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Fuzzy Logic Based Approach for Controlling of a Vehicle in its Longitudinal Motion

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Abstract: Research of many topics in intelligent transportation system (ITS) is the essential study in automobile domain. Adaptive cruise control (ACC) is one of the advanced topics. This paper describes the longitudinal control of the vehicle by using fuzzy logic based approach. The purpose of this paper is to design Fuzzy logic based Adaptive cruise control (ACC). Based on the classical controlling techniques a fuzzy logic based Accelerator controller has been developed. The compared output of the acceleration is used by another controller to decide the speed of the vehicle. Fuzzy rules have been designed according to the input to get the desired output. This controller aims to keep a safe distance from the preceding vehicle by adapting the speed of the host vehicle. Brake setting and throttle setting are the two input variables of the vehicle. Graphical user interface LabVIEW is used in order to investigate the performance of the designed controller.

Key words: Intelligent transportation system · Longitudinal motion · Fuzzy rules · Adaptive cruise control

INTRODUCTION

Autonomous Cruise control are currently under research in the different traffic research programme. Due to increasing much number of vehicles and increasing traffic density, ordinary cruise control(OCC) systems for passenger cars are becoming less significant. Due to the said problem the OCC system makes a car rarely possible to drive a vehicle in a preselected speed.This paper describes the fuzzy logic based intelligent approach in order to control the collision due to much traffic.

Longitudinal control is the necessary elements of an intelligent cruise control system. It helps the vehicle to move forward to reach the destination. The longitudinal control depends upon the vehicle speed, vehicle powertrain as well as the road conditions. Before designing the intelligent cruise control system,vehicle mathematical model is an necessary work in order to achieve the goal. [1] uses the transfer function model of the vehicle.Newton's law of equation is also an important physical parameter in order to design the vehicle mathematical model. Jullierme Emiliano identifies the longitudinal model which is benefited to design the controller for the model in order to achieve the task. He also uses PI based controller for the cruise control system. Cemhatipoglu [5] talks about the smooth intelligent cruise control system. P. Shakouri [8] designs the longitudinal dynamics of the vehicle model using Simulink. Prem jeya Kumar [15] developed the vehicle mathematical model by using basic computer formulation method and by using equation of motion. Raja Ramani [6] describes the formulation of mathematical model of the vehicle by using different laws and equations. R.holves[14] uses fuzzy logic based approach in solving reverse parking problem. M.Sugeno [16] also describes fuzzy based approach in the control of the parking of vehicles. Piter M [17] uses fuzzy logic control algorithm to describe the different intelligent application of a vehicle such as ABS, ASR etc. Rolf Miller[18] uses fuzzy logic algorithm to manipulate/maintain speed and distance from a preceding vehicles. Sang-Jin Ko[12] describes the adaptive cruise control which basically aims on string stability. This Paper deals with the longitudinal control of the vehicle due to collision and accidents. Due to collision of cars can be avoided by using this paper. In this paper we uses fuzzy logic based control algorithm to control the velocity and acceleration of the vehicle in order to avoid accidents. This paper is categorized as follows. In section II we describe the dynamic approach towards the modeling of the car for its longitudinal motion. In section III we proposed the fuzzy logic algorithm in order to design the controller. In section IV we describes the

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overall system for performing required task.In section V Distance and speed control can be explained which is acquired by the designed fuzzy logic. We discuss the results on section VI and section VII concludes the paper with some future work suggestion.

Methodology: System is an important /necessary factor for deciding the controller or for doing research in it. Different advance controlling technique like ABS, CC, ACC, has been designed by observing the system that is the model of the car.This paper deals with two types of longitudinal modeling schemes. One is the transfer function model which is analyzed and adopted from [1], with different constant values. Another modeling technique has been designed from the force balance equation referred from newton's law of motion. Virtual programming platform, Lab VIEW is used to get the mathematical model for the system. After designing the model Fuzzy logic controller has been implemented in order to perform the necessary task. This Proposed controller has been also used to control the longitudinal speed of the vehicle.

Modeling: This research plays an important role to eliminate frontal collision by regulating the vehicle speed. The free body diagram of the Car is shown in fig.1.Equation 1represents the basic mathematical equation which is being obtained from the free body diagram. The vehicle has different forces such as Aerodynamics force, Braking force, Viscous Force or frictional force and engine force. Except the engine dynamic force all the forces opposes the movement of the vehicle that means all other forces are opposite in direction to that of the engine force. So in order to move the vehicle the engine force should be much higher in comparison to all other forces shown in free body diagram. Our aim is to design the controller in order to fulfill the required task, so by considering the system from [1] and [2] and adapting the derivation, we can realize the simple linear transfer function model which is act as the system for designing the controller. In this paper the vehicle model is act as a system to design the controller. The longitudinal dynamics of a vehicle is designed by referring the Newton's law of motion. As per the consideration of Newton's law of motion the force being exerted to the vehicle is the summation of different individual forces such as Viscous force ($F_{viscuss}$), Aerodynamic force ($\vec{F}_{aero}$), Braking force ($\vec{F}_{brake}$) and Climbing force or the Downgrade force ($\vec{F}_g$). This force is also called as gravitational force. These forces plays a role of deciding factor for calculating the force exerted in the vehicle to move the vehicle or for the motion of the vehicle. The mathematical equation to explain the law of motion is given in equation 1.

$$\frac{d}{dt}(m\vec{v}) = \vec{F}_{VISC} + \vec{F}_{AERO} + \vec{F}_{BRAKE} + \vec{F}_{GRAV} + \vec{F}_{ENGINE} \quad (1)$$

From equation 1 'm' represents the mass of the vehicle and 'v' represents the longitudinal velocity. The force equation is posturized in the free body diagram in fig.1. Aerodynamics force, viscous force and braking force as always act on the opposite direction of the movement of the vehicle.

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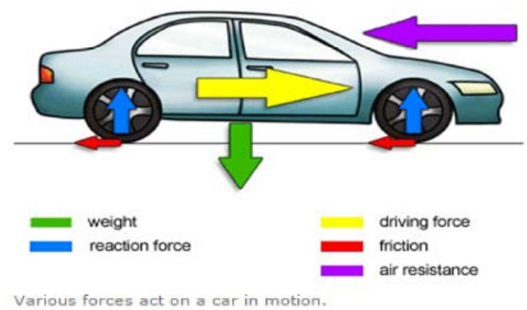

Fig. 1: Various forces acting on a vehicle

Fig. 2: Overview analysis of the system

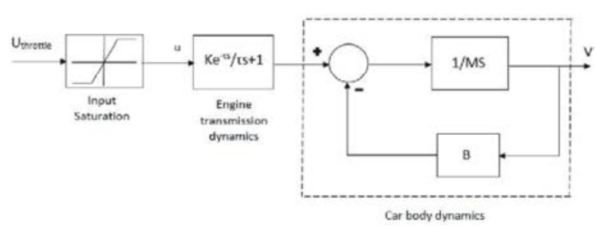

Fig. 3: Process block diagram

For the above condition the force related to gravitational and aerodynamics are neglected.Now the engine force ($\vec{F}_{ENGINE}$) is the only force used to run the car which affects the motion of the vehicle.The transmission system consists of gear box, clutch, speed and torque conversions etc. Generally in automated vehicle gear box does not play a cruisial role for deciding the vehicle speed. The transmission system of a vehicle is a very complicated system. For driving the wheels the transmission system plays an important role by relating the output. So it is a matter of challenge to design the mathematical model of the transmission system.

In this paper simplification proposed by Jullierme [1] and Khairuddin Osman [2] is adapted by taking in to account to the difficulties faced in transmission system. Jullierme [1] shows the use of the first order linear system.The system consists of a time constant ‘T’, static gain ‘K’ and a time delay ‘◎◎’.The input of the system also has been limited to a certain range.The throttle signal which correlate with the model’s input has been restricted to the sluggish speed of the vehicle and to the maximum value which is most appropriate for the safety purpose. Analyzing equation 1 in frequency domain the longitudinal dynamics of the car has been presented in the block diagram in fig.2. Now simplifying the block diagram shown in fig.2 the transfer function of the system is presented in equation 2.

$$G(s) = \frac{v(s)}{u(s)} = \frac{\frac{k}{mT} e^{-\tau s}}{(s + \frac{1}{T})(s + \frac{B}{m})} \tag{2}$$

where v(s) and u(s) are the output and the input of the system respectively. v(s) is the velocity of the vehicle and u(s) is the throttle input to the system. Again considering [2] the symbols represent in the study that is ‘m’ shows the mass of the vehicle. The above transfer function is the final transfer function of the system. Different parameter values have been adopted [3].Table.1 shows this constant parameter values. The controller has been designed after getting the simplified vehicle model for the longitudinal control dynamics. Now assume all the initial condition to be zero. Applying the initial conditions that are zero wind gusts and no grading the model is converted to only the forward path gain and the feedback as shown in fig.2. Now the output state equations are represented in equation 3 and equation 4.

$$v^{/} = \frac{1}{m}(F_d - c_a v^2) \tag{3}$$

$$F_d = \frac{1}{T}(c_1 u(t-T) - F_d) \tag{4}$$

$$Y = v \tag{5}$$

In equation 3 non-linearity arises due to the square term present. To make this nonlinear equation in to linear, we have to differentiate each term. After differentiating the equations it becomes as represented in equation 6 and equation 7.

$$\frac{d}{dt} v' = \frac{1}{m}(-2 c_a v \delta v + \delta F_d) \tag{6}$$

$$\frac{d}{dt} F_d{}' = \frac{1}{T}(c_1 \delta u(t-T) - F_d) \tag{7}$$

And the output equation becomes

$$Y = \delta v \tag{8}$$

Now the transfer function we get by solving these equations are

$$\frac{v(s)}{u(s)} = \frac{\frac{C_1}{mT} e^{-\tau s}}{(s + \frac{2 c_a v}{M})(s + \frac{1}{T})} \tag{9}$$

The time delay also has been simplified by using the power series expansion.

$$e^{-??s} = \frac{1}{(1 + \tau s)} \tag{10}$$

Substituting above equations in the transfer function and by substituting the adapted constant values we got the transfer function as

$$G(s) = \frac{v(s)}{u(s)} = \frac{2.4767}{(s + 0.0476)(s + 1)(s + 5)} \tag{11}$$

The transfer function in equation is a third order, type ‘0’ system. Due to the time delay approximation, the important fact in realizing the system is that the system has been linearized, as the system has been linearized so the further calculation will become much simpler as compared to the nonlinear system. The system is used to follow the command based on the feedback signal.

Fuzzy Logic Algorithm: Fuzzy logic controllers provide a means of converting a linguistic control strategy. It uses the extract knowledge and converts it in to an automatic control strategy. This algorithm allows using qualitative information and expressing this in a quantitative way which is used for decision making. These Fuzzy-logic

Fig. 4: Basic fuzzy logic controller design

algorithms are rule based system which is useful in the context of complex process. It can be used by human operators which don't have knowledge of the dynamics.This algorithm is formulated in linguistic terms, in the form of IF-THEN rule. This algorithm represents expert's knowledge in linguistic control rules. The Algorithm contains a number of sets of Parameters that can be used to modify the control performance.

These are

- The scaling factor for each variable
- The Fuzzy set representing the meaning of linguistic values
- The IF-THEN rules

All these parameters are used as control parameters in different fuzzy logic controllers. Based on the different linguistic input variable such as distance error between the vehicle, the range error rate and Acceleration, Fuzzy controller has been developed, which gives the output as desired acceleration.The structure of the fuzzy logic controller has been shown in fig.4

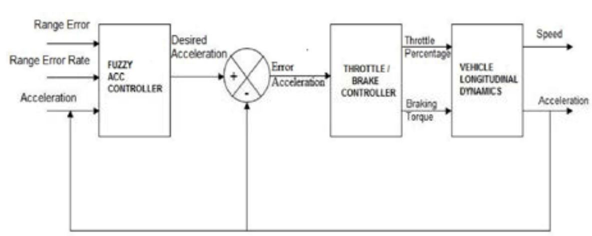

Fig. 5: Fuzzy logic controller system Block diagram

Experimental Setup: The total system has been presented using virtual programming window LabVIEW.The vehicle model has been designed first, After designing the vehicle model the controller design has been taken care. Figure 5 shows the block diagram of the system. It uses 3 inputs such as Range error, Range error rate and Acceleration of the vehicle in order to get the desired acceleration. The Fuzzy logic controller (FLC) is used to get the required output.The Fuzzy rule based approach has been used to find the output of the system. The desired acceleration is now then compared with the vehicles acceleration in present time. The error between both the Acceleration is now used as the input for the switch /ON-OFF controller to decide wheather throttle percentage has to switch or the brake input has to switch in order to control the vehicle speed and acceleration.

Speed Control/Distance Control: The basic goal of control engineering is to refine and apply knowledge about,how to control a process so that the resulting control system will be reliable and achieves high performance in operation.In this paper we are designing a fuzzy logic based controller in order to control the speed of the car.

A Fuzzy controller is composed of the following elements.

- A rule base(a set IF-THEN rules)
- AN Inference mechanism
- A Fuzzification interface
- A defuzification interface

An Inference mechanism imitate the expert's decision making and applying knowledge about how best to control the plant.

The control input has been converted in to information by the fuzzification interface.The defuzification interface converts the conclusion in to actual input for the process.

Fuzzy controller is known as Linguistic controller. The linguistic description has been used in quantified way. The designed system has been classified in to two parts.These are ACC controller and throttle/brake controller. Fuzzy rules has been used to design the ACC controller, throttle/brake controller has been implemented by using ON/OFF controller. The throttle /Brake controller estimates the brake and throttle input in order to decide the speed of the vehicle. Fuzzy rule has been formulated by considering 3 inputs such as Range error, Range error rate and Acceleration of the vehicle. To design the fuzzy rules each input and output has been categorized in some linguistic variable.All the input and outputs with their linguistic variable is shown in fig.11. In order to estimate the speed 35 rules has been estimated. The fuzzy rules has been presented in Table 2.The brake and throttle will not work at the same time by considering the real time application.The input,Range error is defined as the difference between the distances with respect to time which is illustrated in equation 12.

$$e_i = x_{i-1} - x \qquad (12)$$

The range error rate has been defined as the change in range error w.r.t time which is known as the speed of the vehicle. Vehicle Acceleration is another input variable except these two input variables which is used to estimates the desired speed of the vehicle. R. Holve [14] and Sang-Jin Ko [12] describes the generation of fuzzylogic rules and membership function respectively.

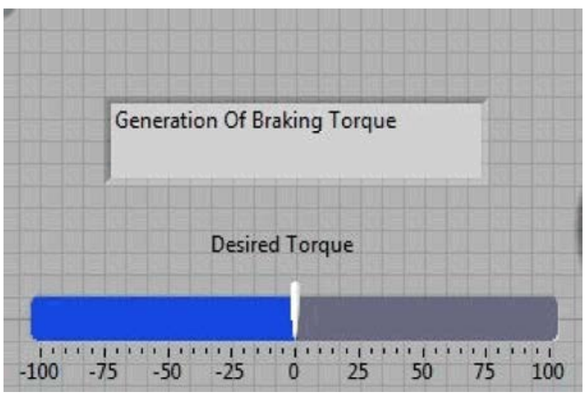

Fig. 6: Generated Output from the fuzzy logic controller

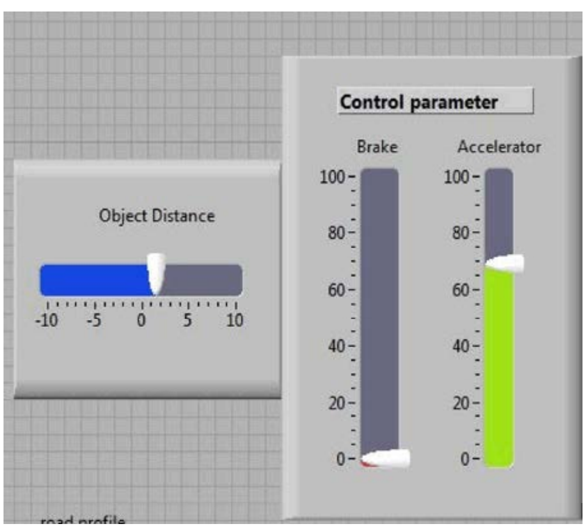

Fig.7 Two input variable for the controller

Result Analysis: The graphical programming language, Lab VIEW is used to model and control the system. The vehicle model is the first part of the paper. Implementing the traditional Newton's law of motion and by using transfer function method the mathematical model of the longitudinal dynamics of the car has been developed.This model depends on friction, slip, torque, aerodynamics. As our target of this paper is to design the controller so these parameters are neglected.we basically focus on the designing of the controller which is the key goal of the paper. In order to design the controller, the first experiment was to validate the model.

After getting the vehicle model we implement the Fuzzy logic controller in order to control the vehicle speed.The diagram shows in fig.5 describes the block diagram of the whole system. Both the controller has been designed in order to assure safety and comfort to the driver and the passengers. The output has been obtained by running the simulation. The switching logic in both controllers is used to switch between the throttle and brake setting. This switching logic has been implemented by a ON-OFF controller. In this research the input is the throttle percentage that is the accelerator to increase the speed and the brake applied which is used to control the speed of the vehicle. This has been designed in order to develop the longitudinal controller. Figure 6 and Figure 7 shows the different modes of the system.The simulation have been verified for certain range of speed. In Fuzzy logic controller based system two different controllers has been used in order to control the speed of the vehicle. The primary controller is the Fuzzy logic controller and on-off controller is used as the secondary controller.The fuzzy logic controller has been used to decide the desired speed for the vehicle according to the different input parameters. The desired speed has been estimated by the fuzzy rules.The fuzzy rule has been designed as per the requirement. Linguistic variable plays an important role in order to create the fuzzy rules. After getting the desired acceleration the ON-OFF controller has been used in order to decide whether throttle setting has to energize or the brake controller has to energize. The Block diagram of the Fuzzy logic based system has been presented in fig.5. All the membership Functions for the input parameters and output parameters with the linguistic variable has been plotted from fig.8 to fig.11 respectively. Figure.12 describes the generated Fuzzy rules for getting the desired acceleration. The generated road profile has been plotted in Fig.13.

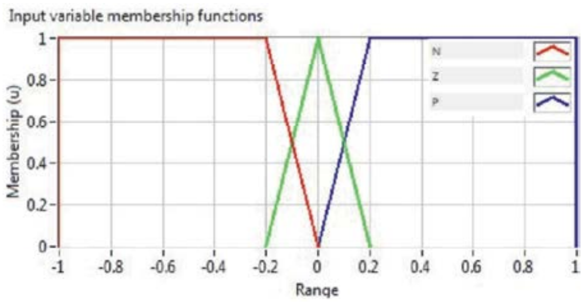

Fig. 8: Membership function for range error

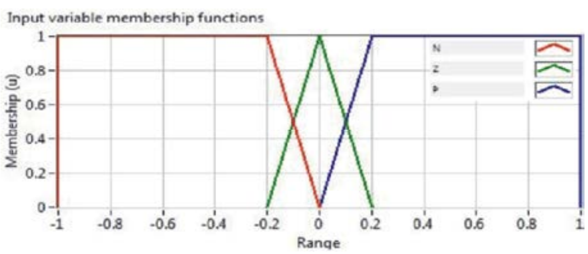

Fig. 9: Membership function for range error rate

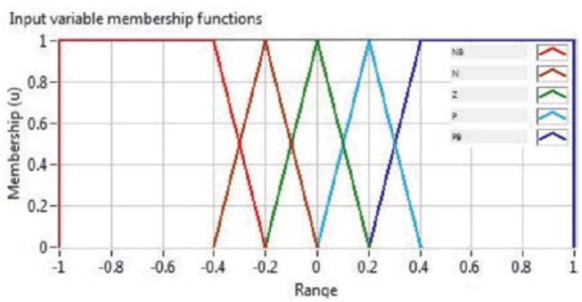

Fig. 10: Membership function for Acceleration

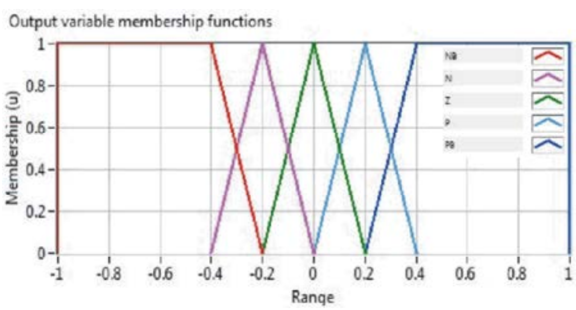

Fig. 11: Membership function for desired acceleration

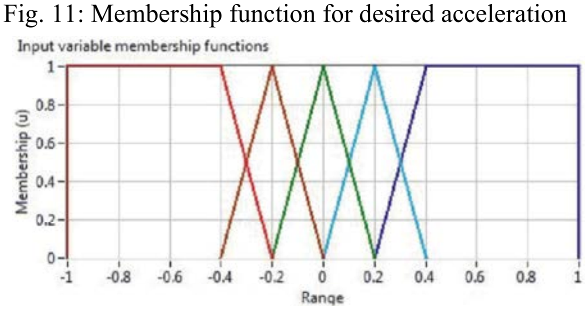

Fig. 12: Membership function for acceleration

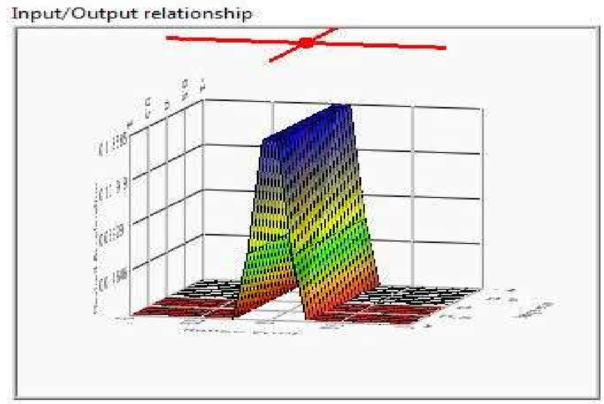

Fig. 13: Input and output relationship

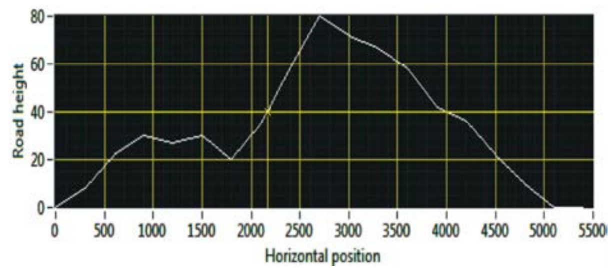

Fig. 14: Road profile

Table 1: Parameter Estimation

Constant parameters	*Assumed values*
M	1500 Kg/
Ca	1.19N/(m/s)2
T	1s
G	9.8m/s2.
C1	743,
T	0.2s,

CONCLUSION

Using newton's law and by balancing different forces The vehicle model has been developed. The controller has been designed in order to control the speed of the vehicle. Intelligent Fuzzy logic controller is used for the control allocation purpose. The vehicle model used in this paper is much simpler which doesn't depends upon the external forces like aerodynamics forces, viscous forces etc. Two input parameter of the vehicle such as Throttle setting and the brake pedal setting are used to control the velocity of the vehicle. Velocity is the output of the system.

The simulation has been verified using the graphical programming window and the results are obtained using LabVIEW.The results are analyzed in section V. Fuzzy logic controller gives more accurate results compared to that of the PID based controller.Research can be done to improve the speed profile of the vehicle by using advanced intelligent controller. By implementing advanced controller safety and moreover performance may improve.

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