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Comparison of PID, GA and Fuzzy Logic Controllers for Cruise Control System

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Abstract: Nowadays, automobile companies give good attention of cruise systems and cruise controllers which are considered as one of the most critical aspects that require precise controller that can accommodate the new development in technology. The movement of running automobiles is variable and complex. For this reason, cruise control system (CCS) has high non-linearity and if a traditional PID controller has been used, it will not give good results in all conditions. This paper presents comparative study of PID controller, PID optimized by GA and fuzzy logic controllers for an automobile cruise control system (ACCS) where it has been used on linearized model of the cruise system. The comparison was for the transient performance; i.e. settling time, rise time and maximum overshoot in addition to the steady state performance i.e. steady state error. MATLAB/SIMULINK and m-file have been used to show the efficiency of each method used and shows the comparison between them. The results indicate that the performance of fuzzy controller has better response regarding the overshoot and the settling time while the PID tuned by using GA gives the shortest rising time. A comparative analysis of each simulated result will be done based on the response characteristic.

Keywords: CCS (Cruise control system), GA (Genetic algorithm), ITAE (Integral time absolute-error criterion)

1. INTRODUCTION

Cruise control system is a controller that designed to keep the vehicle's speed constant in the long run drive. This will help the driver to manage the vehicle speed where it will be automatically upheld. By using the cruise control buttons, the speed of the vehicle will managed and automatically upheld based on the required speed without the application of the accelerator pedal. When the cruise system is activated, the automobile will run steadily and as a result, the unnecessary change of speed will be reduced. This will lead to optimize fuel consumption and in the same time, it will increase the engine efficiency. Also, the pollution caused by exhaust gas will be reduced and the drivers comfort will be improved since it reduces their fatigue in long run drive. Another advantage of using cruise systems is that it reduces the probability of potential crash [1]. Cruise control system consider as one of the most important features that added to the automobiles to be "Automatic Vehicle” [2, 3].In recent years, many studies on intelligent vehicles have been done to overcome exist problems such as accidents, traffic flow and driver burden reductions [3]. Driving in reality needs a highly demanding activity so it requires high level of concentration for long term. Also, driver needs to react within a split second to change situation. For these reasons, cruise system has been used for long distances to assist the driver [4].Automated vehicles which also called smart cars have more developed cruise system which is the Adaptive cruise system. The role of cruise system in smart cars is to keep monitoring the road in case there is a car ahead so it will take an action to reduce the speed from the desired values selected by the driver to a value that ensure safety distance. Once there is free space in front of the car, cruise system will increase the speed gradually until it reaches the desired value. Other smart cars use more complicated cruise systems which have the ability to stop the car completely in case of traffics or special cases that could happened. There are many methods used for cruise control systems. The most popular methods are conventional PID controller, fuzzy logic, genetic algorithm (GA) and state space. For these methods, it is required to select the optimal value of the gain to get the best response [5, 6]. In this paper, three different types of controllers are used; conventional PID, fuzzy logic controller and PID with genetic Algorithm.

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2. MODELING AND SYSTEM ANALYSIS

The cruise control system is actually a close loop control system. The speed adjustment starts from the change in throttle angle then to the engine and gearbox. In the feedback, a speed sensor is used to measure the actual output (speed). The principle structure of cruise control system is shown as Fig. 1. [4]

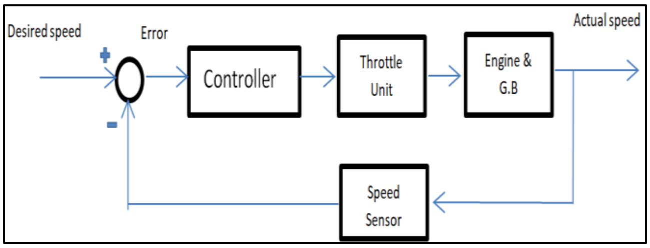


Figure 1. Block diagram of the Cruise control system

The input signal to the controller is the error which is the difference between the desired speed and the actual speed. According to this error, the controller will give throttle control signal that adjust the throttle angle. The opening range of the throttle changed by controller will change the engine speed [2]. The cruise controller regulates the vehicle speed (v) based on desired speed and the actual speed comes from the feedback speed sensor. The regulation of the vehicle speed is done by adjusting the throttle angle (u) while this will change (increase or decrease) the engine drive force Fd. The equation of the system is:

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

Where:

$M\frac{dv}{dt}$: Inertia Force
F_a : Aerodynamic drag force
F_g : Climbing resistance or down ground force
M : Mass of the vehicle and passenger(s)

The linearized model provides the forward transfer function is:

$$\frac{\Delta V(s)}{\Delta U(s)} = \frac{1}{4s^2+5s+1} \qquad (2)$$

While the feedbacks transfer function is;

$$\mathrm{H(s)} = \frac{1}{0.5s+1} \qquad (3)$$

3. CONTROLLERS DESIGN

3.1 PROPORTIONAL- INTEGRAL-DERIVATIVE (PID) CONTROLLER

The use of PID became universal in most industry applications that require accurate control [5]. PID is a combination of proportional, integral and derivative of the error signal. This combination gives very good control method that has been used for most industrial applications where each part gives some advantages for the overall system response. The overall control function can be expressed mathematically as.

$$u(t) = K_p + K_i \int e(t)dt + K_d \frac{d\,e(t)}{dt} \qquad (4)$$

Where K_p the proportional gain, K_i is the Integral gain and K_d is the derivative gain. To obtain a good response, different weights are given per each part so the weighted sum of the three parts (P, I, D) is used to control the process (plant). Despite all the advantages of the PID controller, it has some limitations [5]. First of all, its performance is compromise and reactive because it is feedback control system with constant parameters and it does not have direct knowledge about the process. Secondly, because it is linear, its performance with non-linear system is variable. Also, PID controllers have a problem with the derivative term where it is sensitive to the noise, usually high frequency noise, because it causes large amount of change in the output term of the derivative part [6]. The block diagram of the cruise system with the PID control has been build using the Matlab Simulink as shown in the Fig. 2.

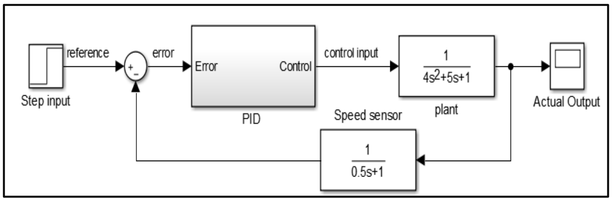


Figure 2. Block diagram of Cruise system with PID controller

According to the PID tuner that has been used to tune the PID controller gains, K_p= 2.2135, K_i=0.5845 and K_d= 1.7255

3.2 Fuzzy logic controller designer

The implementation of fuzzy control has grown rapidly over the last decades. While there is a rapid development in the computer technique, the infiltration of modern methods of controlling is more encountered into the practice; for Example, artificial intelligent, robust control and adaptive control. An important application of the artificial intelligence is the fuzzy logic and its implementations especially in the control field. The importance of the fuzzy controllers is shown in areas in which the mathematical model of the system is unknown or imprecise, or it is inapplicable and complex for the purpose of control. Also, fuzzy logic use simple linguistic expressions that reflect the human experience. For this reason, fuzzy controllers have been used in different types of applications [7].

For the design of the fuzzy controller, there is no systematic methodology but the most used approach is to define a set of membership functions for inputs and outputs which usually be designed by using human linguistic approach after exploitation of the fuzzy logic [8]. The main goal in the design of fuzzy controllers is adjusting certain parameters to be used for controlling a known system (known parameters). The adjustment of these parameters is done by testing them on the system where it is very difficult to adjust them by their influence because fuzzy controller is nonlinear [8]. The input variables for the fuzzy controller are the proportional error (E) and the change in error (CE). Error E is the difference between the reference value and the output of the controller. The change in error (CE) is the difference between the error at time t and (t-1) [9]. The fuzzy logic controller design has three main sections: fuzzication, interferential mechanism and the defuzzication [8]. Cruise control system was described by two dimensional fuzzy control system with two inputs and single output MISO (multi input, single output). The design of fuzzy controller is related with the choice of following parameters:

- Rule base: The choice of control rules in addition to the input and output variables.
- The universe of discourse: The choice of membership functions and their shapes.
- Decision making: It represents the definitions of fuzzy implication and interpretation.
- Defuzzication type.

3.2.1. Nine Rules fuzzy controller design

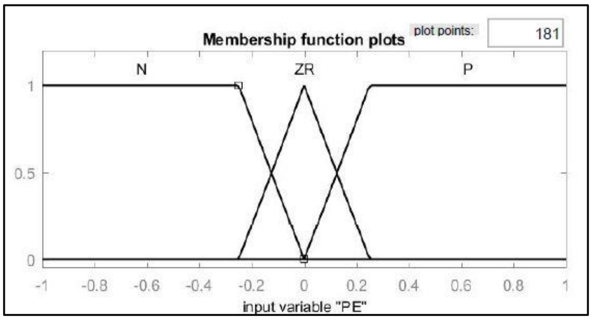
For the design of fuzzy controller, it is recommended to start with few membership functions since it is simple to design and modify. Also, it uses small number of rules; so as a start point, we will use three membership functions for each of the inputs and output and we will have nine rules to cover all possible inputs. These rules are usually written in Table I.

Table I. Fuzzy rules for 9_Rules fuzzy controller

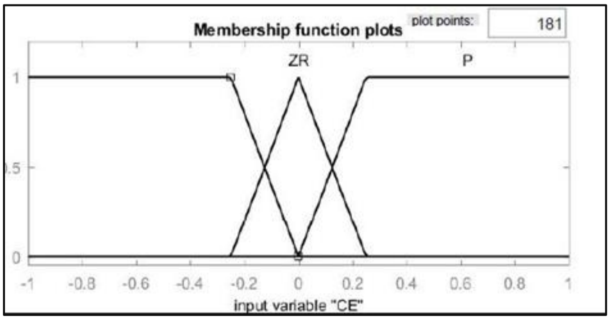
E CE	N	ZR	P
N	N	N	Z
ZR	N	ZR	P
P	ZR	P	P

Where N, ZR and P stand for Positive, Zero and Negative respectively. From Table I, the antecedent part (Error E and Change in error CE), expressed by:
If …… and ………, while the consequent part (Output V), expressed by: then...... For example the first law in the table is: (If E is N and CE is N then V is N).

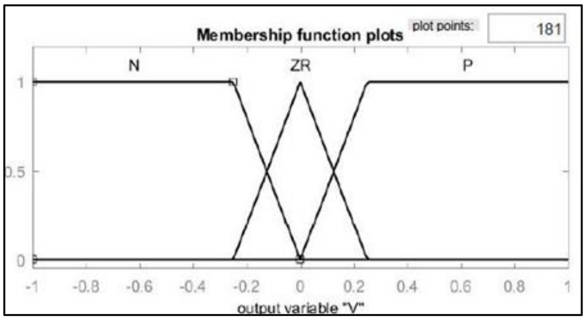
The first test is for the parameter's influence of the membership function. After adjusting them, their influence will be tested on the total system response. The design of these membership functions was depending on many factors including the experimental results of the total system response. For the inputs and output, triangle membership functions have been used for ZR (zero) and it is important to narrow the base of the triangle to reduce the oscillation in the system response. For P and N, trapezoidal membership functions have been used because they have ends extend beyond the universe of viscous as 1; this is important in cases that the value of error or change in error is bigger than 1 or smaller than -1. Shapes of membership functions of the 9_Ruls fuzzy controller of the inputs and output show in Fig. 3.



(a) Fuzzy proportional error (PE).



(b) Fuzzy change in error (CE).



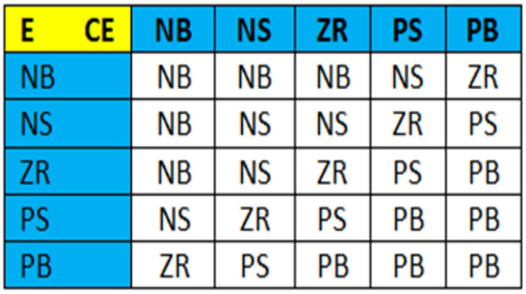
(c) Fuzzy Output (V).

Figure 3. Membership functions for fuzzy PE, CE and V for 9_Rules controller

3.2.2. Twenty five Rules fuzzy design

Next design is for five membership functions. This system will have more membership functions to describe the inputs and output. In the same time, it requires twenty five rules to cover all the possible inputs as shown in Table II.

TABLE II. FUZZY RULES FOR 25_RULES FUZZY CONTROLLER

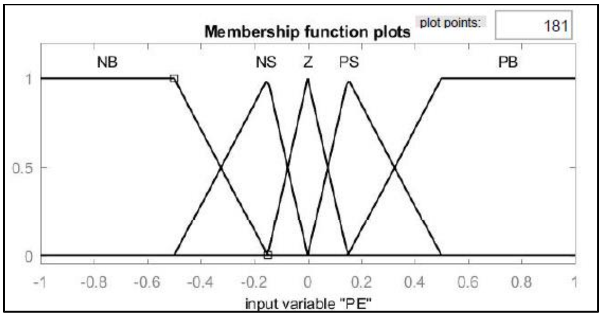


E CE	NB	NS	ZR	PS	PB
NB	NB	NB	NB	NS	ZR
NS	NB	NS	NS	ZR	PS
ZR	NB	NS	ZR	PS	PB
PS	NS	ZR	PS	PB	PB
PB	ZR	PS	PB	PB	PB

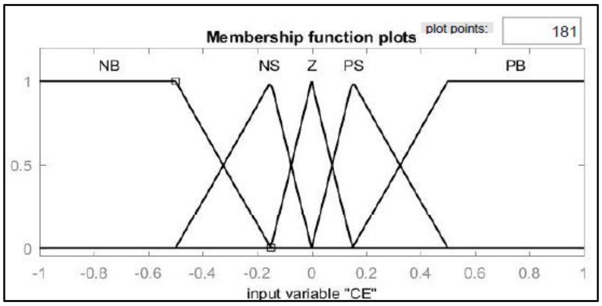
Where: NB: Negative big, NS: Negative small, ZR: Zero, PS: Positive small, PB: Positive big.

For this system, the design of membership shapes needed more modifications. The uniform triangle for NS, ZR, PS did not give good results despite it was better than the previous system (9_Rules fuzzy controller). The problem was in the oscillation near to the zero point and when the error became small, the system was not able to arrive to the desired value.

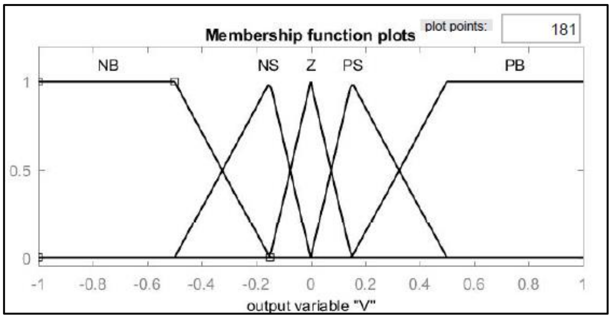
Fig. 4 shows the membership functions of E. CE and the output V for the twenty five rules fuzzy controller.



(A)Fuzzy proportional error (PE).



(b) Fuzzy change in error (CE).



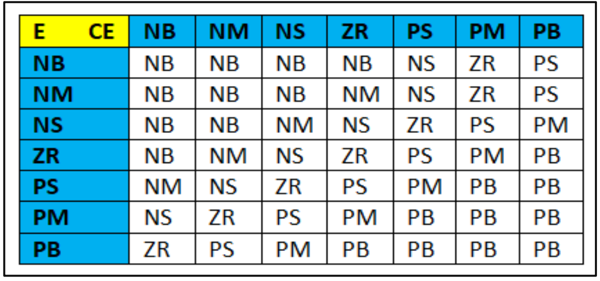
(c) Fuzzy Output (V).

Figure 4. Membership functions for fuzzy PE, CE and V for 25_Rules controller.

3.2.3. Forty nine Rules fuzzy design

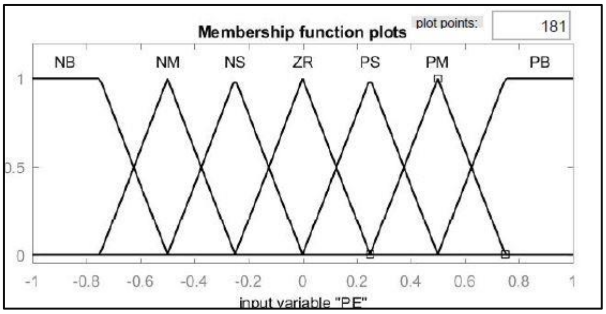
Next design is for seven membership functions. This system will have more membership functions to describe the inputs and output. In the same time; it required forty nine rules to cover all the possible inputs as shown in the Table III.

Table III Fuzzy rules for 49_Rules fuzzy controller

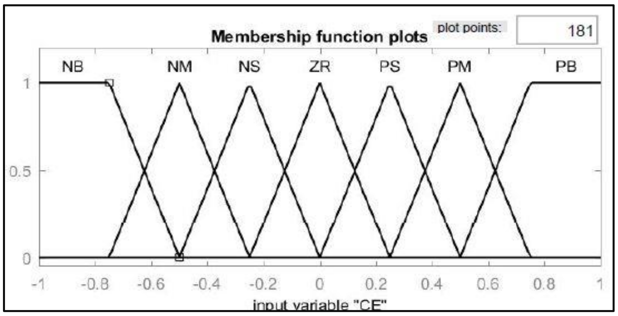


E CE	NB	NM	NS	ZR	PS	PM	PB
NB	NB	NB	NB	NB	NS	ZR	PS
NM	NB	NB	NB	NM	NS	ZR	PS
NS	NB	NB	NM	NS	ZR	PS	PM
ZR	NB	NM	NS	ZR	PS	PM	PB
PS	NM	NS	ZR	PS	PM	PB	PB
PM	NS	ZR	PS	PM	PB	PB	PB
PB	ZR	PS	PM	PB	PB	PB	PB

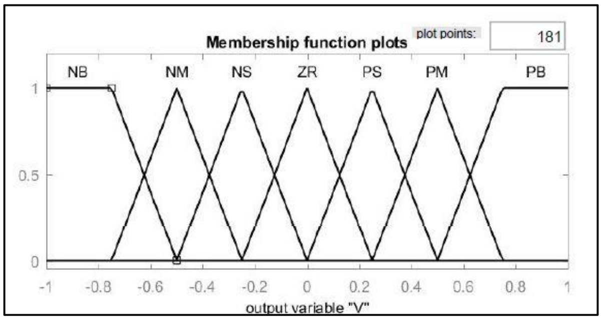
These inputs have seven membership functions with linguistic variable name as Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZR), Positive Small (PS), Positive Medium (PM) and Positive Big (PB). The fuzzy logic controller output has the same membership functions as fuzzy logic controller inputs. Fig.5 shows the membership functions of E. CE and output V for the forty nine rules fuzzy controller.



(a)fuzzy proportional error (PE).



(b) Fuzzy change in error (CE).



(c) Fuzzy Output (V).

Figure 5. Membership functions for fuzzy E, CE and V for 49_Rules controller

Results in Fig. 6 show the effect of both error E and change in error CE on the controller output V, a 3D surface Fig.6 can be shown for the three types of fuzzy control systems (9_Rules, 25_Rules and 49_Rules).

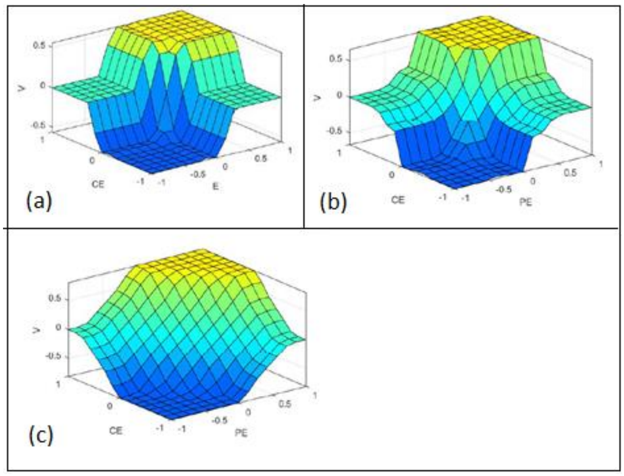


Figure 6. 3D surface fuzzy control system (a) 9_Rules, (b) 25_Rules, (c) 49_Rules

3.3 Genetic Algorithm Controller Design

The arrangement of the genetic algorithm tuning PID controller parameters shown in the Fig. 7. GA is employed to decide on optimally the values of PID controller gains (Kp Ki Kd) for the selected system. The controller is intended on the bases the error reduction of the output response with regard to the reference signal. The error is computed as the performance index, which denotes the "goodness" of the dynamic system performance. A control system performance is considered as an optimum if the values of the parameters (Kp Ki Kd) are select such that the performance index is the smallest. Integral time absolute-error criterion (ITAE) and integral absolute error (IAE) are chosen as an object operates in the controller design procedure. Then the evolution programming is employed to attenuate the areas indicated in Fig. 8.

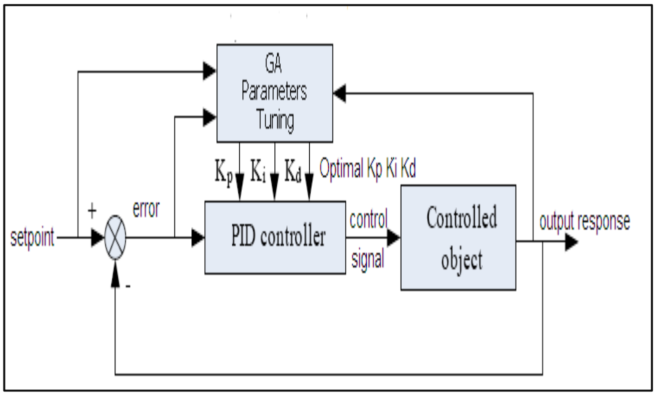


Figure 7. Arrangement of GA tuning PID controller for system

Where Error Criteria (ITAE) and (IAE) are given by:

$$ITAE = \int_0^T t * abs\left(e(t)\right)dt \qquad (5)$$

$$AE = \int_0^T abs\left(e(t)\right)dt \qquad (6)$$

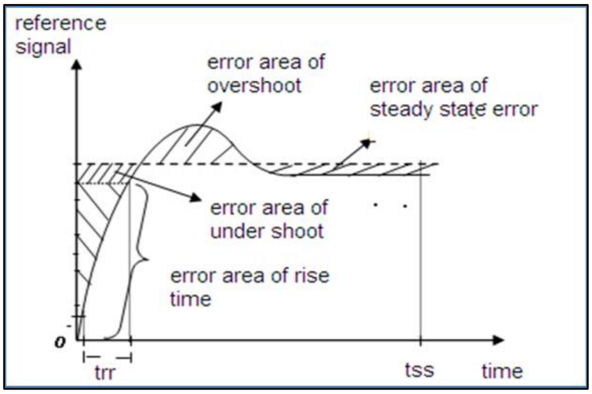


Figure 8. Areas of error for the system response

The major characteristics of the considered optimizer are as outlines in Table IV.

Table IV. Genetic algorithm parameters setting

Population size	40
Generation size	60
Fitness scaling	Rank
selection	Stochastic uniform
Crossover probability	80%
Mutation probability	1%
Fitness function	1/ITAE & 1/IAE
Stalled generation	50

The design process by GA can be abbreviated in the following steps **[11]**.

1- Random generation of initial population (initial Kp Ki Kd for controller suitable solution for problem).each row in matrix is represent chromosome which its value Kp Ki Kd population (P) matrix as shown in equation(7),

$$population = \begin{matrix} kp1 & ki1 & kd1 \\ kp2 & ki2 & kd2 \\ kpn & kin & kdn \end{matrix} \qquad (7)$$

N number of chromosomes in population at each generation.

2- Computation of the fitness value for every individual within the current population (ITAE for every individual in present generation). The fitness function in presented work is given in equation(8).

$$fittness\ function = \frac{1}{ITAE} \qquad (8)$$

3- Selection of bound variety of population that has higher performance than others in keeping with fixed choice techniques.

Best individual = parents in the next generation

4- Creation of new set of solution (new kp ki kd) from the elected individuals (best solution in previous generation).

$$newpopulation = \begin{matrix} kp1new & ki1new & kd1new \\ kp2new & ki2new & kd2new \\ kpnnew & kinnew & kdnnew \end{matrix} \qquad (9)$$

5- Utilizing genetic operators for the new set of solution (crossover & mutation).

6- Repeat previous steps (from 2 -5) till a stop criterion is confirmed. The flowchart of presented work is shown in Fig. 9.

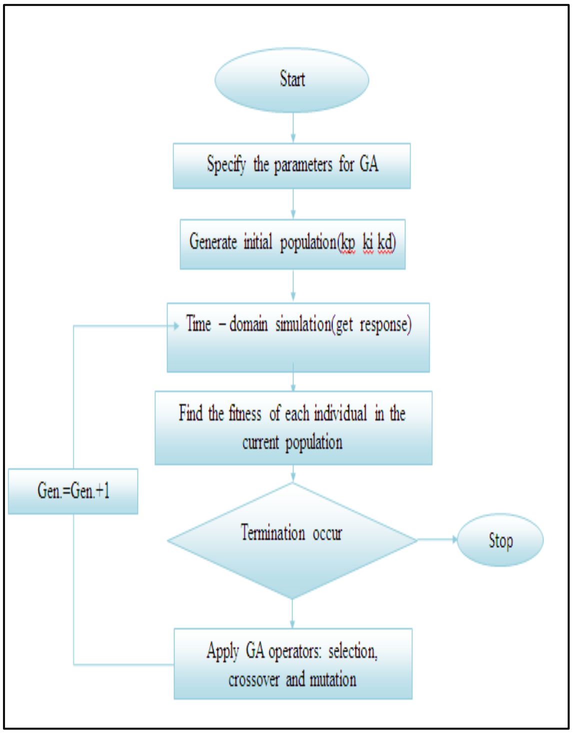


Figure 9. Flowchart of genetic algorithm procedure

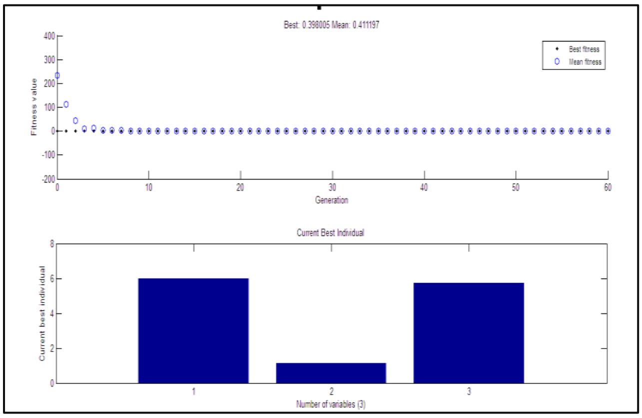


Figure 10. Best fitness and best individual

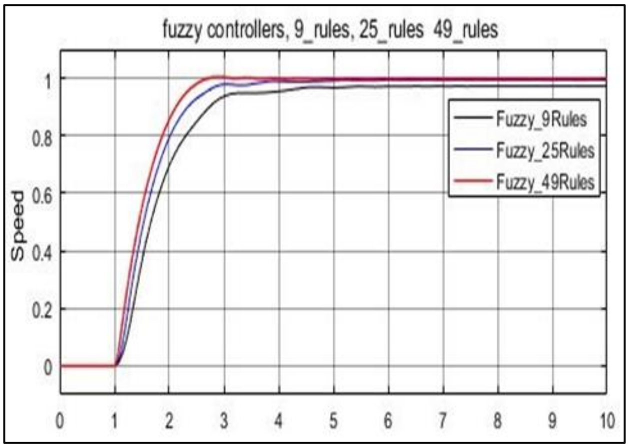
The Variation of fitness during generations in genetic algorithm and the best individual is shown in figure (10). The results in table V summarize the optimal values of gains in PID controller achieved by using genetic algorithm.

Table V. Gains of PID controller enhanced by genetic algorithm

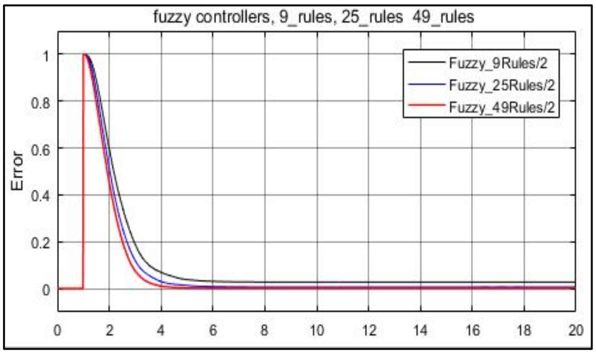
Performance Indices	Lower bounds	Upper bounds	Kp	Ki	Kd
GA_IAE	[0 0 0]	[6 6 6]	5.771	1.105	6
GA_ITAE	[0 0 0]	[6 6 6]	5.405	1.038	5.122

4. SIMULATION RESULT

Several simulation tests have been carried out to compare the performance of fuzzy control systems among themselves then another simulation tests carried out among GA_PID controllers. Finally a simulation test is carried out to compare the performance of PID controller, best PID optimized by GA and best fuzzy logic controller for an automobile cruise control system (ACCS) by using MATLAB computer simulation. A simulation program is designed to compare the stable and dynamic performances for the selected system. Fig.11 shown comparative results for the three fuzzy controllers, 9_rules, 25_rules and 49_rules (a) step response (b)the error signals, for the three types of the fuzzy controllers. The results show the fuzzy controller 49_rules reach faster than others.



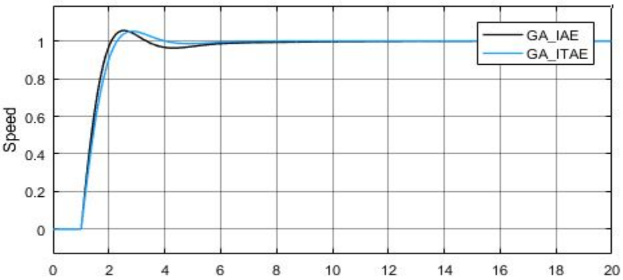
(a) Step response



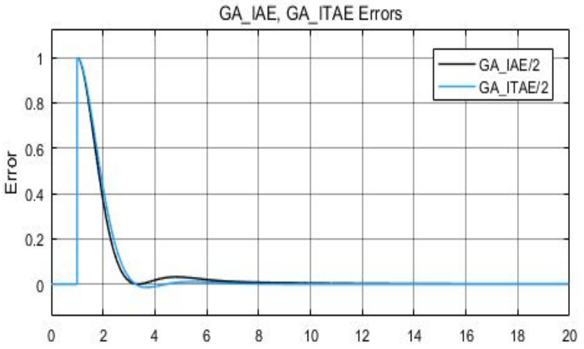
(b) The error signals.

Figure 11. Comparative results for fuzzy controllers (a) step response (b) the error signals.

Fig.12. as shown, is the performance of the PID controller based on genetic algorithm by two types of performance index integral time absolute-error criteria (ITAE) and integral absolute error criteria (IAE).The results show that performance index ITAE minimize lager area of error signals than the IAE criteria for the same conditions.



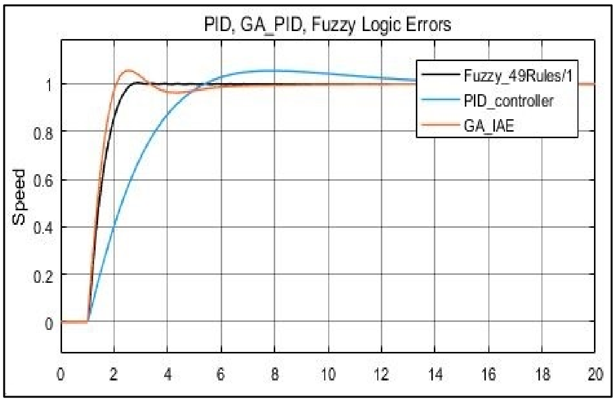
(a) Step response



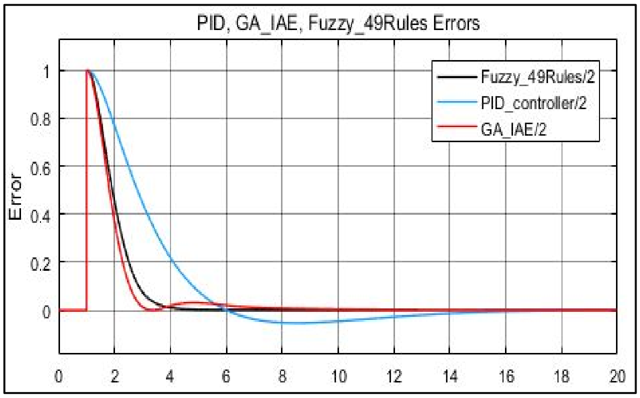
(b)Error signals.

FIGURE 12. COMPARATIVE RESULTS FOR THE GA_IAE AND GA_ITAE CONTROLLERS (A) STEP RESPONSE (B) ERROR SIGNALS.

Fig.13 as shown, is the performance of the conventional PID controller, fuzzy 49_rules controller and GA_PID based on ITAE controller with (a) step response and (b) error signals .The result show that the convectional PID reach settling time more than in fuzzy and GA_PID.



(a) Step response



(b) Error signals

Figure 13. Comparative result for GA_PID, fuzzy and conational PID controllers (a) step response (b) error signals

To evaluate the performance and stability of the system a series of measurement have been achieved .We have selected the maximum overshoot, rise time , settling time, steady-state error and peak time. These measurements are compared and summarized in Table VI.

Table VI. Comparison of the step responses of three controllers on

Controller plan	Maximum overshoot (%)	Rise time	Settling time	Error steady state	Peak time
conational PID	5.5	2.948	11.467	0	7.914
Fuzzy 49_rules	0.40	1.01	2.28	0	2.92
GA_PID (ITAE)	4.51	0.851	2.59	0	2.824

(ACCS)

From the performance comparison in table 6, it is clearly visible the maximum overshoot of the system in fuzzy controller is much better than from the PID & PID tuning by GA but the GA_PID controller gives less rise time as compared to fuzzy and conventional PID controller.

5. CONCLUSION

This paper highlights on the comparison study to have best approach in performance design between PID, Fuzzy logic and GA-PID, so the fuzzy logic is the best in maximum overshoot, settling time, with zero steady state error, while the GA-PID was the best in rise time, peak time with no steady state error. To sum up, the results show that proposed fuzzy and GA-PID controllers have promising performance, fast acting, settling as well as high accuracy, therefore these controllers are more suitable when the high performance of the system is needed.

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