# *Impelementation of Cruise Control system and tuning by PID Controller by using Genetic Algorithm*

*by*

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# Implementation of Cruise Control System and tuning by PID Controller by using Genetic Algorithm

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**Abstract**

Modern automobiles are equipped with various driver assistance functions which enhance safety and relieve driver fatigue. With the development of sensor technology, the Cruise Control system has been put into practice. This case study discusses the modelling and design of a cruise control system. The system model, which is highly nonlinear, has been linearized around the equilibrium point. The controller has been designed for the linearized model, by taking the dominant pole concept in the closed loop characteristic equation. The open loop performance is analysed and according to the design requirements a Proportional-Integral-Derivative (PID) controller is designed and implemented. The PID controller is then tuned using different methods, first by optimising it using the Ziegler-Nichols method. Later, The PID controller parameters, i.e. proportional,integral and derivative parameters have been tuned using Genetic Algorithm (GA). The performance characteristics are then compared and evaluated. The transient and frequency response analysis of the final system is then discussed using Bode plot, and Step response diagrams. This report was done as a requirement for the SiCo-1 Module and submitted to Prof. Dr. Andreas Becker.

**Index Terms**

Cruise Control, System Modelling, PID controller, Genetic Algorithm

## I. Introduction

Automobile cruise control system [7] has become a common feature of modern vehicles for driver comfort in long-distance travels. Cruise Control is a control system to regulate the vehicle speed so that it follows the driver's command and maintains the speed at the commanded level to maintain a safe distance from other vehicles in front of it. Cruise controller design is applied assuming a single-loop system configuration with a linear model and nonlinear model. The purpose of the cruise control system is to maintain a constant vehicle speed despite external disturbances, such as changes in wind or road grade. This is accomplished by measuring the vehicle speed, comparing it to the desired or reference speed, and automatically adjusting the throttle according to a control law.

In this case study, The controller function is designed to augment or modify the open-loop function in a manner that produces the desired closed-loop performance characteristics. The plant functions represent the actuators and the controller part of the system, and the plant parameters are determined primarily by functional aspects of the control task. Before making the decision of controller design, a few design specifications have been set. In this design, we take two considerations to be met which are settling time Ts less than 5s and percentage of overshoot %OS is less than 10%. The PID controller has been utilized for speed control of the cruise control system and the outcomes obtained from improvement utilizing the Genetic Algorithm are contrasted with the ones obtained from the Ziegler-Nichols strategy[2], and relatively better results are obtained in the Genetic algorithm case. The streamlining of the PID controller parameters is a standout amongst the most essential fields in execution and outlining of PID controllers [2].

The rise time of the system must be improved. The implementation of Proportional Control improves the rise time of the system. The overshoot that could happen while accelerating the vehicle to the set speed needs to be avoided. This is taken care of by the Derivative Control. To reduce the steady-state error, there is a requirement that the Integral Control is implemented. There is a possibility that a controller could be designed only by combining any two of the above control terms. But, the cruise control system being a very safety critical system, it is required that all three control terms are implemented to ensure efficiency and accuracy.

## II. METHODOLOGY

The traditional and broadly acknowledged technique for tuning the PID parameters is calculation by the Ziegler-Nichols system. By implementing tuning methods by using the Ziegler-Nichols Method, the efficiency of the PID controller can be improved. For better versatile reaction of the framework, in vicinity of outer glitches, the utilization of different delicate registering procedures like Fuzzy-Logic, Artificial Neural Networks, Genetic Algorithms, Particle Swarm Intelligence, Neuro Fuzzy, Neuro-Genetic, and so on have ceded better results.

In this case study, the optimization of the PID controller additions has been completed for parameter tuning by Genetic Algorithms, while utilizing the Ziegler-Nichols parameters for the determination of the lower and upper headed points of confinement for the introduction of PID parameters.

## III. CRUISE CONTROL SYSTEM

The main function of a cruise control system is to maintain the velocity of the car as per the reference velocity set by the driver. Fig.1 shows the block diagram of the cruise control system used for this case study.

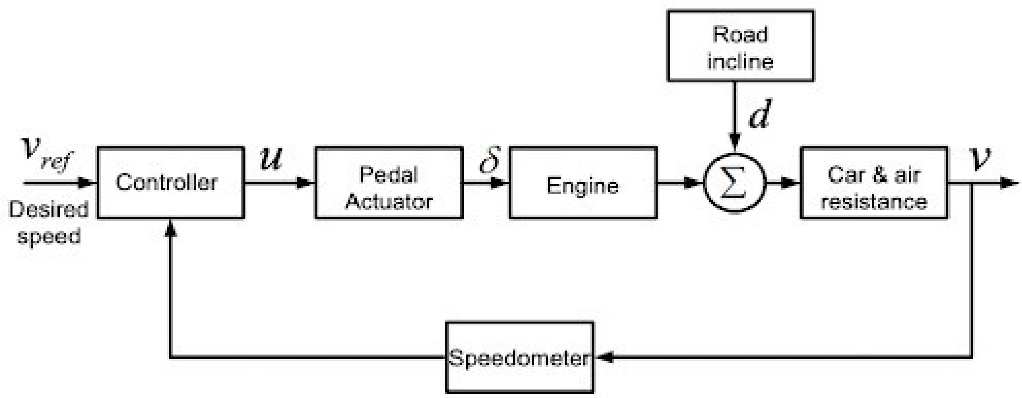


Fig. 1: Schematic block diagram of Cruise Control System [11]

Here, the system calculates the difference, owing to the disturbances, between the actual velocity from the speedometer and reference velocity set. For maintaining this desired velocity, the pedal actuator generates the desired amount of gas pedal depression ($\delta$) when the road inclination angle increases. This is done by the actuators governing the throttle valve of the automobile to maintain the fuel injection to the engine, thus providing an optimum speed. The longitudinal dynamics of the vehicles is governed by Newton's law which is as follows[11]:

$$F_d = M \frac{d}{dt} v + F_a + F_g \tag{1}$$

Here, $M\,(dv/dt)$ is the inertia force, Fa is the aerodynamic drag and $F_g$ is the climbing resistance or the downgrade force. The actuator of the cruise control system is modeled as a first order lag system. The equation for the engine drive force is:

$$F_d = \frac{C_1 e^s}{T s + 1} \tag{2}$$

The forces $F_d$,$F_a$, and $F_g$ are produced as shown in the model of Fig.4, where $V_w$ is the wind gust speed, $M$ is the mass of the vehicle and passenger(s), $\theta$ is the road grade, and $C_a$ is the aerodynamic drag coefficient.

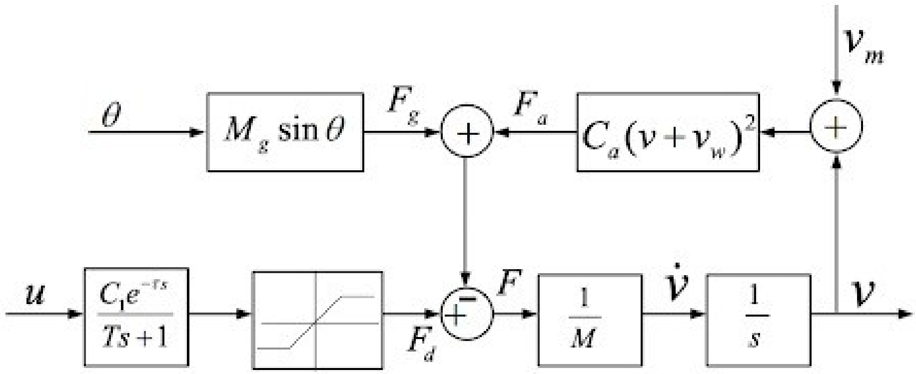


Fig. 2: Dynamic model of a vehicle

As it can be seen the system is highly non-linear. Thus, to design the controller, it is first linearized by setting the initial conditions and all disturbance parameters to zero.

$$\dot{v} = \frac{1}{M}(F_d - C_a v^2) \tag{3}$$

$$\dot{F_d} = \frac{1}{T}(C_1 u(t - T) - F_d) \tag{4}$$

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

The system is further linearized as there still exists non-linearity due to the quadratic term. By using Taylor series expansion, the transfer function becomes

$$G_p(s) = \frac{\Delta V(s)}{\Delta U(s)} = \frac{\frac{C_1}{MT}}{\left(s + \frac{2C_a v}{M}\right)\left(s + \frac{1}{T}\right)\left(s + \frac{1}{\tau}\right)} \tag{6}$$

It is obvious that the system described by this transfer function is a third order system, as a result of the time delay approximation. Despite that, the transfer function has been successfully linearized. The upcoming calculation shall be as difficult as if the linearization has not been done. At least the complexity of the calculations have been reduced.

TABLE I: Parameter used for Modelling

| Symbol | Value | Unit |
|---|---|---|
| $C_1$ | 743 | - |
| $C_a$ | 1.19 | $N/(m/sec)^2$ |
| M | 1500 | kg |
| $\tau$ | 0.2 | sec |
| T | 1 | sec |
| $F_d max$ | 3500 | N |
| $F_d min$ | -3500 | N |
| g | 9.8 | $m/(sec^2)$ |

After substituting the value for the parameters mentioned in Table 4, the transfer function [8] for such a cruise control system is:

$$G_p(s) = \frac{\Delta V(s)}{\Delta U(s)} = \frac{2.4767}{(s + 0.0476)(s + 1)(s + 5)} \tag{7}$$

## IV. PID C ONTROLLERS

Proportional Integral and Derivative – PID controllers because of their simplicity and acceptability, are playing an imperative role in control systems, and for regulating the closed loop response in industrial controls, PID controllers alone contribute 90% of all the PIDs used today[4].

A PID, the controller-based system, is represented in a simple block level diagram as in Fig.3.

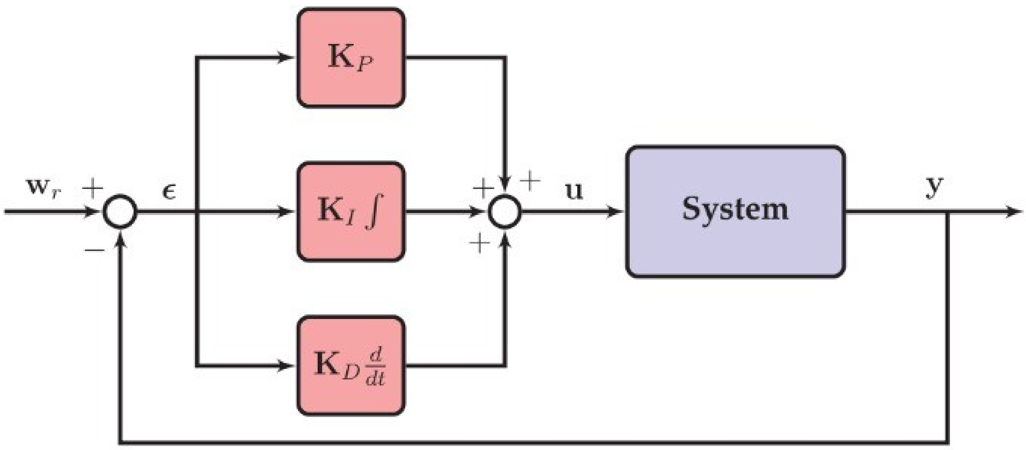


Fig. 3: Proportional-integral-derivative (PID) control schematic.

The general equation for a PID controller for the above figure can be given as[5]:

$$y = k_p.w_r + k_i.w_r.dt + k_d \frac{dw_r}{dt} \quad (8)$$

where KP , KI and KD are the controller gains, y is output signal, wr is the difference between the desired output and output obtained. PID control additionally combines three terms to form the actuation signal, based on the error signal and its integral and derivative in time.

## V. DESIGN SPECIFICATIONS

The design specifications for this study have been considered as:
Maximum overshoot (Mp) 6 10% and
Settling time (ts) 6 5 sec

## VI. DESIGNING AND TUNING OF PID CONTROLLERS

### *A. PID TUNING USING ZIEGLER-NICHOLS METHOD*

The Ziegler-Nichols tuning method is one of the practical techniques to tune a PID controller. According to this method, a PID controller is tuned by first making the Ki and Kd equal to zero, that is,by setting it to the P-only mode. Kp gain is adjusted by bringing the system into marginal stability or sustained oscillations. The corresponding gain is referred to as the ultimate gain (Ku) and the oscillation period is termed as the ultimate period (Pu)[9].

*1) **Determination of the Ultimate Gain (Ku) and Period (Pu)**:* The key step of the Ziegler-Nichols tuning approach is to determine the ultimate gain and period. However, to determine the ultimate gain and period experimentally is time consuming. Since the continuous oscillation mode corresponds to the critical stable condition, for linear systems, such a condition can be easily determined through stability margins. Other tools, such as the Routh criterion and the Root locus, cannot deal with a time-delay directly.

Let the plant have a gain margin Gm at crossover frequency $\omega_c g$. This is equivalent to connecting with a unit gain controller. Therefore, if the controller gain increases by Gm, then the system will oscillate at frequency $\omega_c g$. Therefore, $K_u$ and $P_u$ can be determined from $G_m$ and $\omega_c g$ as follows:

$$K_u = G_m \tag{9}$$

or

$$p_u = \frac{2.\pi}{\omega_c g} \tag{10}$$

$$20log_{10}(k_u) = G_m\ (dB) \Rightarrow 10^{Gm/20} \tag{11}$$

Hence, the other PID parameters can be determined from Ku and Pu using Table 2.

TABLE II: Ziegler Nichols Tuning Parameters

| Controller | Kc | Ti | Td |
|---|---|---|---|
| P | Ku / 2 | - | - |
| PI | Ku / 2.2 | Pu / 1.2 | - |
| PID | Ku / 1.7 | Pu / 2 | Pu / 8 |

Using the above table, the gains for P, PI and PID controllers for the cruise control system were calculated as mentioned in Table 3.

TABLE III: Ziegler Nichols Tuning Parameters

| Controller | Kp | Ki | Kd |
|---|---|---|---|
| P | 6.4052 | - | - |
| PI | 5.7647 | 2.5413 | - |
| PID | 7.5581 | 5.5311 | 2.4787 |

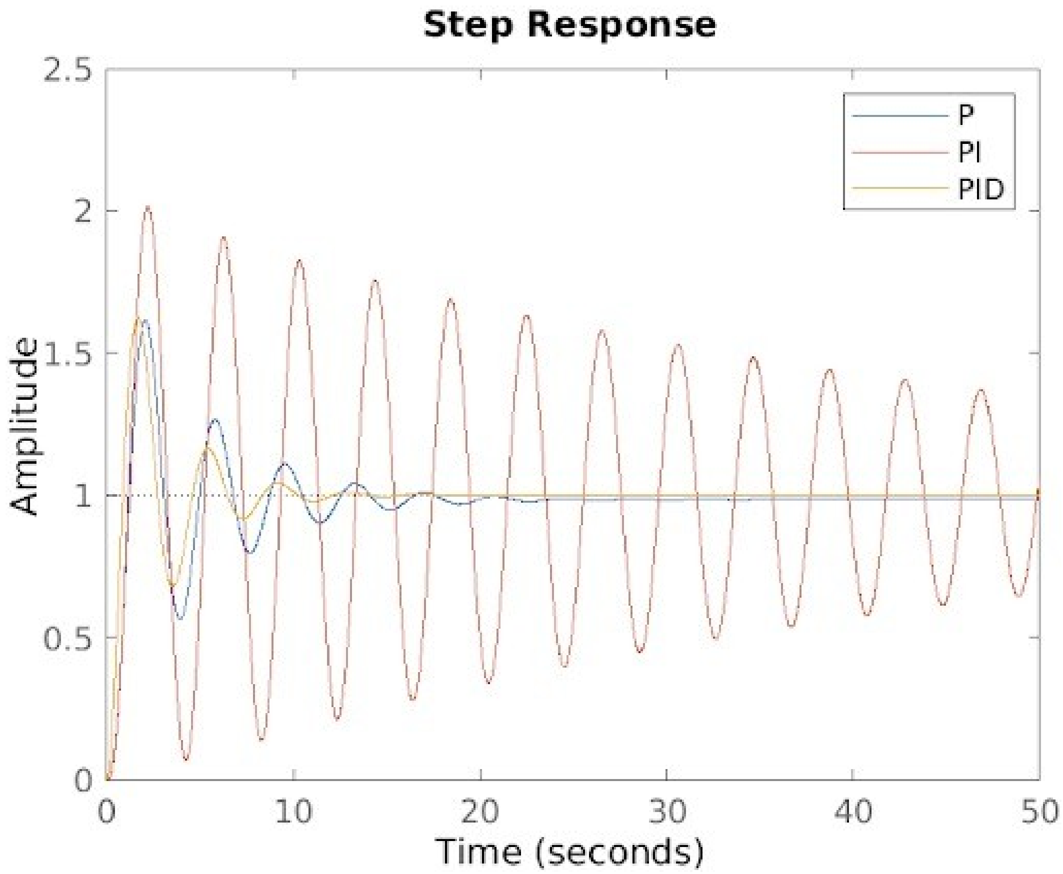


Fig. 4: Comparison of step response of P, PI, PID controller based on ZN tuning

The step response for these different controllers was observed and the results are as shown in Fig.4. The performance characteristics were measured (Table 3) and analysed. The peak overshoot and settling time is considerably large for the PI controller. When comparing PD and PID controllers, the peak overshoot is slightly less for the PD controller, however, the settling time between the two differs by a factor of around 16. Thus the PID controller is the best choice among these three. As it can be seen using the controller is not optimised as per our design requirements, therefore further optimisation is required.

TABLE IV: Comparison of P,PI,PID controller based on ZN method

| Strategy | Peak Overshoot(%) | Rise Time (Tr) | Settling Time (Ts) |
|---|---|---|---|
| ZN P | 61.4294 | 0.7282 | 23.1110 |
| ZN PI | 101.1084 | 0.6819 | 178.7866 |
| ZN PID | 62.4814 | 0.5748 | 11.2887 |

## VII. PID OPTIMISATION USING GENETIC ALGORITHM

Since the Ziegler-Nichols-based PID controllers give an oscillatory reaction, the PID parameters are not ideal for direct execution for the plant. So their sorted-out improvement is a must, so that better parameters can be assessed and when connected to the framework, convey better execution and power. The Genetic Algorithm gives an answer for the improvement of the PID controllers, by minimizing the goal capacity[2][3].

*1) **Genetic Algorithm**:* The genetic algorithm (GA) is one of the simplest algorithms for parameter optimization, which have been widely used for optimization and control in nonlinear systems. GA is frequently used to tune and adapt the parameters of a controller. In GA, a population of many system realizations with different parameter values compete to minimize a given cost function, and successful parameter values are propagated to future generations through a set of genetic rules. The parameters of a system are generally represented by a binary sequence, for a PID control system with three parameters, given by the three control gains KP, KI, and KD. Genetic algorithms are generally used to find nearly globally optimal parameter values, as they are capable of exploring and exploiting local wells in the cost function. In this case study, the transfer function of the cruise control system has been obtained. Classical Zigler-Nichols-based PID controller tuning has been used to tune the controller initially. Since an oscillatory response has been obtained, the parameters are not optimum for the implementation in the real plant. So, genetic algorithms have been used to optimize the controller. The three PID gains are stored in the variable params. Next, it is relatively simple to use a genetic algorithm to optimize the PID control gains. We have run the GA for 25 generations, with a population size of 40 individuals per generation.

*2) **Objective Function for Genetic Algorithm**:* From the basics of the control system, it is known that maximum overshoot is a function of $\xi$ and settling time is a function of $\xi$ and $\omega_n$. The formulas for maximum overshoot and settling time are provided in equation (11) and (12):

Maximum overshoot

$$Mp = e^{\frac{\sqrt{-\pi\xi}}{1-\xi^2}} \tag{12}$$

For 2% tolerance band, settling time

$$t_s = \frac{4}{\xi\omega_n} \tag{13}$$

Substituting the values for $M_p$ and $t_s$,

$$\xi = 0.5913 \text{ and } \omega_n = 1.3529$$

After putting these values in the characteristic equation $(s^2 + 2\xi\omega_n s + \omega_n^2 = 0)$, the dominated poles are $s_{(1,2)} = -0.8 \pm 1.09i$

The characteristics equation of the system with PID controller for unity feedback is given by:

$$1 + G_P(s)G_{PID}(s) = 0 \tag{14}$$

$$1 + \frac{2.4767}{(s + 0.0476)(s + 2)(s + 5)} \left(k_p + \frac{k_i}{s} + k_d s\right) = 0 \tag{15}$$

Substituting the value of s1 in the above equation, the real (R) and imaginary (I) parts are found to be

$$R = 1 - 0.3032k_p + 0.2813k_i - 0.0220k_d \tag{16}$$

$$I = 0.2435k_p + 0.0742k_i - 0.5252k_d \tag{17}$$

The objective function 'f' considered for computing the value of kp,ki and kd as the equation below :

$$f = |R| + |I| \tag{18}$$

The objective function of equation (17) has been optimized through GA for finding the PID controller parameter values. The ranges of the unknown variables kp, ki and kd, and The parameters considered for writing the MATLAB code are Table.5 [10].

TABLE V: Parameters in MATLAB Code

| Parameter | Values |
|---|---|
| No. of population | 40 |
| Max. Generation | 25 |
| Lower Bound [kp ki kd ] | [3 0.1 3] |
| Upper Bound [kp ki kd ] | [4 0.25 4] |

The evolution of the cost function across various generations is shown in Fig.5. As the generations progress, the cost function steadily decreases.

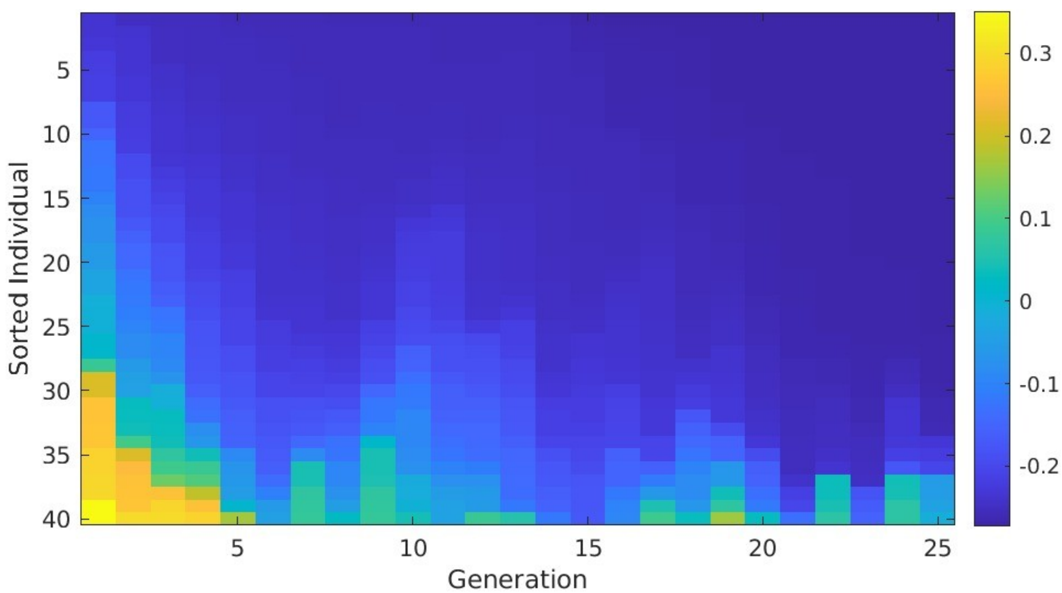


Fig. 5: Cost function across generations, as GA optimizes PID gains

The individual gains are shown in Fig.6 with redder dots corresponding to early generations and bluer generations corresponding to later generations. As the genetic algorithm progresses, the PID gains begin to cluster around the optimal solution (black circle).

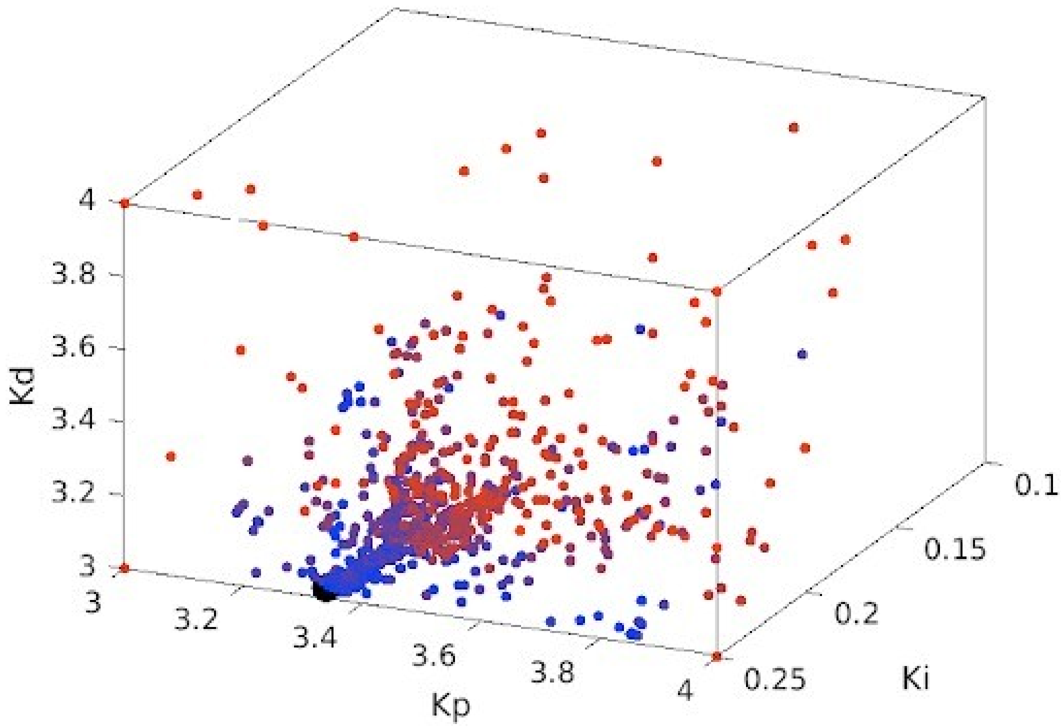


Fig. 6: PID gains generated from genetic algorithms. Red points correspond to early generations while blue points correspond to later generations. The black point is the best individual found by GA.

Fig.7 shows the output in response to the PID controllers from the first generation. In contrast, Fig.8 shows the output in response to the PID controllers from the last generation. Overall, these controllers are more effective at producing a stable step response.

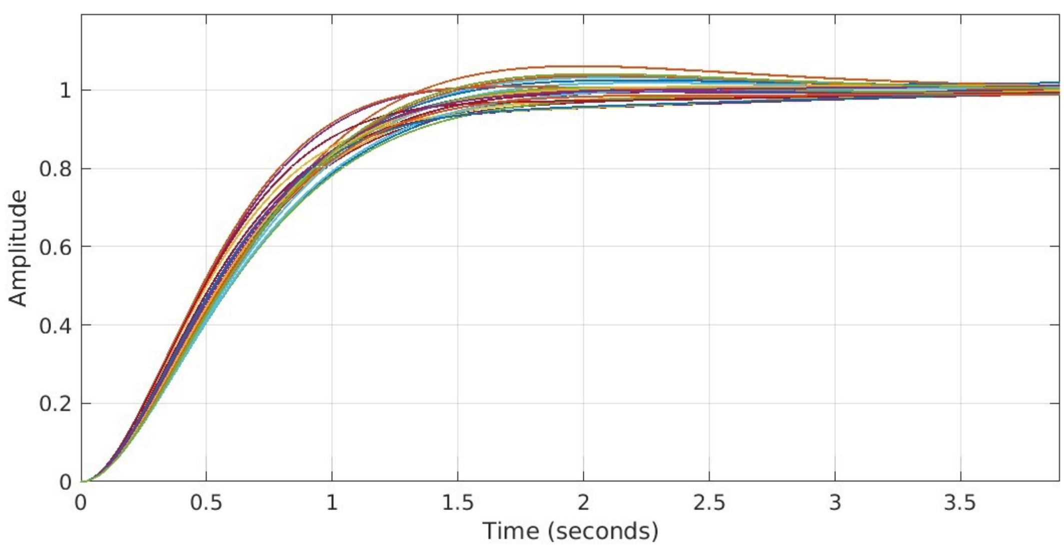


Fig. 7: PID controller response from first generation of genetic algorithm

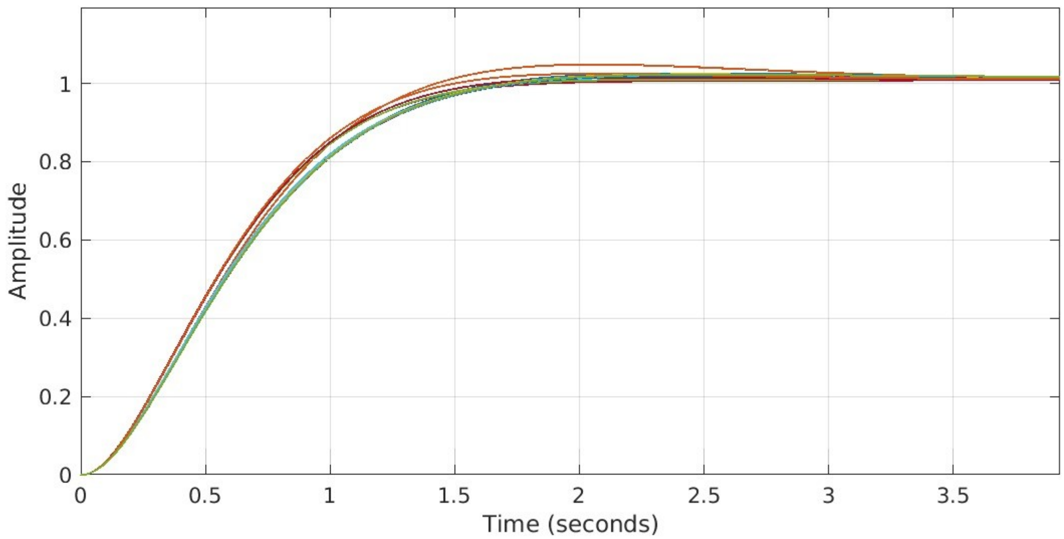


Fig. 8: PID controller response from last generation of genetic algorithm

## VIII. Simulation Results and Discussion

The results of choosing and optimizing the controller for the Cruise Control System were analysed according to the set design requirements. Firstly, the system model obtained was linearized. The open loop performance characteristics based on the step response can be seen in Figure. 9. As shown, the system is not controlled, the rise time is too high and the settling time is very large. Thus, it can be inferred that the system takes a long time to stabilize. The steady state error also has a very high value. The characteristics of P, PI, and PID controllers obtained from the ZN method show that the PID controller has the best response among all. However, there was still a possibility to tune it further. Using a Genetic Algorithm, we further enhanced the control output. From the comparison in Table 6., it can be seen that there is a 60% reduction in the peak overshoot. This resulted in a slight increase in the rise time compared to the PID tuned using the ZN method. The settling time is also lowered from 11.288 to 3.193, thus the system reaches the steady state much faster. Overall, it can be said that PID tuned using Genetic Algorithm gives the best results.

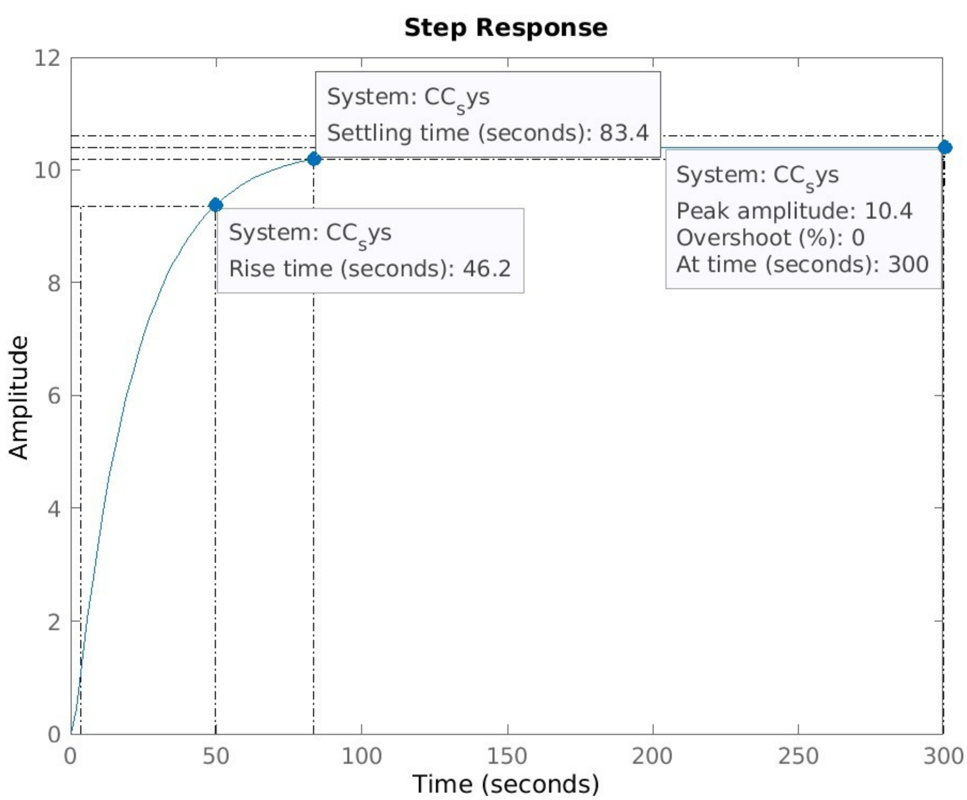


Fig. 9: Step response of system without controller

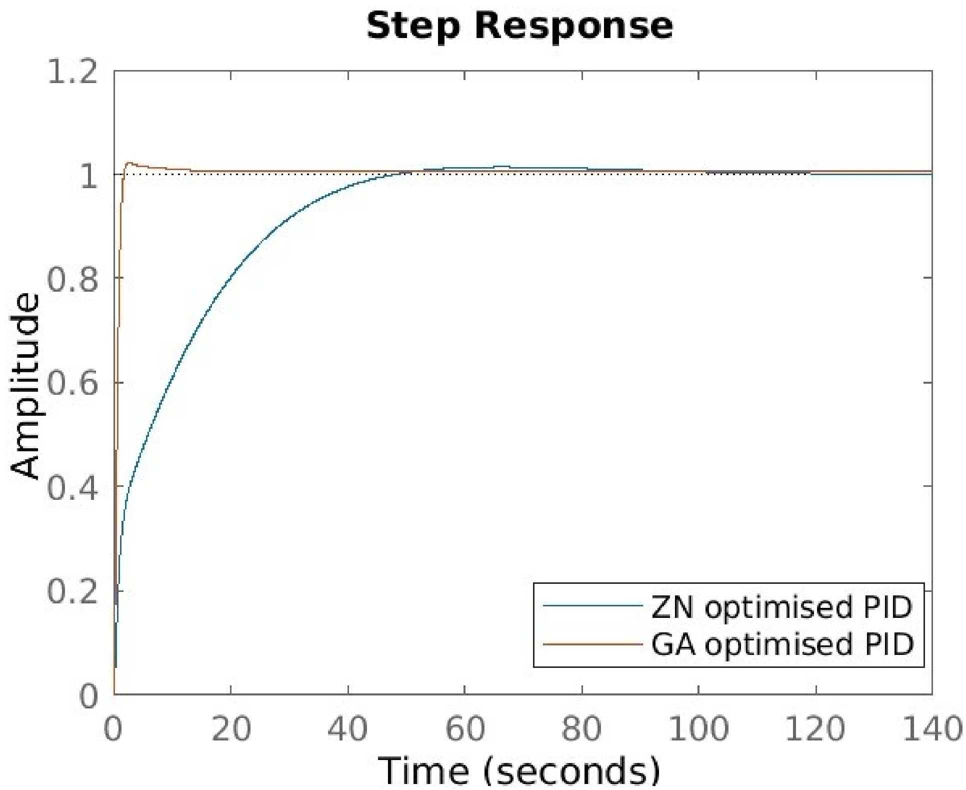


Fig. 10: Step response of system with PID controller optimised by ZN and GA method

TABLE VI: Comparison of performance characteristics of different strategies

| Strategy | Peak Overshoot(%) | Rise Time (Tr) | Settling Time (Ts) |
|---|---|---|---|
| ZN P | 61.4294 | 0.7282 | 23.1110 |
| ZN PI | 101.1084 | 0.6819 | 178.7866 |
| ZN PID | 62.4814 | 0.5748 | 11.2887 |
| Genetic Algorithm | 2.2059 | 1.0235 | 3.1930 |

## IX. CONCLUSION

Implementation of the PID Controller in an Adaptive Cruise Control System will improve the reactivity of the system.The proportional, integral and derivative terms of the PID controllers each play a very important role in improving the efficiency of the Cruise Control system. The use of the Genetic Algorithm for optimizing the PID controller parameters as presented in this case study offers advantages of tremendously decreased overshoot percentage, rise and settling times for the designed cruise control.

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