SOFT COMPUTING BASED ADAPTIVE CRUISE CONTROL

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Abstract

Research on adaptive cruise control (ACC) is presently one of the most important topics in the field of Intelligent Transportation Systems. The main feature of such controllers is that there is adaptation to a user-preset speed and, if necessary, speed reduction to keep a safe distance from the vehicle ahead in the same lane of the road. Adaptive Cruise Control (ACC) operates in Velocity control mode and Distance control mode. ACC acts like a conventional Cruise Controller in the case of velocity control mode. This system has been designed using Fuzzy logic Controller. The inputs of the Fuzzy logic Controller are Distance error and the Speed Error. The output of the Fuzzy logic controller is acceleration or braking. 25 rules have been generated using Fuzzy Logic Controller with the knowledge base of the system The host vehicle adapts to the lead vehicle, but with a slow response. In order to fasten up the response (decrease the response time),Genetic Algorithm is used. Optimization of Fuzzy rule base is done by using the Genetic Algorithm The result shows better improvement over the Fuzzy logic Controller.

***Keywords*:** Adaptive Cruise control, Fuzzy Logic Control, Genetic Algorithm.

1. Introduction

In recent years many studies on intelligent vehicle have been devoted to solve problem such as driver burden reduction, accident prevention, traffic flow smoothing. Every minute, on average, at least one person dies in a crash. Mentally, driving is a highly demanding activity - a driver must maintain a high level of concentration for long periods and be ready to react within a split second to changing situations. Cruise control (CC) system has been developed to assist the driver for driving in long distance on highway. Cruise control can perform only velocity control [Worrawut Pananurak *et al*.(2009)]. The conventional CC becomes less useful in the case of traffic congestion. This drawback can be overcome by Adaptive Cruise Control (ACC). The goal of ACC is to avoid rear end collision by maintaining a safe distance [LI Jing-liang *et al*(2009),Nassare Benalie *et al*(2009)]. ACC reduces the stress of driving in dense traffic by acting as a longitudinal control pilot. The system makes it possible to adapt the distance to the car ahead without the driver's intervention, effectively relieving the driver. Ultrasonic sensor is used to measure the distance between the leading vehicle and the host vehicle. Throttle valve and brake pedal are manipulated to maintain a safe distance between the leading vehicle and the host vehicle. When the roadway ahead is clear the vehicle equipped with ACC changes to the velocity control.

The limitation of conventional ACC systems is that they do not manage speeds under 30 km/h and, consequently, are not useful in traffic jams or urban driving, situation. ACC extensions with the Stop &Go capability are being researched to overcome this drawback. ACC+ stop & Go useful in urban driving and heavy traffic situations, when it is all the more necessary for preventing and averting rear-end collisions and major accidents Stop &Go driving can be said to be a typical maneuver in city streets, where, for instance, speed is reduced to stop the car at a red traffic light. Both throttle and brake pedal automation is needed to install this feature in a vehicle to provide limited warning [José E. Naranjo *et al* (2006)]. This drawback can be overcome by collision warning. It partially covers the entire vehicle with an alert function. It gives warning during the road and the lane departure. Collision avoidance has been the subject of extensive research both in the fields of robotics and intelligent vehicles [www.twoengineers.co.in]. It gives 360° vehicle coverage. The detection capabilities of vision-based intelligent vehicles are mature enough to perform such a task. Braking and steering are manipulated to avoid the collision.

1.1. *Classification of ACC*

Today's modern system has evolved from the basic cruise control system. Each succeeding evolution has increased its functionality over the previous evolution. Based on the application of ACC system can be broadly classified in to

(i) Longitudinal ACC
   a. Distance keeping
   b. Stop &Go
   c. String
(ii) Lateral ACC

a. Lane Detection/keeping/Changing
b. Collision Avoidance

(iii) Cooperative ACC

In Distance Control mode the distance between the host and the leading vehicle is detected by the sensors fixed in the vehicle. Techniques like fuzzy logic, Sliding mode control, PD controller have been incorporated with ACC to make it intelligent. Results shows that the Velocity Control mode has a minimum operating limit (30-40 km/hr) below which the ACC fails. “Stop and Go” has the possibility to slow down the vehicle to a complete standstill. It offers longitudinal support to the driver in an environment characterized by a congested traffic flow on highways and well structured urban roads at speeds lower than 30-40 km/hr [Gerrit Naus *et al*(2008]. A common characteristic of most Automatic Driver Assistant system whether they automate (part of) the driver’s tasks or ‘just’ give an instructive message, is the inclusion of on-board sensors to scan directly the vicinity of the vehicle. The range covered by such sensors however is limited by the nature which restricts the anticipative capabilities of the system.

Vehicle-Vehicle communication combined with advanced position technology solves this problem [Kyongsu Yi *et al*(2001)].The use of inter vehicle communication could help fulfill the goals of intelligent transport society by providing a system for the vehicle to share with others sensor data representing their environment. With communication ACC become Cooperative cruise control systems, which have communication and cooperation between vehicles as primary concern. The cooperative driving, Which is an advanced form of automated highway systems, is defined as flexible portion of automated vehicles with a short inter vehicle distance over a couple of lanes, which enables each vehicle to perform safe and efficient lane changing and merging and passing [Shin Kato *et al*(2002)].

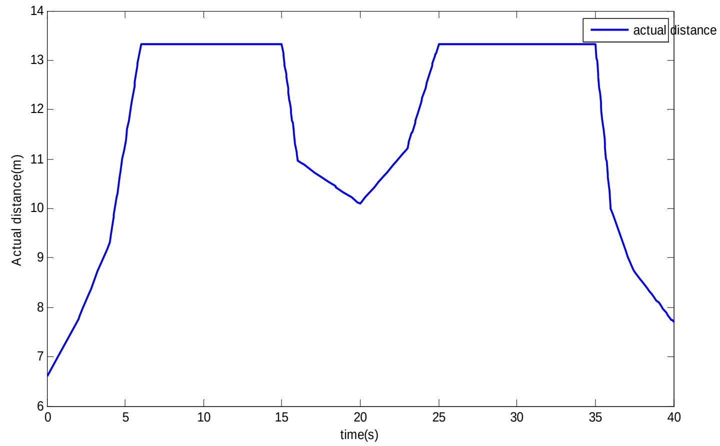
2. Fuzzy Based ACC

A Fuzzy logic controller is an intelligent control system that smoothly interpolates between the rules. Fuzziness describes event ambiguity. It measures the degree to which an event occurs, not whether it occurs. Fuzzy theory is a powerful tool in the exploration of complex problems because of its ability to determine outputs for a given set of inputs without using a conventional, mathematical model. Fuzzy theory becomes easily understandable because it can be made to resemble a high level language instead of a mathematical language. To describe a universe of discourse, fuzzy sets with names such as “hot” and “cold” are used to create a membership function. By determining the degree of membership of an input in the fuzzy sets of this membership function, the role of membership functions play in decoding the linguistic terminology to the values a computer can use.

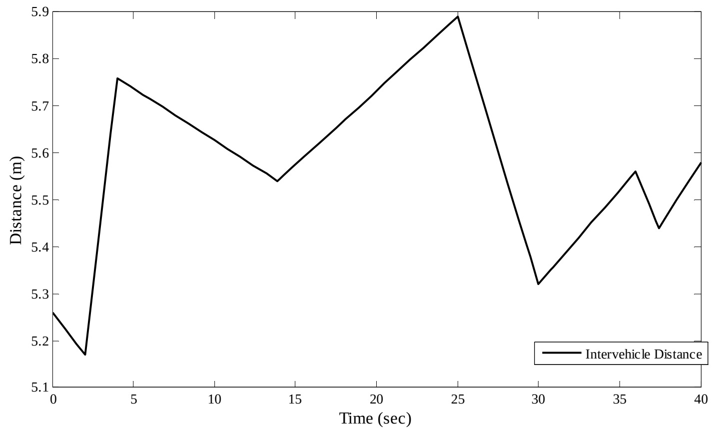
Membership functions are designed by experts with knowledge of the system being analyzed. Fuzzy logic controller is simply a set of rules describing a set of actions to be taken for a given set of inputs .By using a linguistic approach, fuzzy theory can be integrated into control theory using rules of the form IF{condition} THEN{action} [Christopher M. Kumile *et al.*(2005)]. In this same way the input variables can be partitioned into overlapping sets which have a linguistic correlation to form a membership function. These fuzzy sets are most often triangular in shape but trapezoids and Gaussian functions have also been used. The membership values control the degree to which each rule “fires”, illustrating the interdependent relationship between the rule set and the membership functions. .

2.1. Inputs of the Fuzzy Logic Controller

Fuzzy controller of the ACC system process two inputs, (i) Speed error(S error) (ii) distance error(X error). The distance error is the difference between the actual distance and the desired distance. The actual distance is measured by using a Ultrasonic sensor. A scenario is considered for which the simulation is made is shown in Fig.1



(a)



(b)
Fig. 1. Graph of X actual

The desired distance is the distance which is set by the driver to avoid rear end collision even if unpredictable condition occurs due to the leading vehicle. Desired distance is the sum of safe distance and the velocity of the leading vehicle. Time headway is the time take for the host vehicle to reach the lead vehicle at a preset velocity. The desired inter vehicle gap is the product of the time head way and the velocity of the leading vehicle. Inter vehicle gap increases as the time head way increases [Jose E. Naranjo *et al*(2006)].

$$X_{error} = X_{actual} \text{-} X_{desired} \quad (1)$$

$$X_{desired} = X_{safe} + THW.V_h \quad (2)$$

$$THW = \frac{clearance}{lead\ vehicle\ velocity} \quad (3)$$

The speed error is the difference between the velocity of the leading vehicle and the host vehicle. Speed of the lead vehicle is found by using the equation (5). Desired speed is the sum of the current speed of the host vehicle and the compensated speed output.

$$S_{error} = S_{lead} - S_{host} \quad (4)$$

$$S_{lead} = S_{host} + X_{error*3.6} \quad (5)$$

Fuzzy logic controller is used to determine the command to the actuator depending on distance error and relative velocity in order to maintain a safe inter vehicle gap.

2.2. *Fuzzy logic Controller*

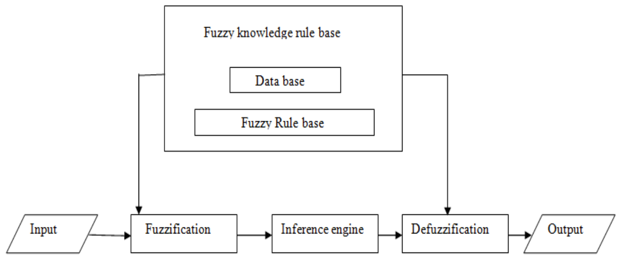


Fig. 2. Framework of Fuzzy Logic Controller

(a) Fuzzification-to calculate the fuzzy output(i.e. to evaluate the input variables with respect to corresponding linguistic term in the condition side)

(b) Fuzzy inference-To calculate the Fuzzy output (To Evaluate the Activation strength of every fuzzy rule base and combine their action sides).

(c) Defuzzification-To calculate the actual output(i.e. to convert the fuzzy output in to precise normal value) [Shuqing Zeng *et al*(1994)]

2.3. *Fuzzification*

The values of the membership function are assigned to linguistic variables using five fuzzy subsets called Negative Medium, Negative small, Zero error, Positive small, positive medium [Philip Thrift]. The linguistic variable X error and S error are the input variables. The output is the firing on ACC which gives desired braking or acceleration. Triangular membership functions are used in both input and output variables.The outputs are divided in two sides; the negative side represents the braking command. The positive side represents the acceleration. Mamdani fuzzy inference method with triangular membership functions are used to determine the compensated speed of the host vehicle.

		Speed error				
		NM	**NS**	**ZE**	**PS**	**PM**
Distance error	**NM**	PM	PM	PM	PS	PS
	NS	PS	PM	PS	ZE	PS
	ZE	PM	ZE	ZE	NS	NM
	PS	PM	PS	NS	NS	NS
	PM	PS	NS	NS	NM	NS

Table.1. Fuzzy Rule Base

The fuzzy inference rules of the ACC system are the collection of linguistic statements in the form of if then statement. Two inputs and one output Mamdani fuzzy logic controller is used. Each linguistic variable has 5 membership functions. 25 rules has been generated with the knowledge base of the system.

This system is modeled in the matlab. 25 rules which has been generated with the knowledge base of the system are given to the fuzzy logic controller. The value of X desired depends on the Speed of the host vehicle. The desired distance varies proportional to the speed of the host vehicle. The value of X error is negative when X actual is less than the X desired, then Speed of the host vehicle has to be reduced. The value of X error is positive when the X actual is greater than the X desired, then the speed of the host vehicle has to be increased. Thus this controls the output of the ACC vehicle. The host vehicle is adapted to the lead vehicle with minimum error. The speed of the new host value is adopted to the X error based on the following equation.

$$S_{h(new)} = S_{h(old)} - output\ of\ fuzzy \times 3.5 \qquad (6)$$

The surface view of 25 fuzzy rules are shown in fig. 3

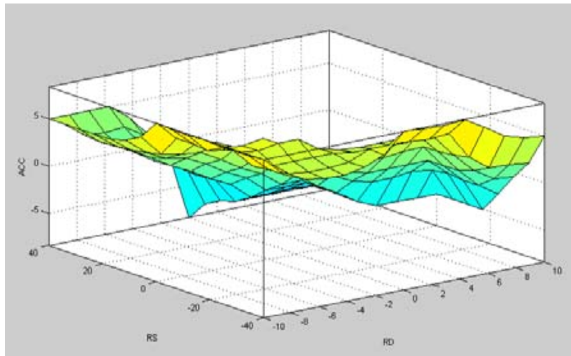


Fig. 3. Surface view of 25 fuzzy rules

2.4. *Output of Fuzzy controlled ACC*

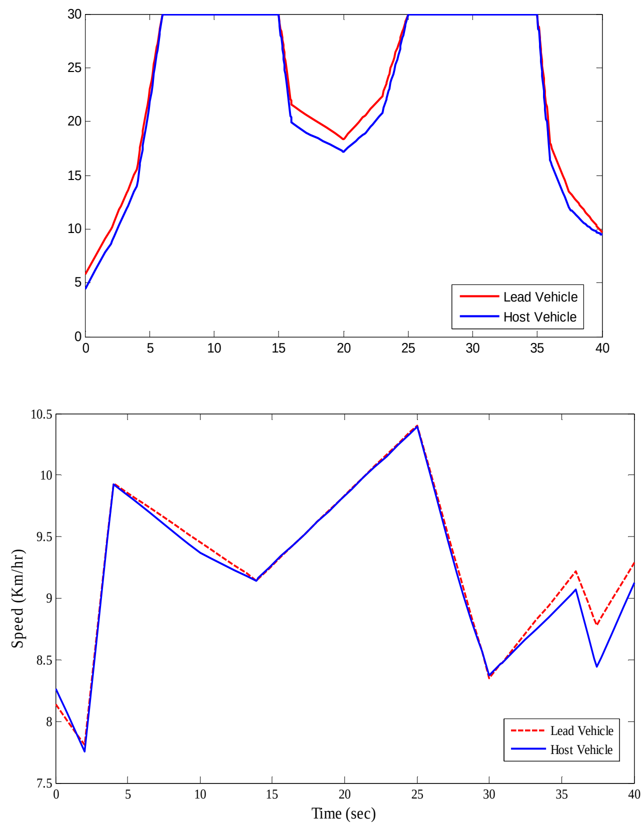


Fig. 4. Output of the fuzzy controlled ACC for the given conditions

The 25 rules which has been framed are implemented in the Fuzzy logic controller. Simulation is done for the above scenarios. In the Fuzzy controlled ACC output, the host vehicle is adapted to the lead vehicle, but the response time is more. The error range varies from 0 to 3.7.This error can be minimized by using Genetic Algorithm based Fuzzy controlled ACC. The optimization of Fuzzy rules for the corresponding situation is done by using the Genetic Algorithm.

3. Genetic Algorithm tuned ACC

John Holland developed GA's to simulate some of the processes observed in natural evolution. Genetic algorithms are general purpose optimization algorithms with a probabilistic component that provide a means to search poorly understood, irregular spaces. Genetic Algorithm does not need derivative and other calculations, but only depends on the objective function and respective generic operators which influence the seeking process carrying out the seek in the mode of seed group.

Genetic algorithms are used to maximize the performance of a fuzzy logic controller through the search of a rule from a given knowledge base to achieve the goal of minimizing the number of rules required. The processes of natural selection cause those chromosomes that encode successful structures to reproduce more often than those that do not. The fitness function is a measure of performance to rank each individual relative to others in the population.

Recombination processes create different chromosomes in children by combining material from the chromosomes of the two parents. Mutation may cause the chromosomes of children to be different from those of their parents. It selects parents from a pool of strings (population) according to the basic criteria of "survival of the fittest**.** Through reproduction, strings with high fitness's receive multiple copies in the next generation while strings with low fitness's receive fewer copies or even none at all.The essence of optimization of fuzzy control rules is to seek the best combination along the fuzzy variable of input and output .In this phase the number and sequence of fuzzy rules are optimized. The parameters of the membership functions are selected randomly. Assume that the initial no of fuzzy rules which are applied to fuzzy logic controller is N. Therefore $3 \times N$ membership functions are needed. Chromosomes of initial population are randomly generated. The cost function of each chromosome is calculated. The chromosomes are sorted by their costs and three genetic operations, reproduction, crossover, mutation are applied to generate next generation [Shuqing Zeng *et al*]. The GA will repeat the procedure until the requirement is achieved and convergence takes place.

3.1. *GA Based Fuzzy Controlled ACC*

The input X actual is the actual distance between the host vehicle and the leading vehicle which is measured for which the simulation is done. The input X error is calculated based on the equation (1). The desired distance is the distance which is set by the driver to avoid rear end collision even if unpredictable condition occurs due to the leading vehicle. Desired distance is the sum of safe distance and the velocity of the leading vehicle. Time headway is the time taken for the host vehicle to reach the lead vehicle at a preset velocity. X desired varies as the speed of the host vehicle varies. The speed error is the difference between the velocity of the leading vehicle and the host vehicle. Speed of the lead vehicle is found by using the equation (5). X error and S error are the two inputs for the GA base Fuzzy controlled ACC. X error and S error are generated using Matlab coding.

3.2. *Fuzzification*

Fuzzification is a process which converts the crisp value in to a fuzzy value. The values of membership function are assigned to the linguistic variables called Negative Medium, Negative small, Zero error, Positive small, Positive medium. The variables X error and S error are the input variables, and the output is the firing on ACC which gives desired braking or acceleration. Triangular membership functions are used for both input and output. For simplicity, the binary code is adopted. The 25 rules are converted in to a binary string by assigning a binary number to each membership function which is given as below.[Rubén Lagunas-Jiménez].

Negative medium :000
Negative small :001
Zero error :010
Positive small :011
Positive medium :100

Each rule consists of two conditions, combined with a logical operator, and an action part. Such rules are independent from each other in terms of position (mostly) and cardinality (always). This reduces the epistasis drastically and hence, the genetic reproduction operations are much more likely to produce good results. The rules are given as if distance error is 000 and speed error is 000 then output is 100. 10 random rules are chosen from 25 fuzzy rules

3.2.1. Crossover

Crossover is a process by which the systematic information exchange between two strings is implemented using probabilistic decisions. Cross over is done with crossover probability (pc=0.6).Two parents are randomly selected and let the parents be 1 & 3.A random number is generated and if the generated random number is less than the crossover probability Crossover has to be done by selecting the crossover site randomly by Interchange the bits [Ahmet Arslan *et al* .(2001)].

Parent= 10000010
00110100
Crossover offspring= 10000100
00110010

3.2.2. Mutation

Mutation is a process in which the occasional alteration of a value at a randomly selected bit position. Mutation is done with mutation probability (pc=0.6).Two parents are randomly selected and let the parent be 3.A random number is generated and if the generated random number is less than the mutation probability mutation has to be done by selecting the mutation site randomly by flipping the bit [Ahmet Arslan *et al* .(2001)].

Parent=10000100 offspring=10000110

3.2.3. Simulation Output

The new generation has been created using cross over and mutation. The fuzzification has to be done and the corresponding rule has to be found out. The 25 fuzzy rules has been reduced to 2 optimum rule in GA based Fuzzy controller. The surface view of the optimized rule is shown in Fig.5

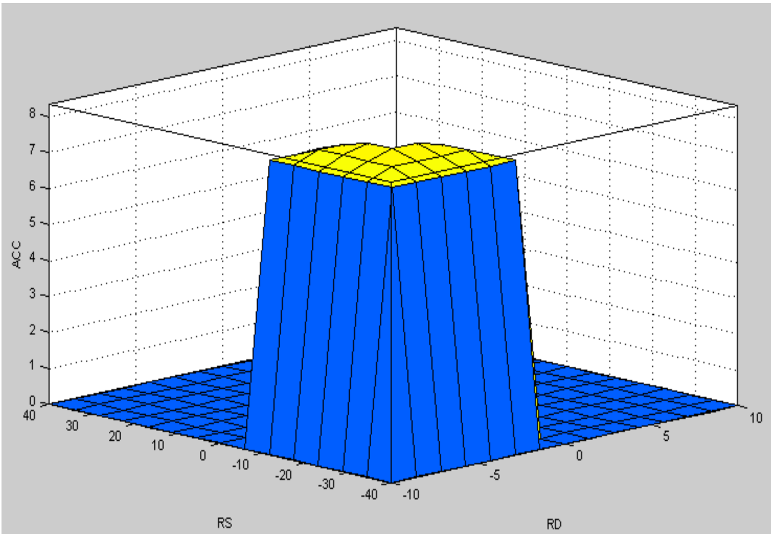


Fig 5. Surface view of Optimized rules

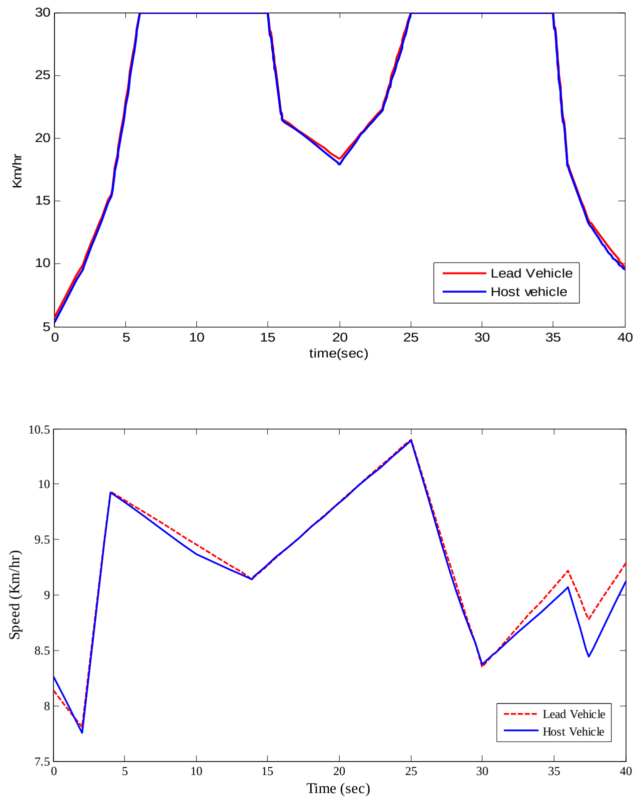


Fig. 6. GA based Fuzzy Controller Output for the given conditions

The optimized rules are applied in the simulation and the results have been compared. The output of the GA base Fuzzy controlled ACC is shown in Fig 4.7.The error value is minimized completely by using GA based Fuzzy ACC controller.It shows better performance compared to that of the Fuzzy logic Controller.The host vehicle is adapted to the lead vehicle with minimum error

4. Conclusion

In this paper , an effort has been put in to simulate an ACC system and to study about the response of the system when using a conventional FLC and a GA tuned FLC. ACC has been implemented in the vehicle to maintain a safe distance between the host vehicle and the leading vehicle. ACC works like a conventional cruise control when there is no vehicle in the front**.** ACC automatically adjust velocity in order to maintain a safe distance between the two vehicles when the vehicle in the front is sensed. ACC maintains a safe distance, but the response time is more. To make the ACC react fast and reliable GA based fuzzy controlled ACC is used. Matlab/Simulink software tool is used for simulation and coding. In GA based Fuzzy controlled ACC the 25 fuzzy rules are reduced to 2 rules which is optimized for that particular situation. The GA based Fuzzy Controller shows better performance compared to that of the Fuzzy controlled ACC**.**

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