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Design of Different Controller for Cruise Control System

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ABSTRACT

In Today automobile industry the cruise control is one of the most critical aspects that require a well-design controller that can accommodate the new development in technology. In this work it is proposed of design different controllers like P,PI,PID and fuzzy logic controller for the cruise control system .A MATLAB model will be develop to simulate the car engine mechanism . Fuzzy logic has expanded substantially in the field of non-linear system as it provides a very simplified approach to design controllers that provide an optimum result. The dynamics of the system will be modeled to provide a transfer function. Finally, a comparative analysis of each simulated result will be done based on the response characteristic

Keywords: ***Cruise control, Dynamic modeling, PI controller, PID controller, Fuzzy logic controller***

I. INTRODUCTION

The cruise control objective is to regulate the speed of the vehicle based on the desired speed. The speed will be measured using speed sensor,then the error and the change of the error will be calculated in order to adjust the speed. Adjusting the speed is to control the throttle position which is proportionally related to the fuel injection to the engine. This will provide the driving force that will move the car according to the Newton's law of motion. Automobile cruise control system is functional as an automatic speed control for a car. Thus, it maintains the speed of the car throughout a journey. The output of the system which is speed is controlled by the controller in order to provide the desired speed at which the car is to be maintained. Normally, the drivers have to press step the acceleration pedal consistently, to maintain the car's speed. The controller provides comfortability and easiness to drivers when driving the car. Comfort ability means driving without having to control the pedals frequently and less tiring. Easiness means controlling the speed of the car by pressing buttons instead of pedals.

The basic problem of cruise control system is to maintain the speed set by the driver or in other words, the speed of the automobile should match a preset value. The main disturbances to this constant speed drive come from the slopes of the road, where gravitational pull effect comes to the front and, second is the wind resistance against the velocity. A schematic diagram of a car in the slope of a road is given in
the Fig.1.

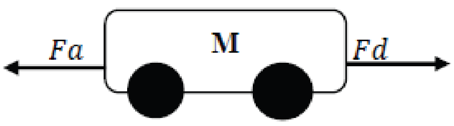

Figure 1: Model of the vehicle in motion

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II. MODELING AND SYSTEM ANALYSIS

The purpose of the cruise control system is regulating the vehicle speed so that it follows the driver's command and maintains the speed at the commanded level. Base on the command signal v_R from the driver and the feedback signal from the speed sensor, the cruise controller regulates vehicle speed v by adjusting the engine throttle angle u to increase or decrease the engine drive force *Fd*. The longitudinal dynamics of the vehicle as governed by Newton's low (or d'Alembert's principle) is

$$F_d = M\frac{dv}{dt} + F_a + F_g \qquad (1)$$

Where *M(dv/dt)* is the inertia force, F_a is the aerodynamic drag and F_g is the climbing resistance or downgrade force. The forces F_d, F_a, and F_g are produced as shown in the model of Fig. 1 , where v_w is the wind gust speed, M is the mass of the vehicle and passenger(s), θ is the road grade, and C_a is the aerodynamic drag coefficient. The throttle actuator and vehicle propulsion system are modeled as a time delay in cascade with a first order lag and a force saturation characteristic. The controller design for this system begins by simplifying the model. Consider to sell all the initial conditions to zero. The same applies to the disturbance parameters. Hence, it is assumed is no wind gust and no grading exists during the movement of the car. Applying this zero initial condition to the block diagram, the model is left with the forward path and the unity feedback loop of the output speed. Since the state variables have been chosen to be the output speed and the drive force, the corresponding state and output equations are found to be

$$\frac{dv}{dt} = \frac{1}{M}(F_d - C_a v^2) \qquad (2)$$

$$\frac{dF_d}{dt} = \frac{1}{T}(C_1 u(t-T) - F_d) \qquad (3)$$

$$Y = v \qquad (4)$$

However, a problem of non linearity arises. There is a squared term in the equation (2). One way to overcome this problem is to linearize all of the state-equations by differentiating both left and right hand sides of the equations with *M*, *Ca*, *C1*, *T* and *v* remain constant. After differentiating, the state-equations become

$$\frac{d\dot{v}}{dt} = \frac{1}{M}(-2C_a v\delta v + \delta F_d) \qquad (5)$$

$$\frac{d\dot{F}_d}{dt} = \frac{1}{\tau}(C_1 \delta u(t-T) - \delta F_d) \qquad (6)$$

$$Y = \delta v \qquad (7)$$

In the equation, δv means that the output is discrete and δFd also means that drive force is discrete. The symbol v means the desired and $\delta u(t\text{-}\tau)$ is the time delay of the engine. Up to this point, both the state and output equations are written in time domain. The linearized model provides a transfer function can be obtained by solving the state-equations for the ratio of $V(s) \,/\, U(s)$.

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$$\frac{\Delta V(s)}{\Delta U(s)} = \frac{C_1/M\tau}{\left(s + {}^{2C_a v}/_{M}\right)\left(s+\frac{1}{T}\right)\left(s+\frac{1}{\tau}\right)} \qquad (8)$$

The following parameter values are adopted However some values need to be modified so that the block diagram could represent the same model with slightly different values just to provide computing and calculation challenges rather than reusing the identical values:

C_1=743, T=1s, τ=0.2s, M=1500kg, C_a=1.19N/(m/s)2,

F_{dmax}=3500N, F_{dmin}=-3500N, and gravity constant g=9.8m/s2.

Hence, after substituting the values of the constants into equation (8), the final form of the linearized transfer function derived from the block diagram through state equation is shown below.

$$G_p(s) = \frac{\Delta V(s)}{\Delta U(s)} = \frac{2.4767}{(s+0.0476)(s+1)(s+5)} \qquad (9)$$

III. CONTROLLER DESIGN

3.1. Proportional-Integral Controller

The combination of proportional and integral terms is important to increase the speed of the response and also to eliminate the steady state error. $C(s)$ the transfer function of PI controller has the form of

$$C(s) = K_P + K_I/S \qquad (10)$$

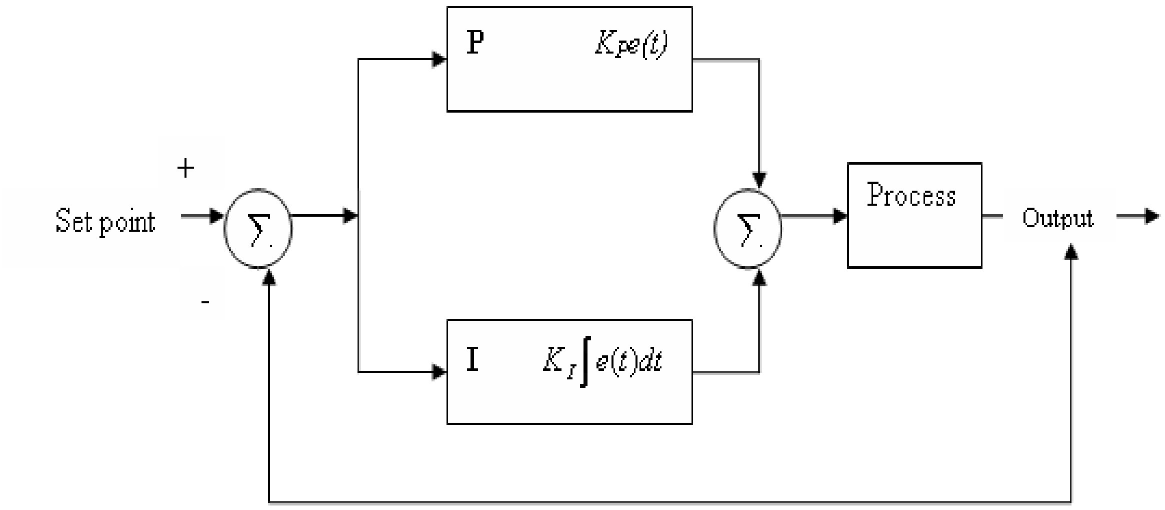

Fig. 2: Block Diagram of PI controller

Where, K_P is proportional gain and K_I is an Integral gain. The proportional term (sometimes called gain) makes a change to the output that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant Kp, called the proportional gain. The contribution from the integral term sometimes called reset is proportional to both the magnitude of the error and the duration of the error.

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3.2 Proportional-Integral-Derivative Controller

A proportional-integral-derivative controller (PIDcontroller) is a generic control loop feedback mechanism widely used in industrial control systems - a PID is the most commonly used feedback controller.

A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs. In this section, the method to obtain the controller for the car suspension system is described when a PID scheme is used to perform control actions and $C(s)$ the transfer function of PID controller has a form

$$\mathbf{C(s) = K_P + K_I/S + K_D S} \quad \mathbf{(11)}$$

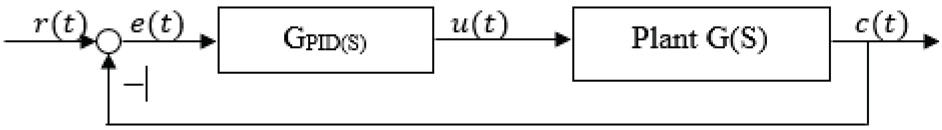

Fig. 3: Block Diagram with PID controller for Cruise control system F

The PID controller calculation involves three separate parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D.

The proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors, and the derivative error has been changing. The weighted sum of these three actions is used to adjust the process via a control element such as the disturbances of a Car suspension system.

3.3 Fuzzy Logic Controller

The fuzzy logic controller used in cruise control system has two inputs: speed error (e) , derivative of error $d(e)$ and one output , the actuator control (u) . The control system consists of three main stages: Fuzzification, fuzzy inference system and Defuzzification. The linguistic variables such as (High Negative, Small Negative, Medium Positive, etc) are used to represent the domain knowledge with their corresponding values lying between -50 to +50 for inputs and -3000 to +3000 for output. Fuzzification stage converts the crisp values into fuzzy rules, while fuzzy inference system processes the inputs data and computes the controller outputs in scope with the rule base and data base. Fig. 2 shows the block diagram of the plant within FLC (fuzzy logic controller).The defuzzification interface transforms the conclusions reached by the inference mechanism into the output of the plant.

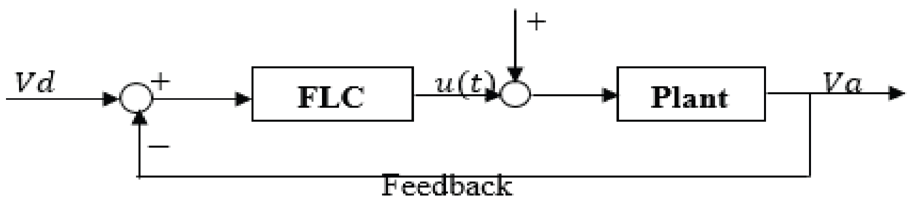

Figure 4: Block diagram of fuzzy cruise control

IV. DESIGN OF PI, PID & FUZZY LOGIC CONTROLLER

In this section, PI PID and Fuzzy Logic Controllers are applied to the Cruise Control System. To design these Controllers MATLAB/SIMULINK is used.

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4.1 Design of PI Controller

The test presented in this section is related to the PI Controller performance for the Cruise control system. The main purpose of this implementation is to get the desired response of the system. The Simulink model of the Cruise Control system using PI Controller is shown in Fig. 5

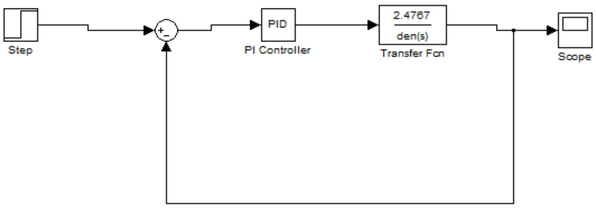

Fig.5: Simulink Model of Cruise Control System using PI Controller

The values of K_P and K_I are 3.5907 and 0.163 respectively are taken. The response of the Cruise control System using PI Controller is shown in Fig. 11. Without derivative action, a PI-controlled system is less responsive to real and relatively fast alterations in state and so the system will be slower to reach set-point and slower to respond to perturbations than a well-tuned PID system.

4.2. Design Of PID Controller

The test presented in this section is related to the PID Controller performance for the bus suspension system. The main purpose of this implementation is to get the desired response of the system. The Simulink model of the Car Suspension system using PID Controller is shown in Fig. 6

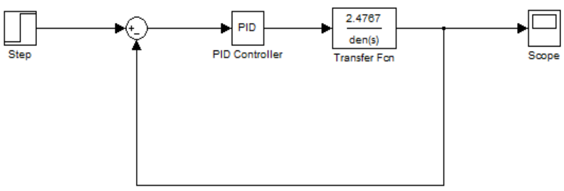

Fig. 6: Simulink Model of Cruise control System using PID Controller

The values of K_P, K_I and K_D are 3.5907, 0.163 and3.3021 respectively. The response of the Cruise control System using PID controller is shown in Fig. 12. By the use of PID Controller, the performance characteristics of Cruise control System are drastically improved.

4.3 Fuzzy Logic Controller Design

The structure of membership functions for the inputs and output variables of cruise control system are shown in Fig. 7,8,9 respectively. Triangular membership functions (trimf) have been used is because of their simplicity. These memberships have an important role in the control of the system. Cruise control system is controlled based on the rules designed by the expert's knowledge. The rules base used are shown in Table 1. The table consists of seven membership functions for both inputs. Forty nine rules are generated from those memberships as an output

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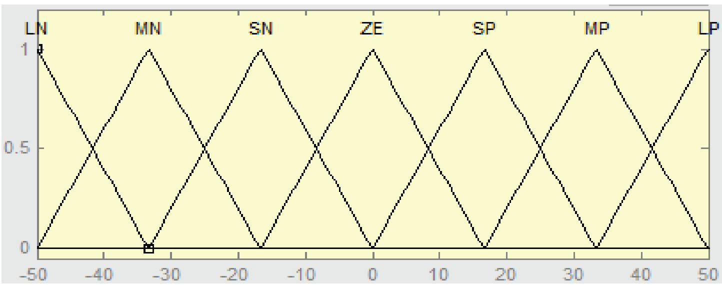

Figure 7: Membership function for speed error

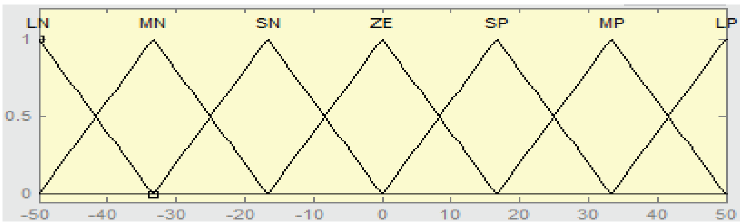

TABLE 1: LOOK UP TABLE CONSTRUCTION

			Speed error-e					
		LN	MN	SN	ZE	SP	MP	LP
	LN	HN	HN	HN	HN	MN	SN	ZE
	MN	HN	HN	MN	MN	MN	ZE	SP
	SN	HN	HN	MN	SN	ZE	SP	MP
--de	ZE	HN	HN	HN	ZE	SP	MP	HP
r								
	SP	MN	MN	ZE	SP	SP	HP	HP
	MP	MN	ZE	MN	MP	MP	HP	HP
of	LP	ZE	MN	MN	HP	HP	HP	HP

Figure 8: Membership function for derivative error

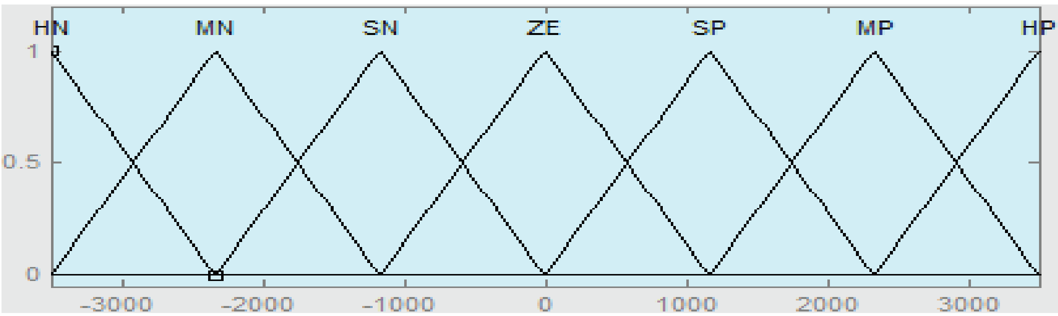

Figure 9: Membership function for output actuator control

The corresponding abbreviations are:

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HN: High negative

LN: Large Negative

MN: Medium negative

MN: Medium Negative

SN: Small negative

SN: Small Negative

ZE: Zero

SP: Small Positive

SP: Small positive

MP: Medium Positive

MP: Medium positive

LP: Large Positive

HP: Add high positive

Table 1 can be interpreted as follow: **If** the error is Large Negative (LN) ***and*** derivative error is Medium Positive (MP) ***then*** the actuator control is Medium Negative (MN). In addition, each statement from Table1 has its own meaning. For examples:

1. The error is Small Negative and derivative error is Small Positive, this indicates that the actual speed is somehow higher than the desired speed and dropping to the desired speed after.
2. The error is Large Positive and derivative error is Large Negative, this indicates that the actual speed is very below the desired speed but still increasing.

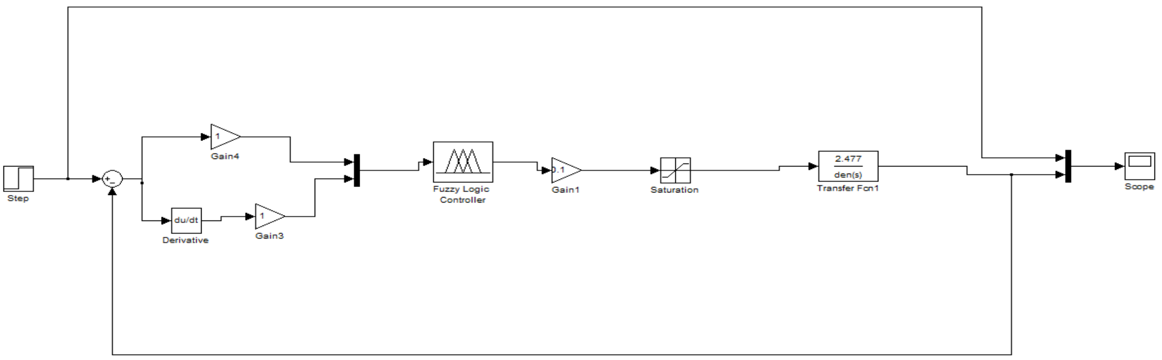

Figure 10: Simulink model with FLC for cruise control

V. SIMULATION AND RESULT

In this work, both uncontrolled and controlled model are simulated and compared based on the design specifications. All the simulation results are shown in Figure 11, Figure 12, and Figure 13 respectively. The speed (Km/h) versus time (sec) relationship of uncontrolled model shows that both the maximum speed and time limits are exceeded, it is clear that the design specification doesn't match

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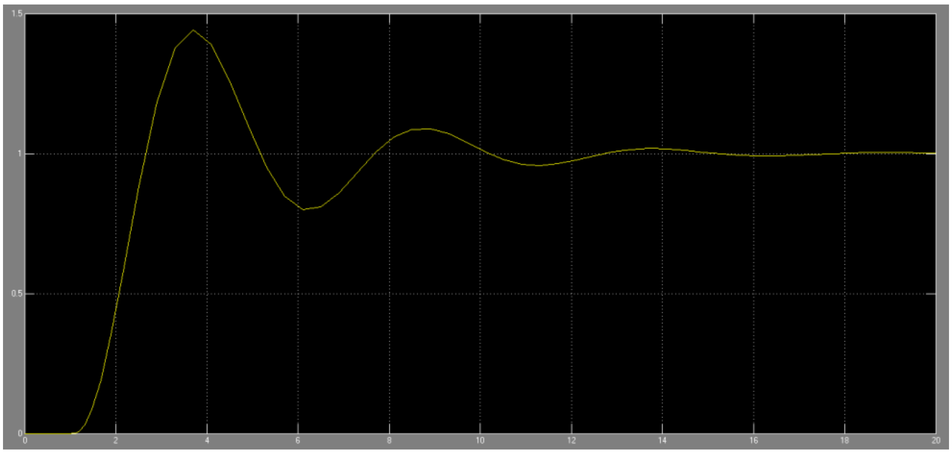

Figure 11: Response With PI Controller

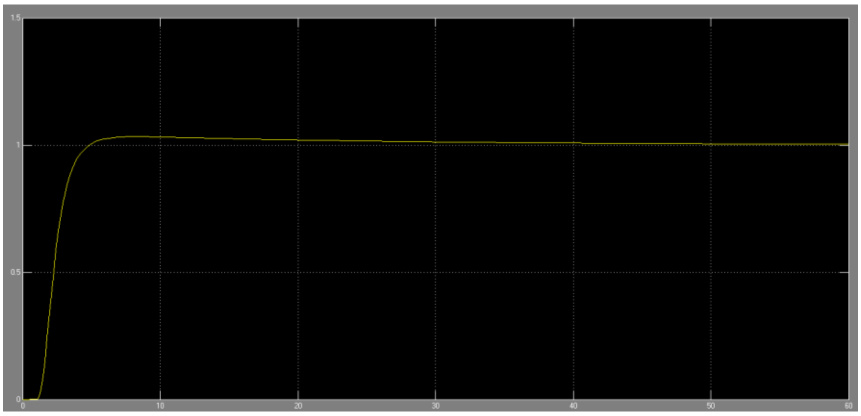

Figure 12: Response With PID Controller

Figures 12-13 show responses of the system using Fuzzy logic and PID controller respectively. It is clear that fuzzy logic controller has small overshoot and small amplitude compared to PID controller. This means that fuzzy controller provides smooth response. Figure 11 shows the responses of the tuned PID controller. The blue color represent the response of tuned initial value with high oscillation while the green color shows the manual tuned response which gives better performance with fast response and settling time.

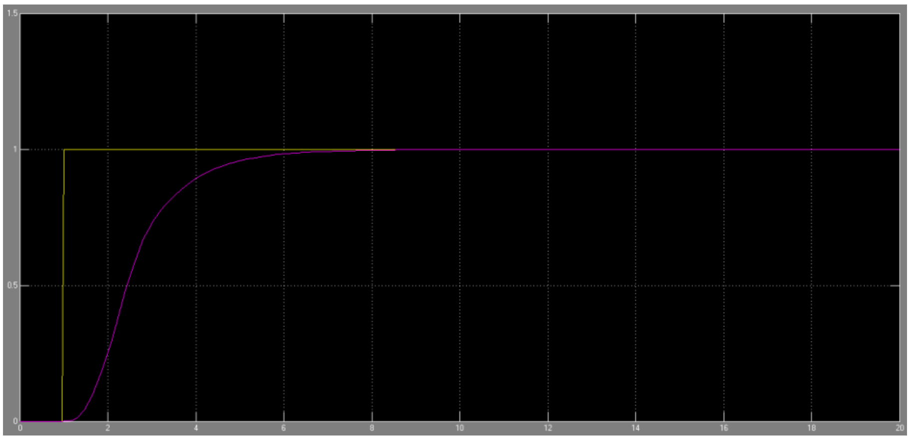

Figure 13: Response With Fuzzy Logic Controller

To know the stability of the system; the percentage overshoot *(%OS)*, peak amplitude, settling time *(TS)*, steady state error and rise time *(TR)* are compared and summarized in Table 3. After comparing both controllers, fuzzy logic is more stable than PID controller.

Table 2: Comparison Result For Pi , Pid And Fuzzy Logic

Properties	PI	PID	FUZZY LOGIC
Settling time	15 sec	5.5 sec	2 sec
Rise time	2.7	3.4	4.5
Overshoot	0.4	0.05	0

V. CONCLUSION

Automobile cruise control system has become a common feature of the modern vehicles for driver comfort in long-distance travels. It reduces the physical as well as the mental stress of drivers in highway drives by providing them relief from regularly stepping on the pedal for adjusting gas and looking at the speedometer for avoiding speeding tickets. It also adds to the safety of the passengers by reducing the risks of high-speed accidents. It is primarily velocity or speed control, which works on the principle of throttle position controlling according to speed requirements. Cruise control also improves the dynamic performance of the automobile, reduces pollution due to exhaust and heightens the comfort level of riders.

In this paper, the idea of fuzzy logic and PI and PID controllers is presented. The controllers have been designed for cruise control system. The characteristics of Fuzzy and PI and PID responses are shown in TABLE 2. Better control performance and great stability can be estimated from fuzzy controller. PI and PID controller produces the responses with small rise time compared to Fuzzy logic controller, but it offers high percentage overshoot and peak amplitude which can cause poor performance of the system. Further work can be done by the use of a Fuzzy-PID controller.

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