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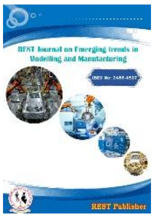

Performance Analysis of PI and PID Controllers in Process and Cruise Control Systems

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Abstract

Proportional-Integral (PI) and Proportional-Integral-Derivative (PID) controllers are commonly employed in process and Cruise Control Systems (CCS) to control system behaviour. PID controllers have a derivative action to improve transient response and system stability, while PI controllers use proportional and integral actions to minimise steady-state errors. This study explores the performance of both controllers in these applications by designing and implementing them within each system. The methodology involves simulating the systems under different conditions, including variations in setpoints and disturbances, to observe how the controllers manage dynamic behavior. The study assesses both controllers' performance in various scenarios, emphasising their capacity to manage disruptions and preserve stability. The study's objective is to offer a thorough comprehension of the design and performance characteristics of PI and PID controllers in process and CCS, offering insights into their suitability based on specific system requirements and performance goals. The PI controller is found to be the best choice for certain applications due to its simplicity and effectiveness.

Keywords: PI and PID controllers, Cruise control systems, Adaptive Cruise Control.

Introduction

Controllers are necessary in order to add the necessary zeros and poles in order to attain the desired transient reaction and enhanced steady-state inaccuracy. Stated differently, a short settling time with a small percentage of overrun is indicative of an intended transient reaction. Low percentage exceed means that the waveform deviates slightly from the stable state, or the value it reaches at the highest point period, expressed as a percentage of the steady state value. Low settling time means that it requires fewer seconds for the transient's reducing oscillations to reach and maintain a value within 2% of the steady state value. Once the transitions have passed, an acceptable steady state error indicates that the input-output difference is negligible. It is necessary for the inverter to have a simple sinusoidal wave that has minimal Total Harmonic Distortion (THD), a small proportion of overshoot, and great reduction in steady state error. Recent years have seen the growth of contemporary technologies aided by power electronics. The power inverter is an essential part that aids in the control and conversion of electric power, which is the primary function of power electronics and has a variety of uses [1]. In order to activate a variety of devices, power inverters transform DC power into AC power. Its main applications include induction motors, UPSs, automatic voltage regulator systems, active power filtering, and many more. Regardless of the type of load attached to them, the power inverters in these networks must generate a waveform of sinusoidal output voltage that is precise, flawless, and impeccable. Possessing a feedback controller will enable this [2] [3]. The inverter's ability to regulate both voltage and frequency allows for classification. Several industrial processes depend on precise management of liquid levels and flow rates, especially in the chemical processing sector where accuracy has a direct bearing on both the security and quality of the final product. The versatility and strong performance of PID controllers in preserving desired system behaviour have historically made them the preferred choice. Notwithstanding their extensive application, PID controller tuning for nonlinear systems—like coupled tank systems—can be extremely difficult due to the intricate interactions and fluctuating dynamics of these systems. Due to their widespread use in industry, coupled tank systems are ideal for examining the efficacy of various control schemes since they need precise management of the liquid flow across connected tanks. Fractional-order controllers are generally more resilient than regular controllers for dynamic and nonlinear systems. Using fractional powers in integrated and derived interactions allows fractional-order controllers to operate better, extending the capabilities of classical controllers. A more adaptable response to changing system dynamics is provided by fractional-order controllers, which are obtained from integer-order controllers using fractional powers. Significantly more flexibility in controller design is made possible by the added divisional and integral-order parameters, which improves system durability and dynamic performance adjustment. Particularly when dealing with high and low-frequency dynamic behaviour, this enhanced flexibility is essential to striking a balance between the system's stability and reaction velocity. An Adaptive Cruise Control (ACC) vehicle's main goal is to minimise crashes by improving changeover or braking manoeuvres. The technical capabilities of cars with ACC systems ought to be taken into account while reducing speed in the event of an impact [4,5]. A number of elements, including sensor accuracy, control algorithm design, and the system's ability to respond to actual traffic situations, influence the efficient an ACC system is. In addition, the system's effectiveness could be impacted by the state of the roads, the weather, the behaviour of other cars, and other variables. Reading scholarly sources on assessing different research regarding ACC systems requires an understanding of the dynamics of the control system that is offered as well as the influence that is generated by multiple factors in order to establish an effective ACC system.

Literature Review

Salam et al., have used software modelling to create a 1-phase PWM inverter with the main objective of studying the waveforms of the input and output [6]. Gunasekaran et al., have stated that, for nonlinear CCS, fractional-order PID controllers were designed with wind drag and wheel rolling friction are taken into consideration [5]. Idir et al., have claimed that the Harris Hawks optimisation algorithm was used to investigate how different approximation techniques affected a Low-Order Fractionalised PID (LOA/FPID) controller for controlling the pitch angle of an aeroplane. They applied Carlson, Oustaloup, and Matsuda's fractional integral approximation techniques along with a traditional feedback loop. Both the potential benefits of the GPID controller presented in this work and the continuous efforts to create novel adaptive cruise control devices using fractional-order approaches are highlighted in this collection [7]. Tumari et al., have stated that due to their enhanced efficiency in dynamic systems, fractional-order PID controllers have become more and more popular in recent years. The Marine Predators Algorithm-based automatic voltage regulator tuning tool has improved the power system's dynamics and reliability [8]. According to Ali et al., a PLC can be used to build an IoT-enabled level management mechanism, increasing the controller's capability for remote control and surveillance [9]. Chakraborty et al., have conducted additional research into the usage of PLCs in water level management. By creating a PLC-SCADA-based method for managing water storage in semi-automatic plants, they were able to increase operational efficiency and dependability [10]. In order to control liquid levels, Yahya et al. investigated a PID-based PLC control module, proving the dependability of PLCs in control tasks [11]. Suharti et al.'s work, which focused on a PLC-related flow control system specifically made for chemical engineering applications, demonstrated how effective PLCs are in managing complex processes conditions [12]. Gao et al., have described a complex and nonlinear system cannot be controlled using the conventional PID approach. In order to correct nonlinearity in dynamic frameworks, fractional calculus is given far higher importance in the field of control systems [13]. Safaei and Tavakoli The integrator and differentiator of the fractional PID controller are of order λ and μ, respectively. The enhanced performance of our controller over the traditional PID controller has been verified. Five parameters are used to classify FOPID controllers: derivative and proportional gain, integration and derivative order [14]. According to Muresan et al., the error history data stated that the FOPID type controller can accurately alter the results and has storage capability to enhance performance. Lastly, adjusting the low-frequency characteristics and closed high-frequency loop is made easier by the extra fractional order terms [15].

Research Methodology

The research methodology for the study on the evaluation of PI and PID controller performance and CCS begin with a thorough literature review to understand the theoretical background and practical applications of these controllers. Mathematical models for both process and CCS are developed, capturing the dynamics of the systems, including the vehicle's velocity and resistance forces. The controllers, PI and PID, are designed based on the error signal between the desired and actual outputs. The system is simulated using MATLAB/Simulink, incorporating various tuning methods for the PI and PID controllers to optimize performance. Essential performance indicators such as rise and settling time, overshoot, and steady-state error are chosen for comparative analysis. Sensitivity analysis is performed to evaluate the robustness of the controllers under varying system parameters. The controllers' performance is assessed under various conditions, including step changes in setpoint and external disturbances like road gradients. Each controller's advantages and disadvantages are determined by analysing the simulation data. Both transient and steady-state behaviors are compared to determine the most efficient controller for each application. Experimental validation through simulation ensures the reliability of the results. A critical evaluation of the findings highlights the practical applicability and performance differences of the PI and PID controllers. Conclusions are drawn regarding the suitability of each controller for process and CCS.

1. System Modeling

The dynamics of the process and CCS are modeled mathematically. For a typical cruise control system, the dynamics can be represented as:

$m \cdot \frac{dv(t)}{dt} = F_{engine}(t) - F_{resist}(t),$

where:

- m is the mass of the vehicle.
- $v(t)$ is the velocity of the vehicle.
- $F_{engine}(t)$ is the force generated by the engine.
- $F_{resist}(t)$ includes forces due to friction, air drag, and incline.

The engine force is modeled as proportional to the throttle input *u(t):* $F_{engine}(t) = K \cdot u(t)$

where *K* is the proportionality constant.

The resistance force can be expressed as:

$F_{resist}(t) = c_r + c_d \cdot v(t)^2,$

where c_r is the rolling resistance constant and c_d is the drag coefficient.

2. PI and PID Controller Design

The control objective is to maintain a desired speed v_{set}. The error is defined as:

$e(t) = v_{set} - v(t).$

Proportional Controller (P):

$u(t) = K_P \cdot e(t),$

where K_P is the proportional gain.

- **Integral Controller (I):**

$u(t) = K_P \cdot e(t) + K_i \cdot \int e(t)\, dt,$

- where K_i is the integral gain.
- **Derivative Controller (D):**

$u(t) = K_P \cdot e(t) + K_i \cdot \int e(t)\, dt + K_d \cdot \frac{de(t)}{dt},$

where KdK_dKd is the derivative gain.

The block diagram for PI and PID controller, PID controller for Cruise control system is shown in figure 1, 2, 3 respectively.

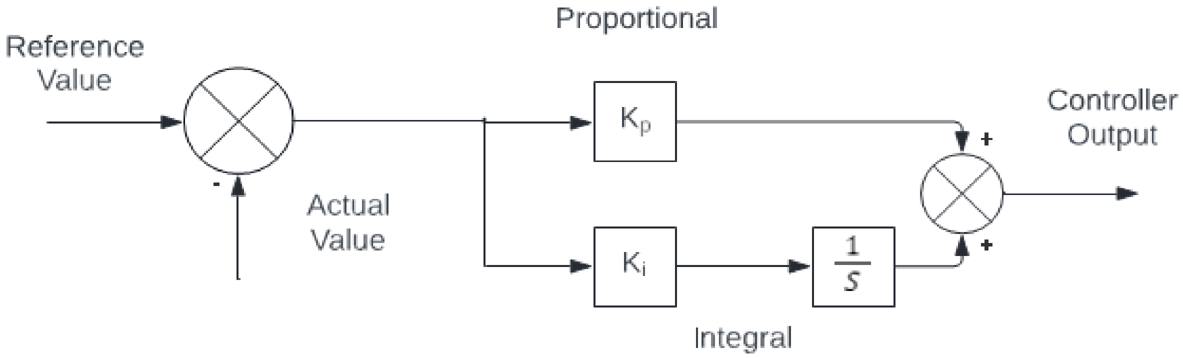

Figure 1. PI Controller

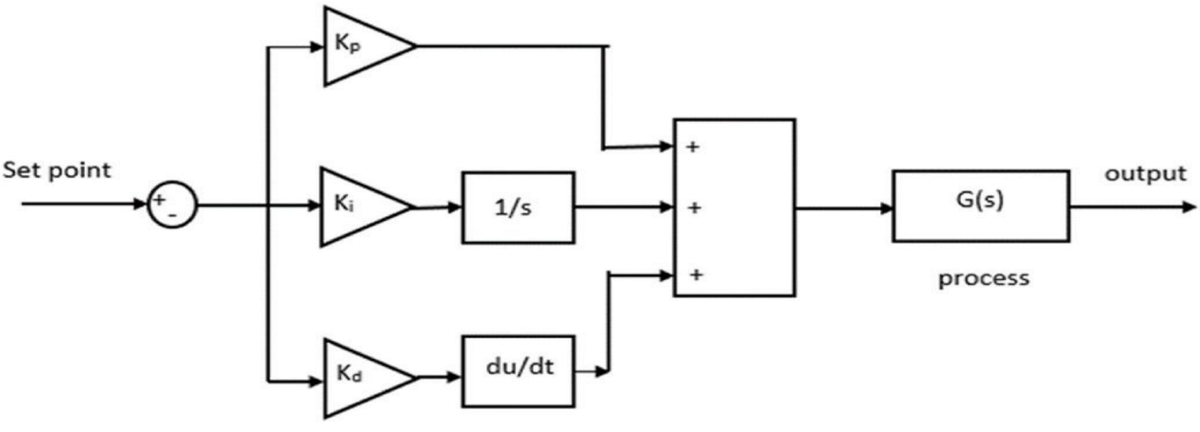

Figure 2. Block diagram of PID controller

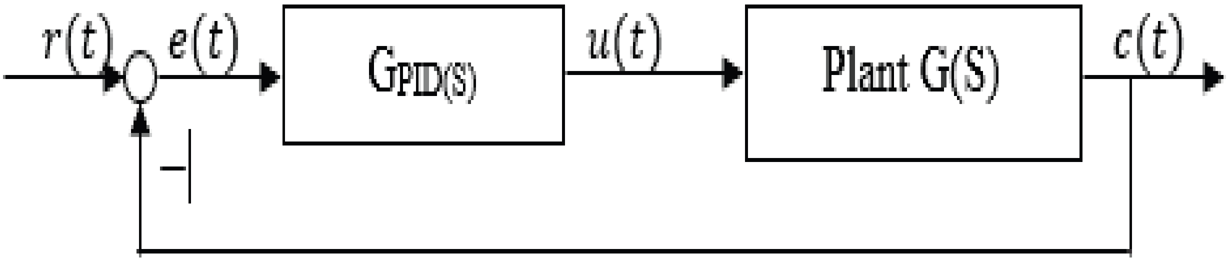

Figure 3. Block Diagram with PID controller for Cruise control system

Functionality of the cruise control system

Regardless of changes in the road's slope or wind resistance, the cruise control system keeps the car moving at a steady speed. Based on input from the speed sensor, the device automatically modifies the throttle control. Figure 4 shows the block diagram of cruise control system

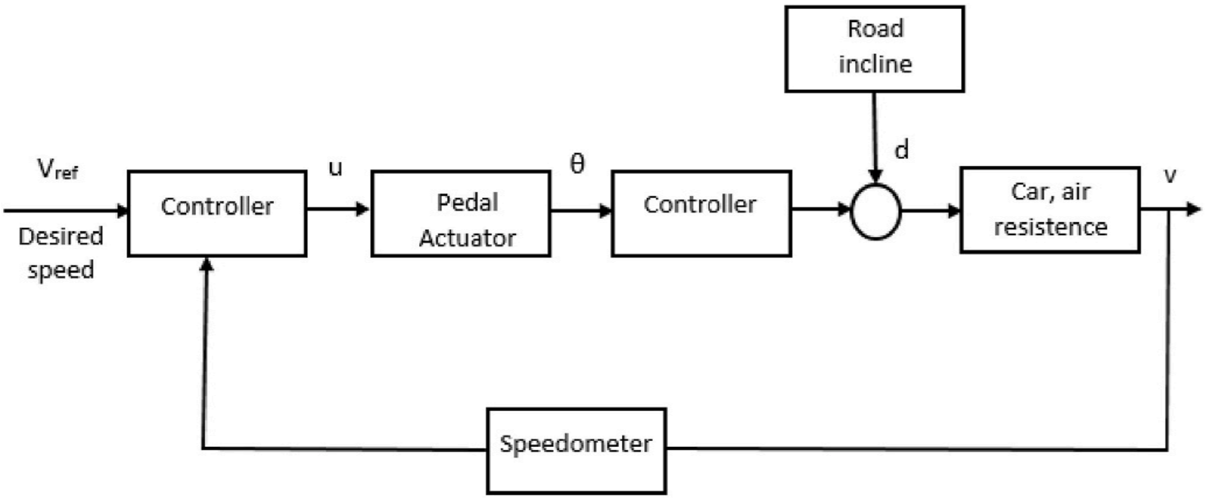

Figure 4 Cruise control system

Fuzzy Logic Controller

The fuzzy logic controller used in CCS consists of one output, the actuator control (u), and two inputs are the speed error (e) and derivative of error d(e). The three primary phases of the control system are defuzzification, fuzzy inference system, and fuzzyification. High and Small Negative, Medium Positive, and other linguistic variables are employed to express domain expertise; their equivalent values fall within -50 to +50 for inputs and between -3000 to +3000 for outputs. While the system for fuzzy inference evaluates the input data and determines the controller results in scope using the rule base and data base, the fuzzification stage transforms the crisp results into fuzzy rules. The block diagram of the FLC (fuzzy logic controller) plant is displayed in figure 5.

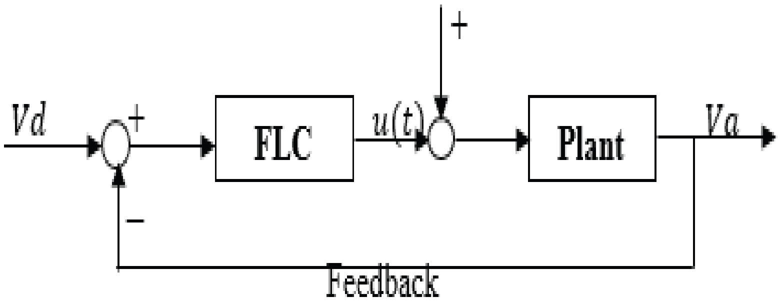

Figure 5. Block diagram of fuzzy cruise control

PI Controller Design

This section presents a test pertaining to the Cruise control system's PI Controller functionality. Getting the system to respond as intended is the primary goal of this approach. Figure 6 displays the Cruise Control system's Simulink model utilising PI Controller.

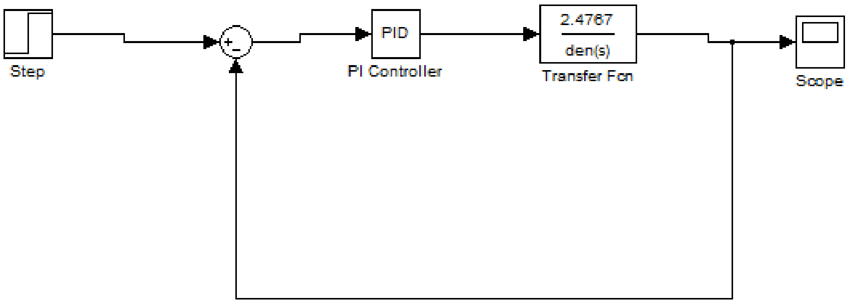

Figure 6. Cruise Control System Simulink Model with PI Controller

PID Controller design

This section presents a test pertaining to the bus suspension system's PID Controller performance. This implementation's primary goal is to get the system to respond as intended. Figure 7 displays the Simulink model of the PID controller-based car suspension system and figure 8 shows the simulink model with FLC for cruise control system.

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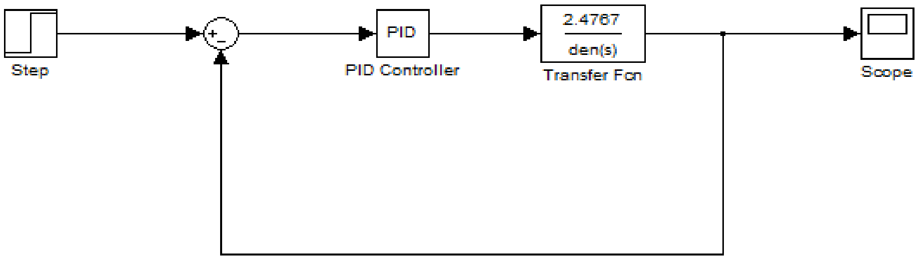

Figure 7. Simulink Model of Cruise control System using PID Controller

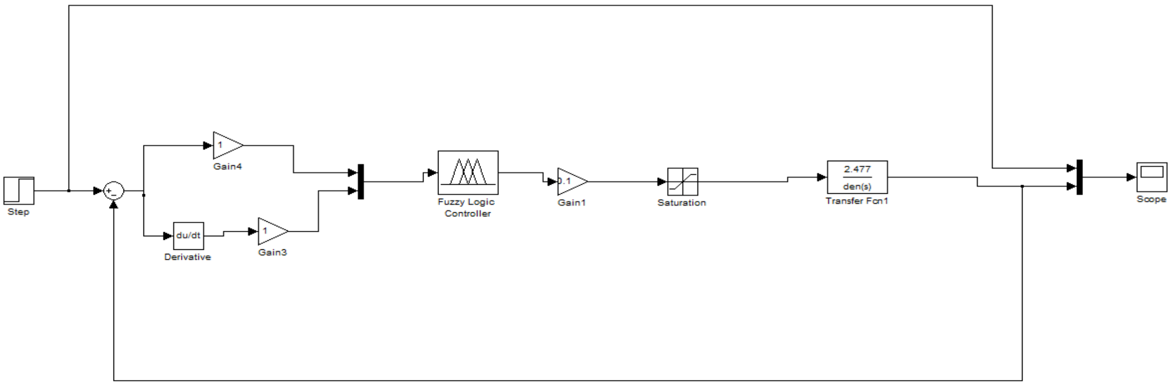

Figure 8. Simulink model for cruise control with FLC

Simulation and Result

This work compares and simulates both controlled and uncontrolled models according to the design requirements. Figures 9, 10, and 11 each display the outcomes of the simulation. It is evident that the design requirement differs from the uncontrolled model's speed (Km/h) against time (sec), which indicates that both the maximum velocity and time restrictions are surpassed.

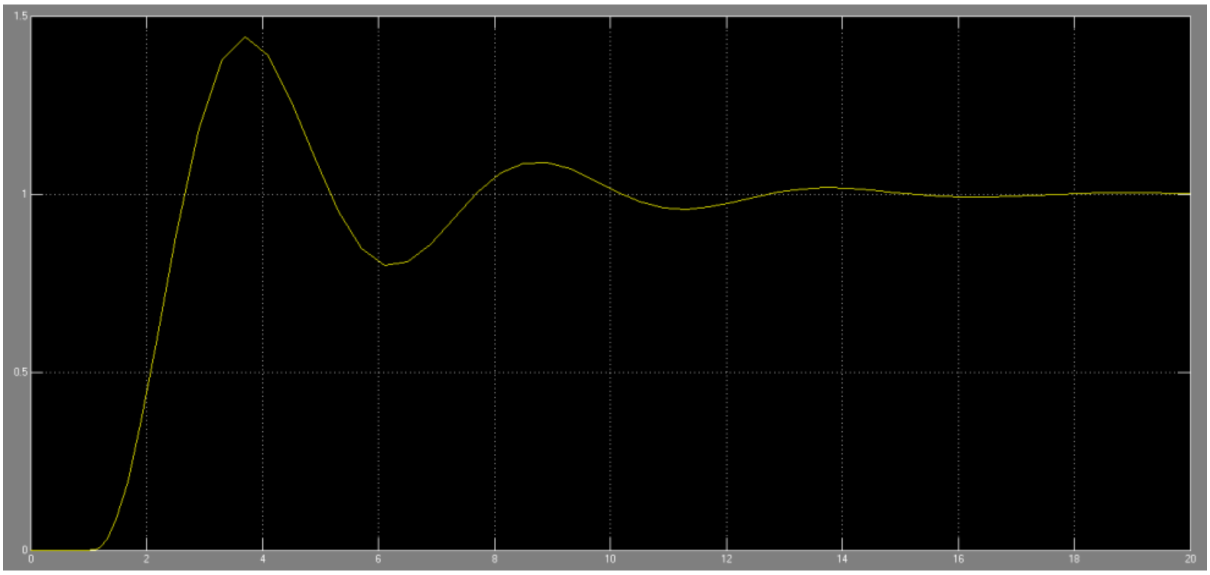

Figure 9. Response of PI Controller

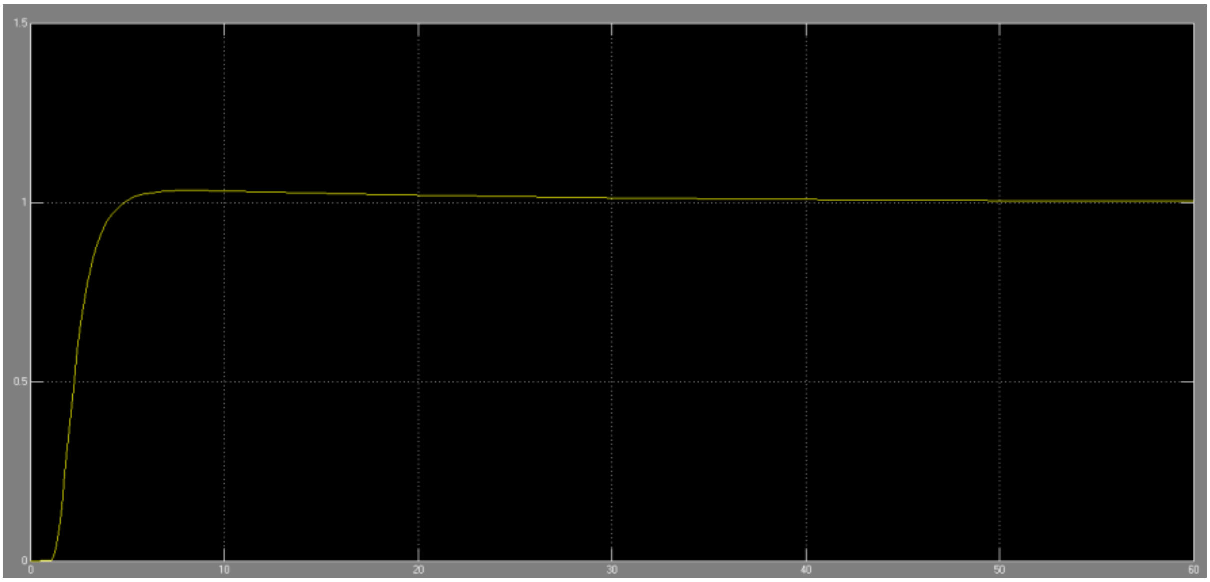

Figure 10 PID Controller Response

The system's reactions employing a PID controller and fuzzy logic are displayed in figures 10, 11, respectively. It's evident that fuzzy logic controllers have less amplitudes and overshoots than PID controllers. In other words, the fuzzy controller responds smoothly. Green indicates the manually adjusted response, which provides greater performance with a faster response and a shorter settling period, whereas blue indicates the response of a tuned beginning value with significant oscillation.

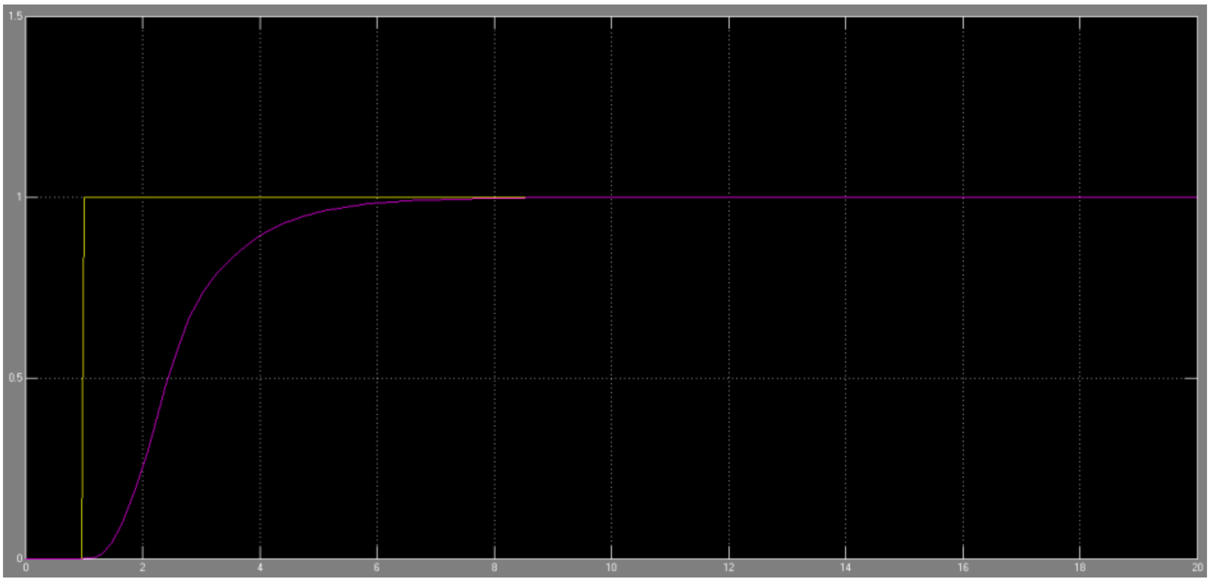

Figure 11. Response with Fuzzy Logic Controller

Conclusion

In order to make long-distance driving more comfortable, new cars now frequently have CCS. By relieving drivers of the burden of constantly pressing the gas pedal to adjust their fuel and checking the speedometer to prevent speeding citations, it lessens the physical and emotional strain that comes with driving on highways. Additionally, it increases passenger safety by lowering the likelihood of high-speed collisions. The basic idea behind velocity or speed control is the regulation of throttle position in response to speed demands. In addition to enhancing the vehicle's speed, cruise control lowers exhaust emissions and increases passenger convenience. This paper introduces the concepts of fuzzy logic, PI, and PID controllers. Fuzzy controllers are thought to provide excellent stability and better control performance. In contrast to fuzzy logic controllers, PI and PID controllers generate outputs with shorter rising times; however, they have higher peak amplitude and percentage overshoot, which can result in substandard system reliability. An additional task can be accomplished by employing a fuzzy-PID controller.

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