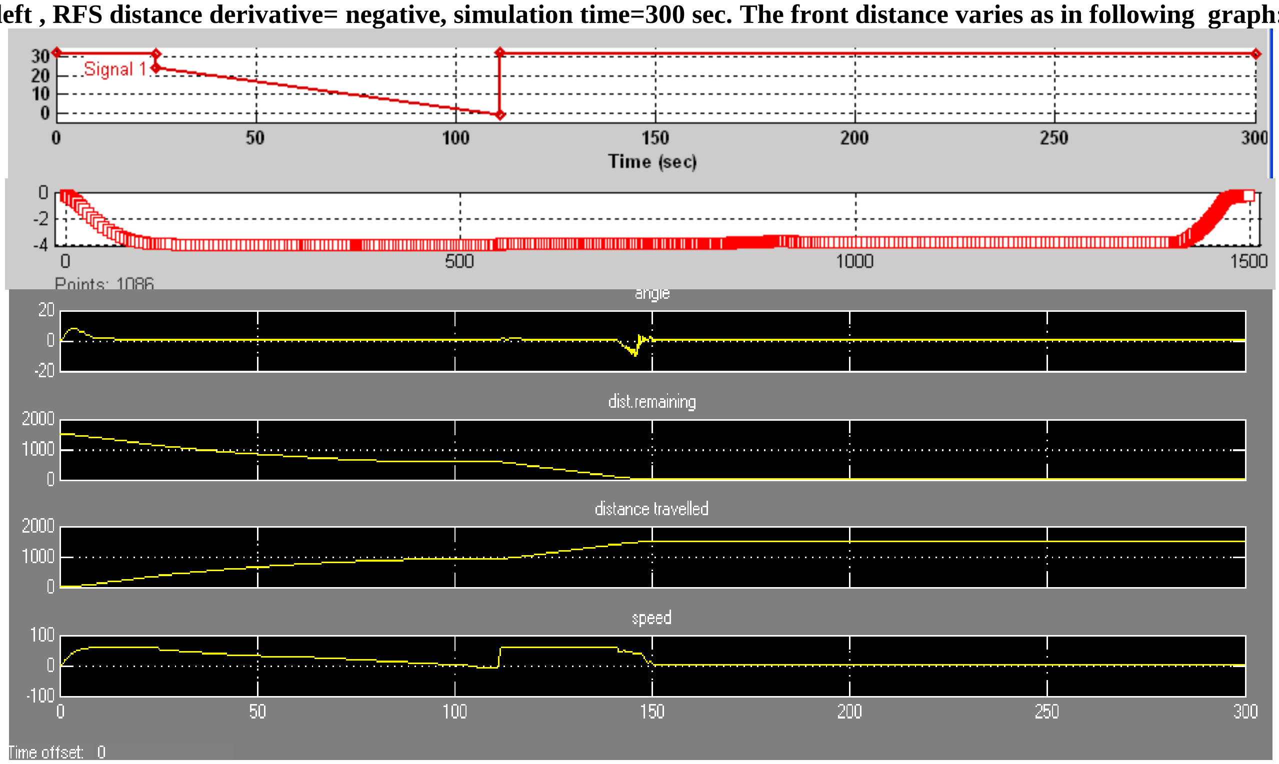
Explanation 6: This result describes that the vehicle has aligned towards the target at 40 degree left until the left side of the road is close and RFS derivative is positive. The meaning of RFS positive is that if the vehicle does not align towards the target it will slowly be moving away to the target. When the side is close, the vehicle moves parallel to the side. As soon as the space available in the left, the vehicle aligns towards target again. This process continues though at very low speed but due to side close to vehicle creeps towards the target.

CASE 7: Left and right 90 degree closeness , input speed =30km/hr.,road width =10 meter,target distance=1500 meter,target angle=0 degree , RFS distance derivative= negative, simulation time=300 sec. FL90 and FR90 closeness varies respectiveluy as following graphs:



Explanation 7: This result describes that the vehicle speed reduces where the left or right closeness distance becomes less than 0.75 m. Higher the closeness (or less the distance FL90 or FR90) higher is the speed reduction. The speed will remain unaffected if the FL90 or FL90 is greater than 0.75m

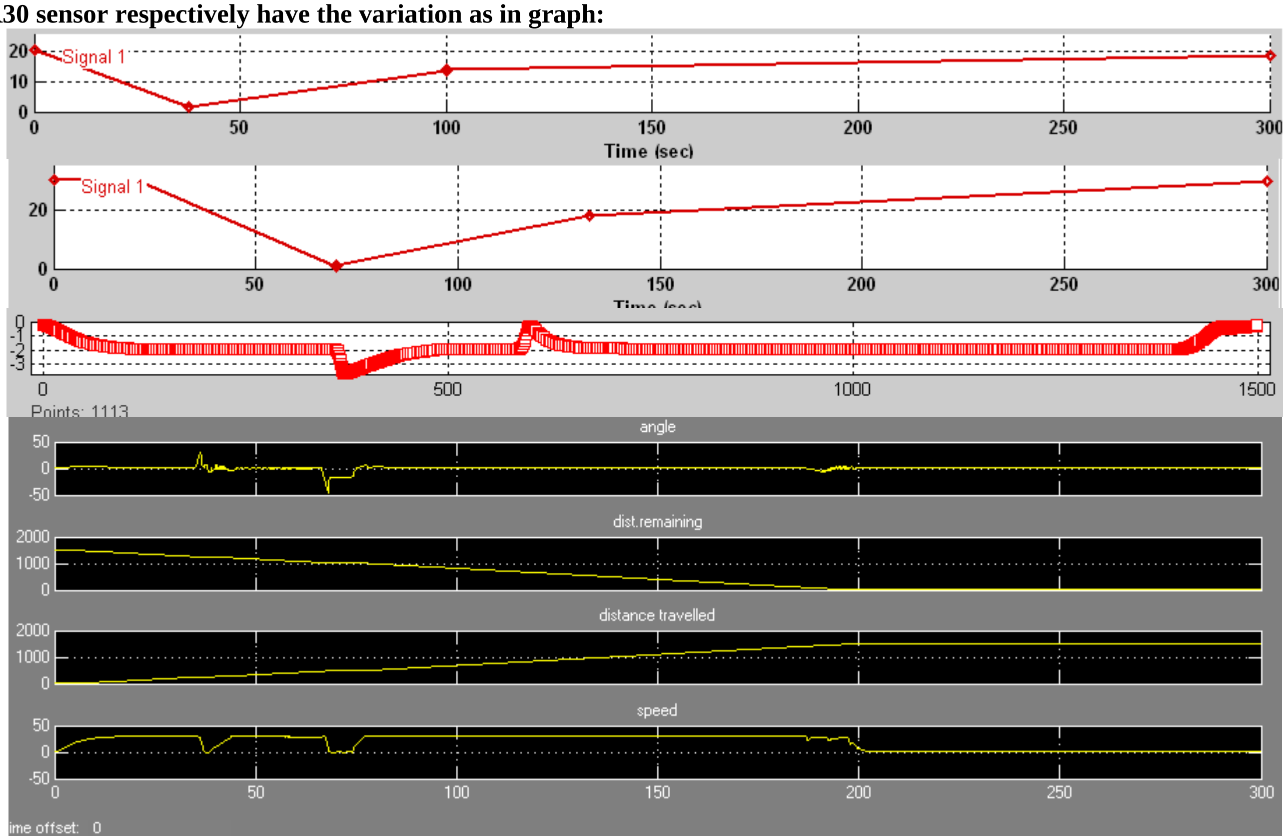
CASE 8: Front obstacle Avoidance, input speed =60 km/hr.,road width =10 meter,target distance=1500 meter,target angle=20 degree left , RFS distance derivative= negative, simulation time=300 sec. The front distance varies as in following graph:



Explanation 8: This result describes that the vehicle speed reduces where the front obstacle distance becomes 30 m. Higher the closeness from front obstacle higher is the speed reduction. The speed will remain unaffected if the front obstacle distance given by

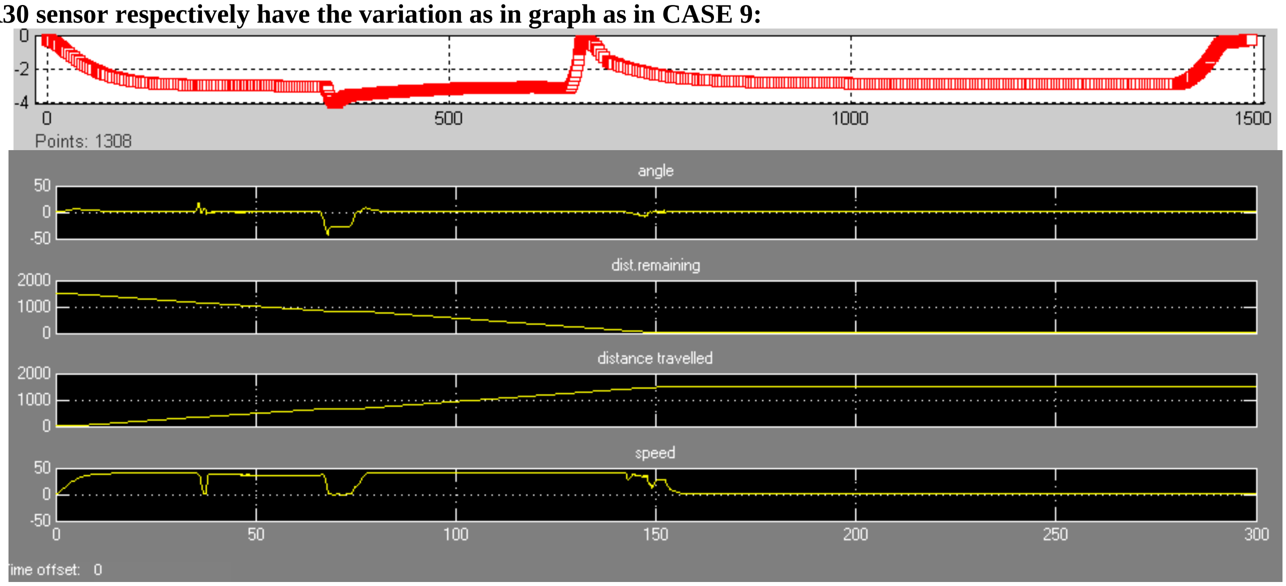
FM0 sensor is greater than 30 meter. At some point between 104 to 111 sec. time the speed is reversed because during this time the front obstacle distance is less than zero. Until the distance becomes equal to or greater than 1.25m the vehicle will be continuing to move backside.

CASE 9: Left and Right 90 degree obstacle avoidance, input speed =30 km/hr.,road width =10 meter,target distance=1500 meter,target angle=20 degree left , RFS distance derivative= negative, simulation time=300 sec. The distances given by FL30 and FR30 sensor respectively have the variation as in graph:



Explanation 9: The result represents that the vehicle turns right for left 30 degree obstacle and turns left for right 30 degree obstacle. The speed reduction is also seen at the points where the turning occurs. The turning starts if the projected distance of the left obstacle in cross direction to left corner of the vehicle or the projected distance of right obstacle in cross direction to right corner of vehicle is starts to be less than 0.75 meter.

CASE 10: Left and Right 90 degree obstacle avoidance, input speed =40 km/hr.,road width =10 meter,target distance=1500 meter,target angle=20 degree left , RFS distance derivative= negative, simulation time=300 sec. The distances given by FL30 and FR30 sensor respectively have the variation as in graph as in CASE 9:



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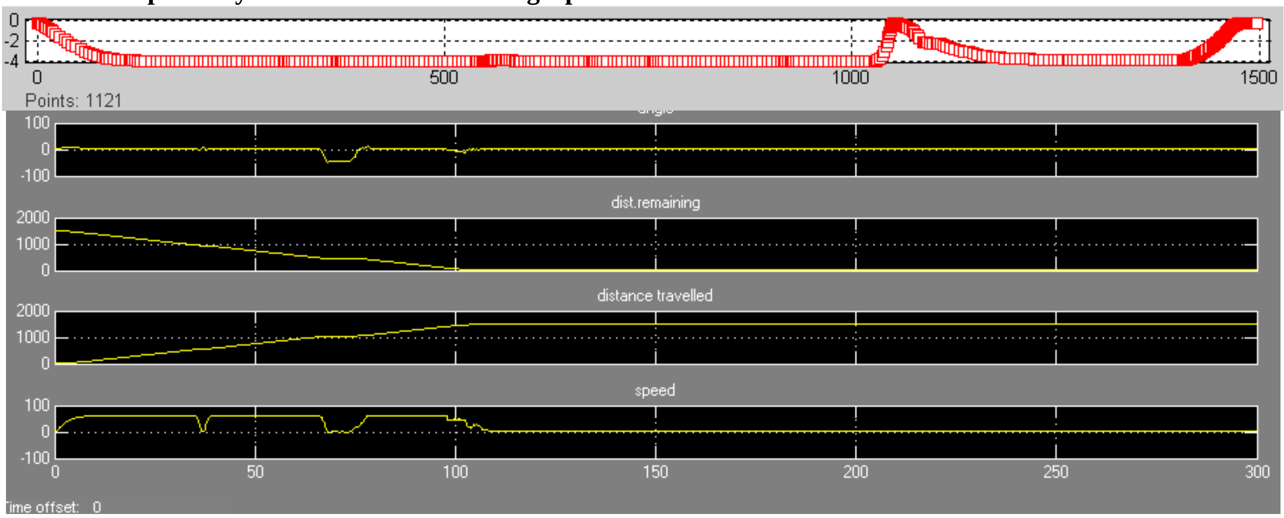
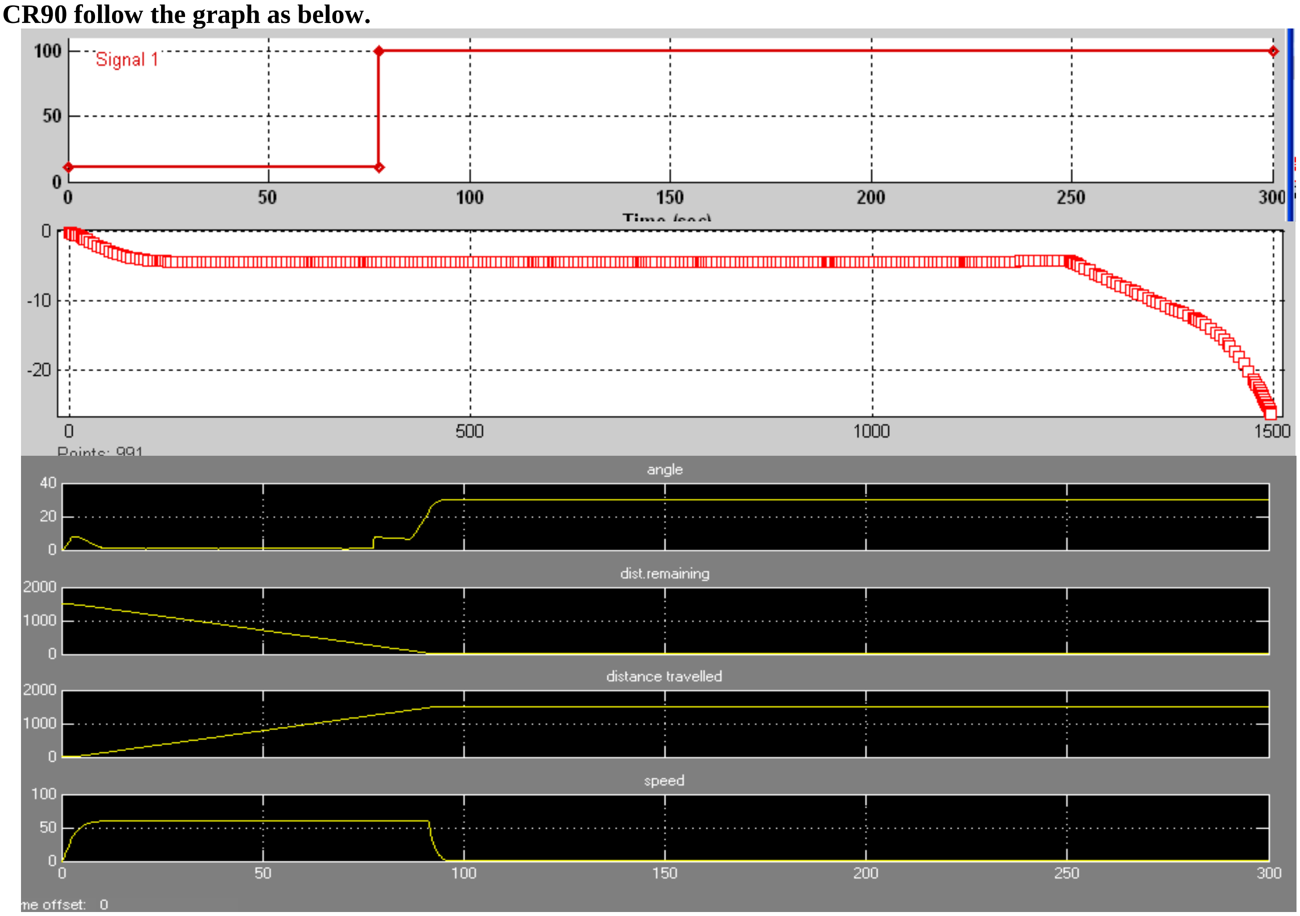
Explanation 10: The result represents that the vehicle turns right for left 30 degree obstacle and turns left for right 30 degree obstacle. The speed reduction is also seen at the points where the turning occurs. The vehicle is running near the divider and so the vehicle cannot turn more and more to the right because the divider is faced in closeness.

CASE 11: Left and Right 90 degree obstacle avoidance, input speed =60 km/hr.,road width =10 meter,target distance=1500 meter,target angle=20 degree left , RFS distance derivative= negative, simulation time=300 sec. The distances given by FL30 and FR30 sensor respectively have the variation as in graph as in CASE 9:



Explanation 11: The result represents that the vehicle is running close to the divider and so the vehicle cannot turn right even though the left turning is same as Cases 8 and 9 .the speed reduction is seen at the points where the turning occurs. Also the target alignment is seen at end.

CASE 12: Left and Right 90 degree obstacle avoidance, input speed =60 km/hr.,road width =10 meter initially,target distance=1500 meter,target angle=30 degree right , RFS distance derivative= negative, simulation time=300 sec. the variation of the CR90 follow the graph as below.



Explanation 12: Here it is seen that the vehicle follows the divider until the increased distance of CR90 has reached. As soon as this location has been reached the vehicle aligns towards the target.

CONCLUSION

The results shown above are in compliance with the practical performance. The results shown above ascertain us that it can perform well in all types of real road environments. So by these results we can conclude that the MSANFIS proves to be excellent techniques by which it could easily been possible to integrate all the behaviors like wall following, target alignment, lane speed, wall (divider) following behavior, tilting avoidance due to turning, obstacle avoidance, traffic signal, speed breaker, speed increase when obstacles crossed, overtaking, passing, opposite side vehicle collision avoidance, limited time to reach the goal, etc. The results related with all the behaviors and in varying conditions of other factors at the same time cannot be shown here due to consistency of paper. These results are shown in the literature. Due trainable behavior, the stages of the MSANFIS structure can be trained to suit any required performance. In future we will be taking the effect of up and down road, Right Lane rule (Left Lane Rule in India).During sudden environmental change (accidental conditions) we will be making the effort to incorporate control scheme that will take the action same as the efficient driver. The action will be the function of rate of sudden change of conditions, velocity, clearances and type of change. The MSANFIS technique will also be used for the manipulator control and biped robot control.

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