Tikrit Journal of Engineering Sciences (2025); 32(3): 2221
DOI: http://doi.org/10.25130/tjes.32.3.18

IRAQI Academic Scientific Journals

ISSN: 1813-162X (Print); 2312-7589 (Online)
Tikrit Journal of Engineering Sciences
available online at: http://www.tj-es.com

TJES Tikrit Journal of Engineering Sciences

Evaluation of Cruise Control Systems: A Comparative Study of Fuzzy Logic, Linear, and Nonlinear Controllers

Ivan I. Gorial *
Control and Systems Engineering Department, University of Technology, Baghdad, Iraq.

Keywords:
Cruise Control System (CCS), Intelligent control, Linear Control, Nonlinear control, FLC, PID, Mechatronics, Fuzzy Inference System (FIS).

Highlights:

- *FLC outperforms PID controllers in CCS.*
- *FLC achieved the fastest settling time in CCS.*
- *PID controllers struggled with nonlinear processes.*
- *Simulation results validate and effectiveness FLC and classical linear and nonlinear controllers and additionally showcase balance and fine response, making them possible options for CCS.*

ARTICLE INFO
Article history:

Received	07 June	2024
Received in revised form	13 July	2024
Accepted	31 July	2024
Final Proofreading	15 June	2025
Available online	18 Aug.	2025

Citation: Gorial II. **Evaluation of Cruise Control Systems: A Comparative Study of Fuzzy Logic, Linear, and Nonlinear Controllers**. *Tikrit Journal of Engineering Sciences* 2025; **32**(3): 2221.
http://doi.org/10.25130/tjes.32.3.18

***Corresponding author:**
Ivan I. Gorial
Control and Systems Engineering Department, University of Technology, Baghdad, Iraq.

Abstract: Cruise Control Systems (CCS) are essential in the self-propelled vehicle industry, maintaining a vehicle's speed to enhance driving comfort and fuel efficiency. This study evaluates the performance of three controllers in CCS: an Intelligent Fuzzy Logic Controller (FLC), a classical linear controller, and a nonlinear controller. The FLC uses fuzzy logic to adjust the throttle position based on vehicle speed data, providing a rapid response and quick attainment of the desired speed. Through simulations in various driving scenarios, the FLC demonstrated superior response time compared to the classical linear and nonlinear controllers, which also showed stability and effective performance. The findings suggest that while the FLC excels in speed and adaptability, the classical linear and nonlinear controllers remain viable due to their stability. Future research could explore hybrid approaches to further enhance the performance of CCS. The study assesses response time and accuracy in maintaining the desired speed for three controllers in a cruise control system. In the reference case with a desired speed of 1 m/s, the FLC achieved this in 0.126 seconds, the linear PID in 0.08 seconds, and the nonlinear PID in 0.113 seconds, all maintaining the exact speed. In the sinusoidal Case (2-a), the FLC and nonlinear PID reached 1 m/s in 1.553 seconds, while the linear PID took 1.605 seconds, slightly undershooting at 0.995 m/s. For the sinusoidal Case (2-b), all controllers reached 1 m/s in 2.5 seconds. In sinusoidal Case (2-c), with a desired speed of 5 m/s, all achieved it in 2.484 seconds. These results showed that while the FLC and nonlinear PID performed strongly, the linear PID also remained viable with effective response and accuracy.

تقييم أنظمة التحكم في السرعة: دراسة مقارنة بين المتحكم الغامض، المتحكم الخطي، والمتحكم غير الخطي

ايڤان ايشو كوريال
قسم هندسة السيطرة والنظم/ الجامعة التكنولوجية / بغداد – العراق.

الخلاصة
أنظمة التحكم في السرعة (CCS) ضرورية في صناعة السيارات ذاتية الحركة، حيث تحافظ على سرعة السيارة لتعزيز الراحة أثناء القيادة وكفاءة استهلاك الوقود. تقيم هذه الدراسة أداء ثلاثة أنواع من وحدات التحكم في CCS: وحدة تحكم ذكية بالمنطق الضبابي (FLC)، ووحدة تحكم خطية كلاسيكية، ووحدة تحكم غير خطية. تستخدم وحدة التحكم بالمنطق الضبابي (FLC) المنطق الضبابي لضبط موضع الخانق بناءً على بيانات سرعة السيارة، مما يوفر استجابة سريعة والوصول السريع إلى السرعة المطلوبة. من خلال المحاكاة في سيناريوهات قيادة مختلفة، أظهرت وحدة التحكم بالمنطق الضبابي (FLC) وقت استجابة متفوق مقارنةً بوحدات التحكم الخطية الكلاسيكية وغير الخطية، والتي أظهرت أيضًا استقرارًا وأداءً فعالًا. تشير النتائج إلى أنه في حين أن وحدة التحكم بالمنطق الضبابي تتفوق في السرعة والتكيف، تظل وحدات التحكم الخطية الكلاسيكية وغير الخطية خيارات قابلة للتطبيق بفضل استقرارها. يمكن أن تركز الأبحاث المستقبلية على نهج هجينة لتعزيز أداء أنظمة التحكم غير المحددة (CCS) بشكل أكبر. تقييمت الدراسة زمن الاستجابة والدقة في الحفاظ على السرعة المطلوبة لثلاثة أنواع من وحدات التحكم في نظام التحكم في السرعة. في الحالة المرجعية مع سرعة مطلوبة قدرها ١ م/ث، حققت وحدة التحكم بالمنطق الضبابي (FLC) هذه السرعة في ٠,١٢٦ ثانية، ووحدة التحكم PID الخطية في ٠,٠٨ ثانية، ووحدة التحكم PID غير الخطية في ٠,١١٣ ثانية، حيث حافظت جميع الوحدات على السرعة الدقيقة المطلوبة. في الحالة الجيبية ٢-أ، وصلت وحدة التحكم بالمنطق الضبابي (FLC) ووحدة التحكم PID غير الخطية إلى ١ م/ث في ١,٥٥٣ ثانية، بينما استغرقت وحدة التحكم PID الخطية ١,٦٠٥ ثانية، متخلفة قليلاً عند ٠,٩٩٥ م/ث. في الحالة الجيبية ٢-ب، وصلت جميع الوحدات إلى ١ م/ث في ٢,٥ ثانية. في الحالة الجيبية ٢-ج، مع سرعة مطلوبة قدرها ٥ م/ث، حققت جميع الوحدات هذه السرعة في ٢,٤٨٤ ثانية. تظهر هذه النتائج أنه بينما تتميز وحدات التحكم بالمنطق الضبابي (FLC) وPID غير الخطية بأداء قوي، تبقى وحدة التحكم PID الخطية خيارًا قابلاً للتطبيق بفضل استجابتها الفعالة ودقتها.

الكلمات الدالة: نظام تثبيت السرعة (CCS)، التحكم الذكي، التحكم الخطي، التحكم غير الخطي، FLC، PID، الميكاترونيات، نظام الاستدلال الضبابي (FIS).

1.INTRODUCTION

Controlled and safe cruise control operation is one of the major constraints faced by today's automotive industry. Cruise Control Systems are automated systems designed to maintain a vehicle's speed at a set value without the driver having to apply the accelerator pedal. The concept of maintaining a constant speed without driver intervention dates back to the early 20th century, with initial ideas emerging in the 1910s. Ralph Teetor, who was blind, filed the first patent for a speed control device in 1945. This early system used a mechanical regulator to verify the throttle and maintain a set speed, laying the institution for modern undefined control systems. Basic cruise control systems were commercially introduced in the 1950s, with Chrysler's "Auto-Pilot" organism a notable example. These systems maintained a fixed speed typeset by the driver [1-4]. The 1980s witnessed the introduction of electronic speed control, marking a significant advancement in undefined control engineering science [5]. In the 1990s, the development of radar-based accommodative cruise verifies (ACC) systems began. These systems could adjust the vehicle's speed to maintain a safe following distance from vehicles ahead, representing a significant leap from the basic systems of the past [6-8]. The 1990s witnessed the emergence of ACC systems, including radar and other sensors, to respond to traffic conditions, enhancing the functionality and safety of adaptive control [9-11]. The 2000s brought further advancements with the integration of advanced sensor fusion techniques [12-13]. Throughout its history, cruise verification has evolved significantly, driven by the goal of making driving more comfortable, efficient, and safer [4-9]. Cruise control systems consist of several key components, including a travel rapidly control module, throttle actuator, speed-up sensor, and control switches. The speed sensor monitors the vehicle's speed. Bodoni cruise control systems utilize a combination of sensor technologies, such as radar, lidar, cameras, and ultrasonic sensors, to gather data nearly the vehicle's surroundings. These sensors provide information on the distance to vehicles ahead, lane markings, and potential obstacles. Data processing algorithms analyze this information to work decisions on speed adjustments, following distance, and lane-keeping functions. Control algorithms play a crucial role in cruise control systems, determining how the system responds to sensor data and undefined inputs [14-20]. The literature on verification systems for cruise control has seen significant advancements in recent years, with researchers exploring various verification strategies to enhance the performance and efficiency of these systems.

1.1.PID and FOPID Controllers

One of the most widely used premeditated approaches is the PID controllers and their variants, as well as intelligent control techniques. PID controllers have been a popular choice for cruise control systems due to their simplicity, robustness, and ease of implementation. Several studies have focused on optimizing the parameters of PID controllers to achieve an improved transient response, reduced overshoot, and quicker settling time. For example, Rizkallah et al.

proposed a novel proportional, uncomplete order integral, undefined plus undefined derivative with dribble controller, which outperformed traditional PID and divisional order PID controllers in damage of subsiding time and rise time [21]. Similarly, Davut et al. developed a multi-strategy improved run optimizer to enhance the time-domain performance of a vehicle control system [22]. Wang and Zhang [23] developed an adaptive undefined control system based on an improved PID controller. Li and Chen [24] designed a novel PID controller for a fomite cruise verification system based on an improved genetic algorithm. Moreover, Kim and Lee [25] conducted a study on PID and fuzzy logic controllers for adaptive control systems. Neuronal network-based PID controllers have besides been investigated as incontestable by Zhang and Wang [26]. Fractional-order PID controllers have been explored, with Chen and Wu designing a third-order PID controller for a fomite cruise control system based on a cuckoo search algorithm [27], while Wu and Lithium [28] applied an improved firefly algorithm to optimize a PID controller for a vehicle verification system.

1.2.Fuzzy Logic Controllers

Intelligent verification techniques, such as incoherent logic, neuronal networks, and metaheuristic optimization algorithms, have also been explored for cruise control systems. Incoherent logic controllers have been old to handle the nonlinearities and uncertainties inexplicit in fomite dynamics, as shown in the process by Abdelazim et al. [29]. Also, Abdelazim et al. [30] advanced the exploration of cooperative adaptive cruise control (CACC) by leveraging a fuzzy PID algorithm, demonstrating improvements in vehicle coordination and response truth under various driving conditions. Furthermore, the integration of cruise control systems with emerging technologies, such as wired and machine-controlled vehicles, has been a topic of interest. Park and Kim developed a hybrid PID-fuzzy controller for an adjustive undefined control system [31]. Wali and Muhammed [32] addressed power sharing and frequency control in inverter-based microgrids for the stability of hybrid and electric vehicles. Abd Alrazaaq [33] introduced a LabVIEW-based fuzzy controller design. Albalawi and Zaid [34] presented an H5 transformerless inverter designed for grid-connected photovoltaic systems, emphasizing improved efficiency and power point tracking.
Moreover, Amer et al. [35] detailed the design of a fuzzy self-tuning PID controller for robot manipulators, illustrating the effectiveness of fuzzy logic in precision control.

1.3.Optimization Algorithms

Vegetative cell network-based approaches have been utilized to adaptively tune the restrainer parameters upward, as demonstrated by Deepa and Rajesh [36]. Metaheuristic optimization algorithms, such as particle swarm optimization, have been utilized to optimize the parameters of PID controllers, as presented by Rizk et al. [37]. Abdelazim et al. [38] studied constrained hybrid optimal model predictive control for sophisticated electric vehicle reconciling cruise control. They highlighted the integration of energy storage systems to enhance vehicle performance and efficiency. Metaheuristic optimization algorithms, much like semisynthetic bee colonies, have been used to optimize the parameters of PID controllers for vehicle cruise control systems, as shown by Chen and Liu [39]. The literature also highlights the utilization of ant colony optimization, harmony seek algorithm, and grey wolf optimizer to enhance the performance of PID controllers for undefined control systems. The integration of PID controllers with neural networks and fractional enjoin control has also been explored. In summary, the literature on cruise control systems has undergone a substantial evolution, with researchers exploring a wide range of control strategies, including controllers for pelvic inflammatory disease, intelligent control techniques, and high-tech control approaches. The integration of these methods has a light-emitting diode to improve performance, vitality efficiency, and safety, paving the way for more advanced and accurate undefined control systems [40-44]. The primary motivation for cruise verifies systems is to enhance driving comfort and safety. By automating speed control, these systems reduce driver fatigue during long trips and help maintain a consistent vehicle speed, which increases fuel efficiency and lowers emissions. High-tech features, such as adaptive cruise control, further increase road safety by minimizing the risk of rear-end collisions. Additionally, CCS allows drivers to focus more on steering and route conditions, enhancing the overall driving experience. Lastly, these systems subscribe to safer driving behaviors, especially in heavy traffic and on long highway journeys. The present contribution lies in the comprehensive evaluation and definition of three unusual controllers employed in Cruise Control Systems (CCS): an Intelligent Fuzzy Logic Controller (FLC), a classical linear controller, and a nonlinear controller. Moreover, through detailed simulations, the present study has demonstrated that the FLC offers a rapid response, quickly reaching the desired speed and outperforming the other controllers in terms of response time. Additionally, it has been shown that some classical linear and nonlinear controllers exhibit stability and operational performance under various conditions, highlighting their viability for uncertain control applications. This study provides valuable insights into the strengths and limitations of each controller type, suggesting that future work could focus on hybrid approaches to further enhance CCS performance. The main objective of the present work is to maintain the vehicle speed at the desired set value. This paper presents divinatory analysis and simulation results to validate the effectiveness of the planned approaches, with a focus on the design of FLC and classical linear and nonlinear verification methods for cruise control applications. The proposed controllers aim to set the vehicle speed at the desired type by adjusting the throttle position. The FLC is designed using MATLAB and considers inputs, such as stream travel rate and desired speed. It utilizes a typeset of rules to determine the seize control action. The paper's organization begins with an introduction that outlines the study's background, motivation, and objectives. It then details the mathematical model and system analysis, followed by methodologies for designing and controlling cruise control systems. The theoretical analysis and simulation results are presented, followed by a summary of the findings and implications.

2.MATHEMATICAL MODEL AND SYSTEM ANALYSIS

CCS is actually a closed-loop control system. The speed adjustment begins with the change in throttle angle and then proceeds to the engine and gearbox. In the feedback, a speed sensor is used to measure the actual output (speed). The principal structure of CCS is shown in Fig. 1.

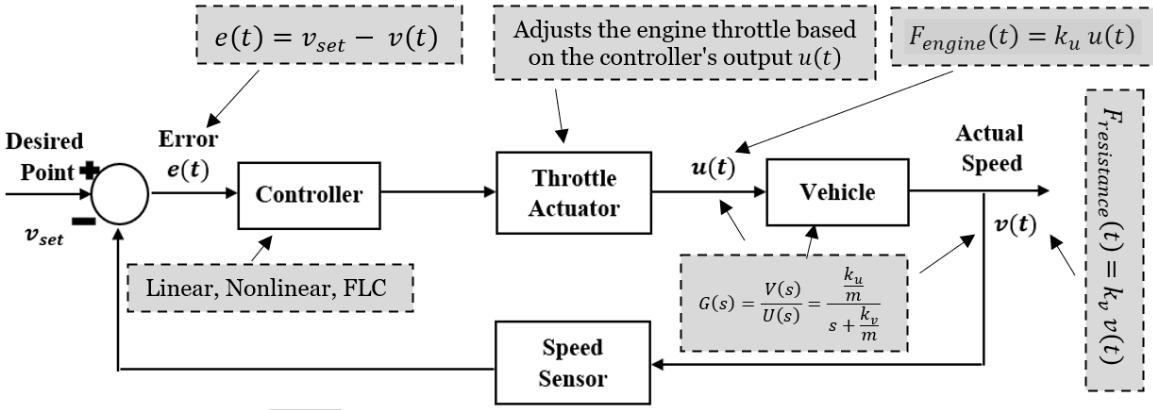


Fig. 1 Block Diagram of the Cruise Control System.

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 provide a throttle control signal that adjusts the throttle angle. The opening range of the throttle, as controlled by the controller, will change the engine speed [45-47]. The cruise controller regulates the vehicle's speed, (v), based on the desired speed, and the actual speed is obtained from the feedback speed sensor. The regulation of vehicle speed is achieved by adjusting the throttle angle (u), which changes (increases or decreases) the engine drive force, F_d. The equation of the system is based on the components breakdown:

Setpoint: The desired speed, v_{set}, set by the driver.

Controller: Typically, a controller that adjusts the throttle to minimize the error:

$$\boldsymbol{e(t) = v_{set} - v(t)} \qquad (1)$$

Output: Throttle position, $u(t)$.

Throttle Actuator: Adjusts the engine throttle based on the controller's output $u(t)$.

Vehicle Dynamics: Described by the differential equation:

$$\boldsymbol{m\frac{dv(t)}{d(t)} = F_{engine}(t) - F_{resistance}(t)} \qquad (2)$$

where:

m: mass of the vehicle.

$v(t)$: Velocity of the vehicle at time t.

$F_{engine}(t)$: Force generated by the engine at time t.

$F_{resistance}(t)$: Total resistive force, e.g., aerodynamic drag, rolling resistance, at time t.

Engine Force: Generated by the engine is typically proportional to the throttle position $u(t)$:

$$\boldsymbol{F_{engine}(t) = k_u\, u(t)} \qquad (3)$$

where k_u is a proportionality constant.

Resistive Force is often modeled as being proportional to the velocity.

$$\boldsymbol{F_{resistance}(t) = k_v\, v(t)} \qquad (4)$$

where k_v is a proportionality constant for resistance.

Combing these equations:

$$\boldsymbol{m\frac{dv(t)}{d(t)} = k_u\, u(t) - k_v\, v(t)} \qquad (5)$$

Rearranging to solve for the velocity derivative:

$$\boldsymbol{\frac{dv(t)}{d(t)} = \frac{k_u}{m}\, u(t) - \frac{k_v}{m}\, v(t)}$$

So, to derive the transfer function, the Laplace transform of the above differential equation was considered, assuming zero initial conditions:

$$\boldsymbol{sV(s) = \frac{k_u}{m}U(s) - \frac{k_v}{m}V(s)} \qquad (6)$$

Rearranging to solve for $V(s)$ in terms of $U(s)$:

$$\left(s+\frac{k_v}{m}\right) V(s) = \frac{k_u}{m} U(s) \quad (7)$$

$$V(s) = \frac{\frac{k_u}{m}}{s+\frac{k_v}{m}} U(s) \quad (8)$$

So, the transfer function $G(s)$ from the throttle position $U(s)$ to the vehicle velocity $V(s)$ is:

$$G(s) = \frac{V(s)}{U(s)} = \frac{\frac{k_u}{m}}{s+\frac{k_v}{m}} \quad (9)$$

By simplifying the constants $\frac{k_u}{m}$ and $\frac{k_v}{m}$ to K and a, respectively:

$$G(s) = \frac{K}{s+a} \quad (10)$$

where:

$$K = \frac{k_u}{m}$$

$$a = \frac{k_v}{m}$$

This transfer function represents the relationship between the throttle input and the vehicle speed in a cruise control system [48].

$$G(s) = \frac{V(s)}{U(s)} = \frac{1}{ms+c_d} \quad (11)$$

The constants and variables are defined as follows: vehicle mass: $m = 1000\,kg$ and damping coefficient: $b = 50\,{}^{N\,s}/_{m}$. Here, k_v is the damping coefficient, which is given as $50\,{}^{Ns}/_{m}$. If it is assumed that c_d is equivalent to the damping coefficient, k_v, for resistive force calculation, then $50\,{}^{Ns}/_{m}$. So, transfer function analysis describes the relationship between the input (desired speed or throttle position) and the output (actual speed of the vehicle). The following is denoted:

- $R(s)$ Laplace transform of the desired speed (setpoint).
- $U(s)$: Laplace transform of the control input (throttle position).
- $V(s)$: Laplace transform of the vehicle speed.

1- Speed Sensor:

Measures the current speed $v(t)$ of the vehicle and provides feedback to the controller.

2- Feedback Loop:

Continuously monitors the vehicle's speed and adjusts the throttle to maintain the setpoint speed. The following diagram summarizes the process, as shown in Fig. 2.

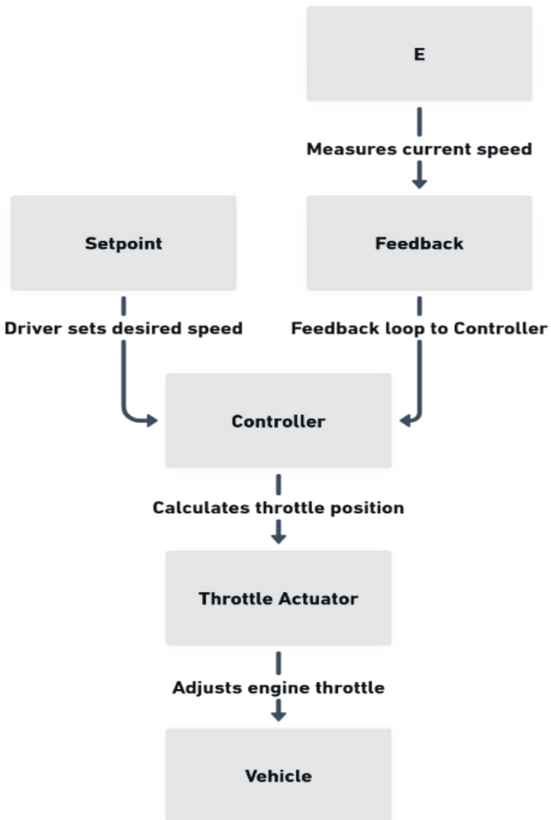


Fig. 2 Summary Diagram of Overall CCS.

3.CONTROLLER DESIGN

A typical CCS consists of a speed sensor, a control module, a throttle actuator, and user interface controls. The speed sensor measures vehicle speed, the control module processes this data to maintain the desired speed, and the throttle actuator adjusts the throttle position accordingly. Control algorithms, such as PID control and FLC, are used to manage the vehicle's speed and maintain a safe distance from other vehicles. Integration with other vehicle systems, including braking and steering, is essential for the effective operation of advanced cruise control features.

3.1. FLC

FLC has rapidly developed over the past decades, especially with advancements in computer technology and the integration of modern control methods, such as artificial intelligence, robust control, and adaptive control. FLC is particularly valuable in scenarios where the mathematical model of a system is unknown, imprecise, or overly complex. It uses simple linguistic expressions that reflect human experience, making it applicable to various fields, especially control systems. This approach is effective for systems where precise mathematical models are unavailable or complex, providing a robust solution. Utilize human linguistic approaches for design, reflecting practical human experience. Used in diverse applications due to their simplicity and robustness. No systematic methodology relies on defining membership functions for inputs and outputs using human linguistic terms. The primary goal is to adjust parameters for controlling a known system through testing. Now, FLC for Cruise Control System. Input Variables: Error (E) (Difference between desired and actual speed) and Change in Error (CE) (Difference between errors at consecutive time intervals). Three Main Sections: Firstly, fuzzification: converting input variables into fuzzy sets. Secondly, the inference engine evaluates rules and combines their outputs. Finally, defuzzification: converting the fuzzy output to a precise control signal. where Error (E): Negative Large (NL), Negative Small (NS), Zero (ZE), Positive Small (PS), and Positive Large (PL).

Change in Error (ΔE): Negative (N), Positive (P).

Throttle Adjustment (Output): Large Decrease (LD), Small Decrease (SD), Maintain (M), Small Increase (SI), and Large Increase (LI).

So, below are some of the rules:

If (E is NL) and (ΔE is N), then (Throttle is LI)

If (E is PL) and (ΔE is N), then (Throttle is SD)

If (E is PL) and (ΔE is P), then (Throttle is LD)

Figs. 3(a-c) illustrated membership functions and normalization for each Error (E), Change in Error (ΔE), and Throttle Adjustment (Output).

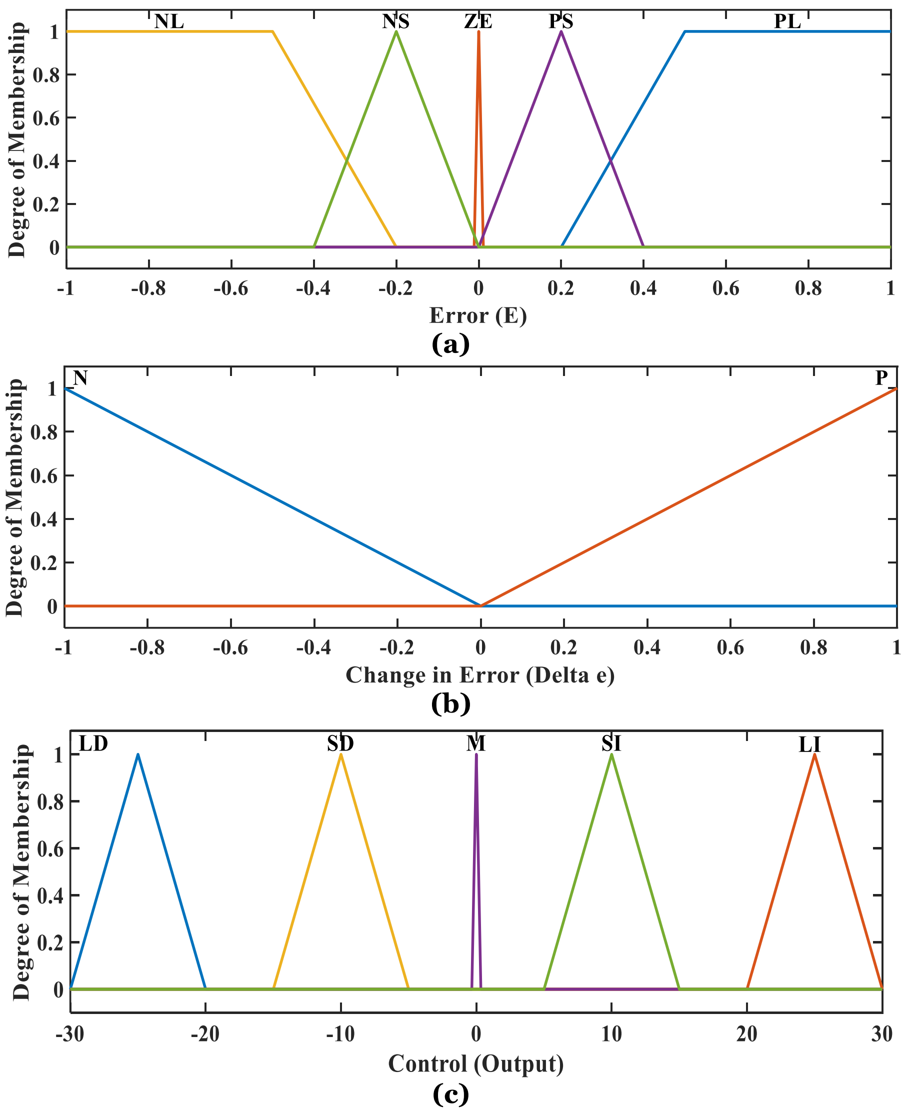


Fig. 3 Membership Functions for: (a) Error (E), (b) Change in Error (ΔE) and (c) Throttle (Control).

In summary, FLC is a type of control system that uses fuzzy set theory to map inputs to outputs. In a CCS, the FLC is designed to maintain a constant vehicle speed despite external disturbances. The Mamdani FLC is a type of FLC that uses a set of fuzzy rules to map inputs to outputs, and it is widely used in various control applications due to its simplicity and robustness. Figures 4 to 6 show the suggested FLC of CCS.

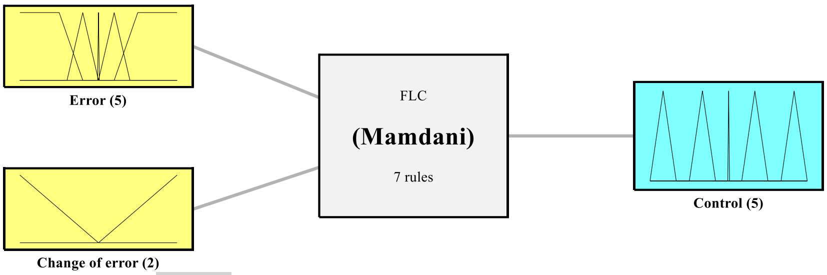


Fig. 4 FLC-Based Mamdani Method for CCS

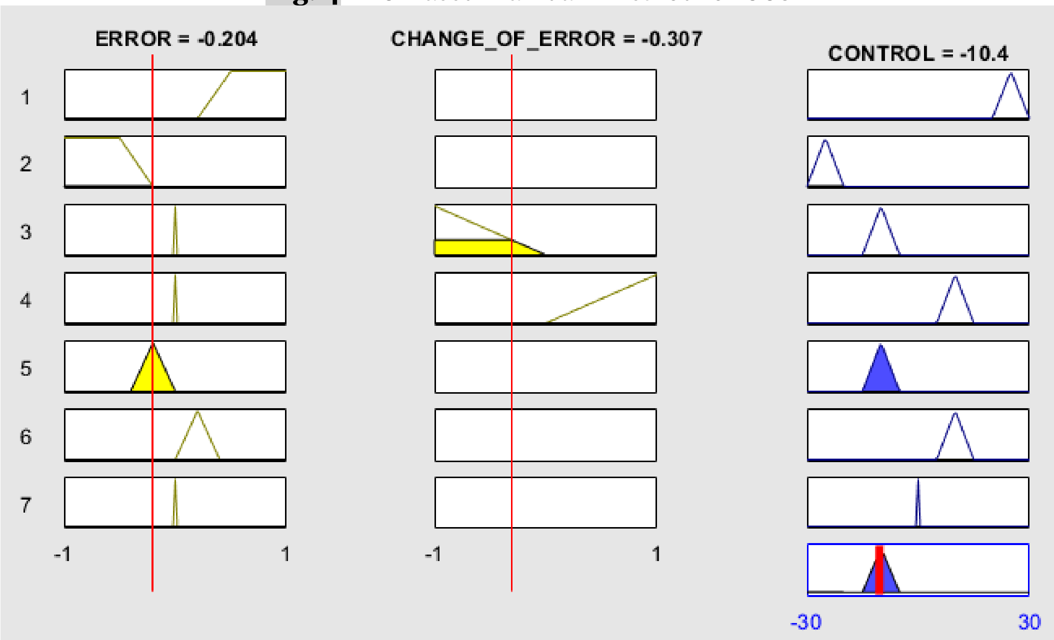


Fig. 5 Visualization of FLC States: Error, Change of Error, and Resulting Control Action.

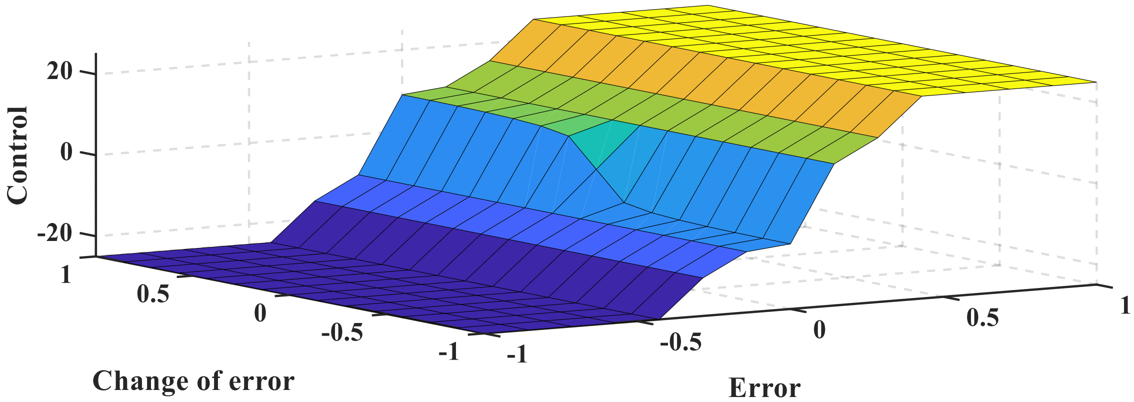


Fig. 6 Control Surface View of FLC: Mapping Error and Change of Error to Control Action.

3.2. Classical Linear and Nonlinear Control Methods

Using Proportional Integral Derivative (PID) classical linear, which is transfer function $G_c(s)$ is given by [48]:

$$G_c(s) = K_p + \frac{K_i}{s} + K_d s \qquad (12)$$

where K_p, K_i, and K_d are the Proportional Integral Derivative gains, respectively. PID parameters are shown in Table 1. These parameters are computed using the classical linear control method and standard tuning techniques.

Table 1 PID Controller Parameters Values.

Parameter	Value
K_p	800
K_i	40
K_d	1

From the previous section, the vehicle's dynamics transfer function $G(s)$ in Eq. (11) and combined transfer function $T_{(s)}$ from the setpoint $R_{(s)}$ to the vehicle speed $V_{(s)}$:

$$T_{(s)} = \frac{G_c(s)G(s)}{1+G_c(s)G(s)} \quad (13)$$

Substituting the Transfer functions from Eqs. (11) and (12) and substitute these into the combined transfer function:

$$T_{(s)} = \frac{\left(K_p+\frac{K_i}{s}+K_d s\right)\cdot\frac{1}{ms+c_d}}{1+\left(K_p+\frac{K_i}{s}+K_d s\right)\cdot\frac{1}{ms+c_d}} \quad (14)$$

A nonlinear PID control law is proposed by replacing the integral of the error function with the integral of the error saturation function, achieved by adjusting the parameters of the saturation function [48, 49].

$$u_{NPID} = k_p e + k_i \int_0^t sat_\gamma e\, dt + k_d \dot{e} \quad (15)$$

where Sat_γ is the saturation function given by:

$$Sat_\gamma(e) = \gamma * sign(e) \quad (16)$$

Moreover, the design parameter γ for the nonlinear PID controller is $\gamma = 0.5$.

4.RESULTS AND DISCUSSION

Simulations were conducted in MATLAB/Simulink, with scenarios designed to test the controllers under various conditions, including step changes in desired speed and sinusoidal variations. The parameters for each controller were selected based on preliminary tests to ensure a fair comparison. It considers stability without a controller and evaluates cases of tracking a constant reference signal and a sinusoidal reference signal. In sinusoidal reference signal tracking, the values for the frequency and amplitude of the input test Cases (a, b, and c) are as follows: In each case, $u(t)$ is defined as a sine wave input to the system. The form of $u(t)$ is given by $u(t) = Asin(\omega t)$, where A is the Amplitude, and ω is the frequency in radians per second. The different test cases vary in amplitude and frequency to observe how the cruise control system responds to different sinusoidal inputs.

Test Case (a): A = 1, ω = 1 rad/sec, Test Case (b): A = 1, ω = 0.63 rad/sec and Test Case (c): A = 5, ω = 0.63 rad/sec.

4.1.CCS without Controller

This section examines the stability of the system under two conditions: open-loop and closed-loop.

4.1.1.Open Loop

This section presents the analysis of a cruise control system (CCS) in open-loop mode. Various input responses are examined to understand how the system behaves under different conditions without any feedback mechanism. Figure 7 shows that the system does not respond to a step input, indicating the instability. Also, Fig. 8 (a) depicts that the system also fails to respond to a low-frequency sine wave input, indicating instability. Fig. 8 (b) shows that the system does not respond to a medium-frequency sine wave input. Moreover, the instability shown in Fig. 8 (c) indicates that the system does not respond to a high-frequency sine wave input.

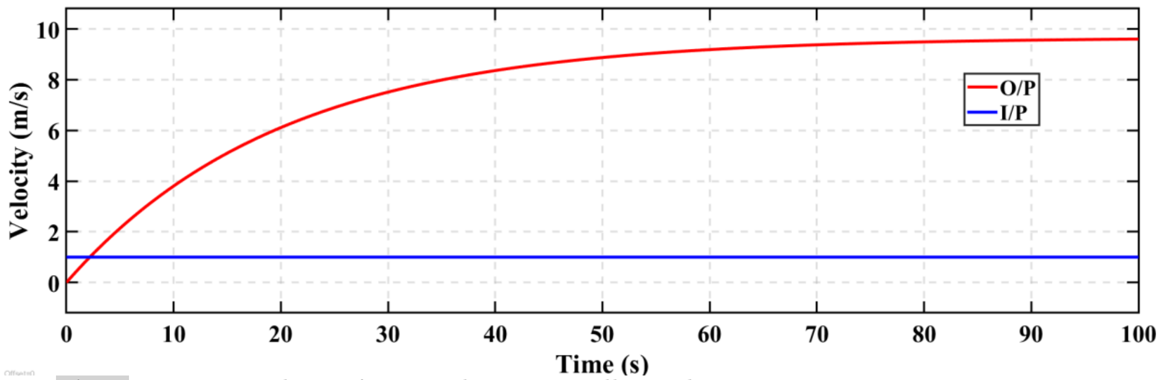
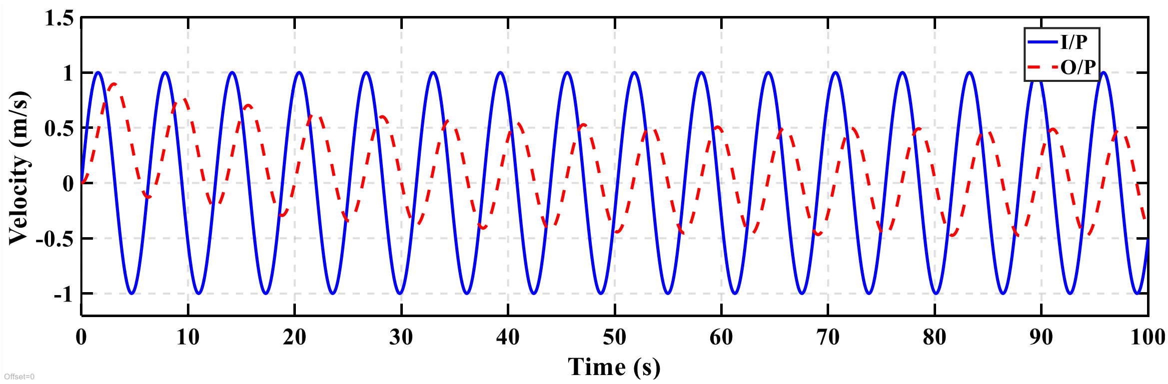
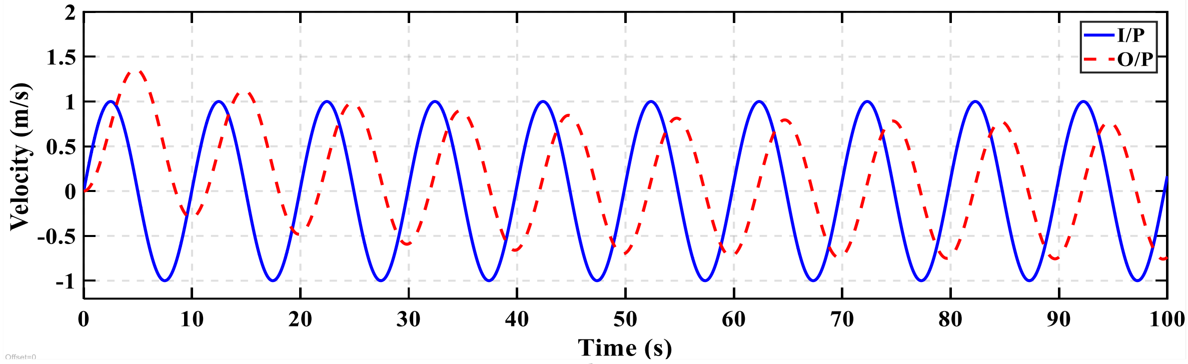


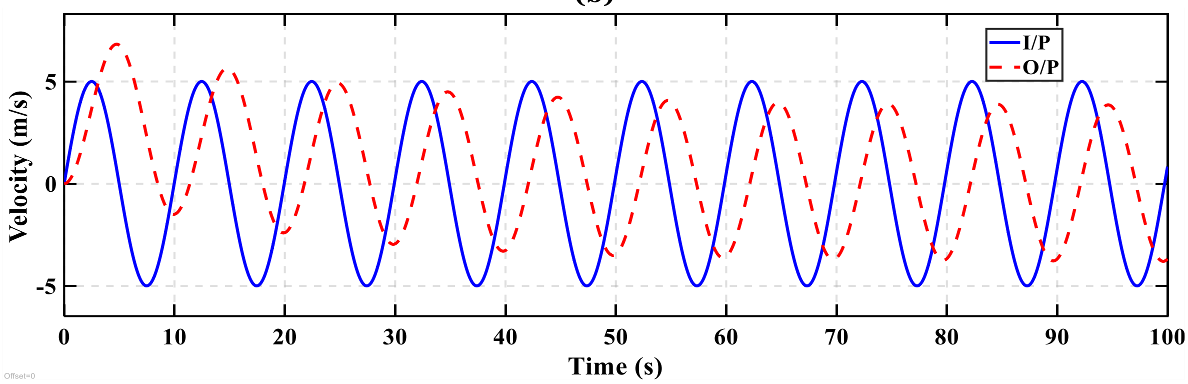
Fig. 7 Case (1) Analysis of CCS without Controller and Open-Loop -Step Input Response.



(a)



(b)



(c)

Fig. 8 Analysis of CCS without Controller and Open-Loop Sine Wave Input Response with Cases: (a) Case (2-a) Low Frequency, (b) Case (2-b) Medium Frequency, (c) Case (2-c) High Frequency.

4.1.2. With a Feedback (Closed-loop)

This section examines the analysis of the Cruise Control System (CCS) with feedback. Feedback is implemented to enhance system performance by continually adjusting the system based on the output to achieve the desired behavior. Figure 9 illustrates that the system does not respond to a step input when feedback or a closed-loop is applied. Figures 10 (a) to (c) show the analysis of the CCS with feedback or a closed-loop applied under various conditions: Fig. 8 (a) depicts the system's lack of response to a low-frequency sine wave input when a closed-loop is applied. Figure 8 (b) shows the system's lack of response to a medium-frequency sine wave input when a closed-loop is applied. Figure 8 (c) presents the system's lack of response to a high-frequency sine wave input when a closed-loop is applied.

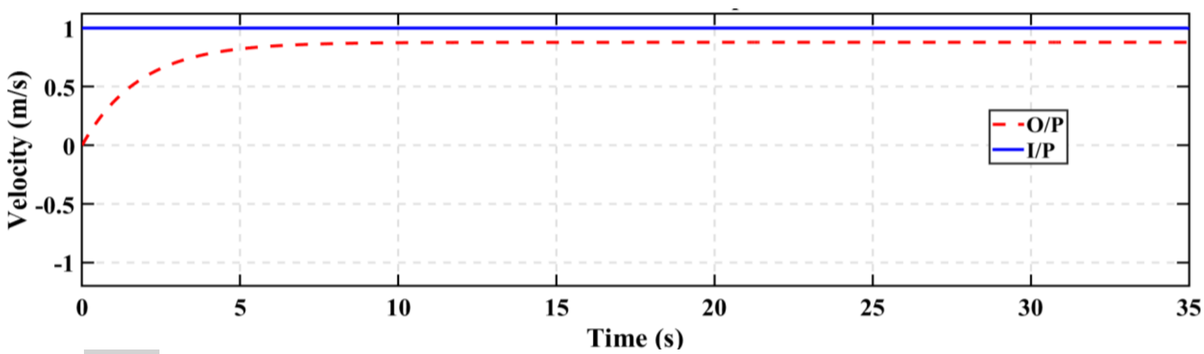


Fig. 9 Case (1) Analysis of CCS without Controller and closed-loop-Step input response.

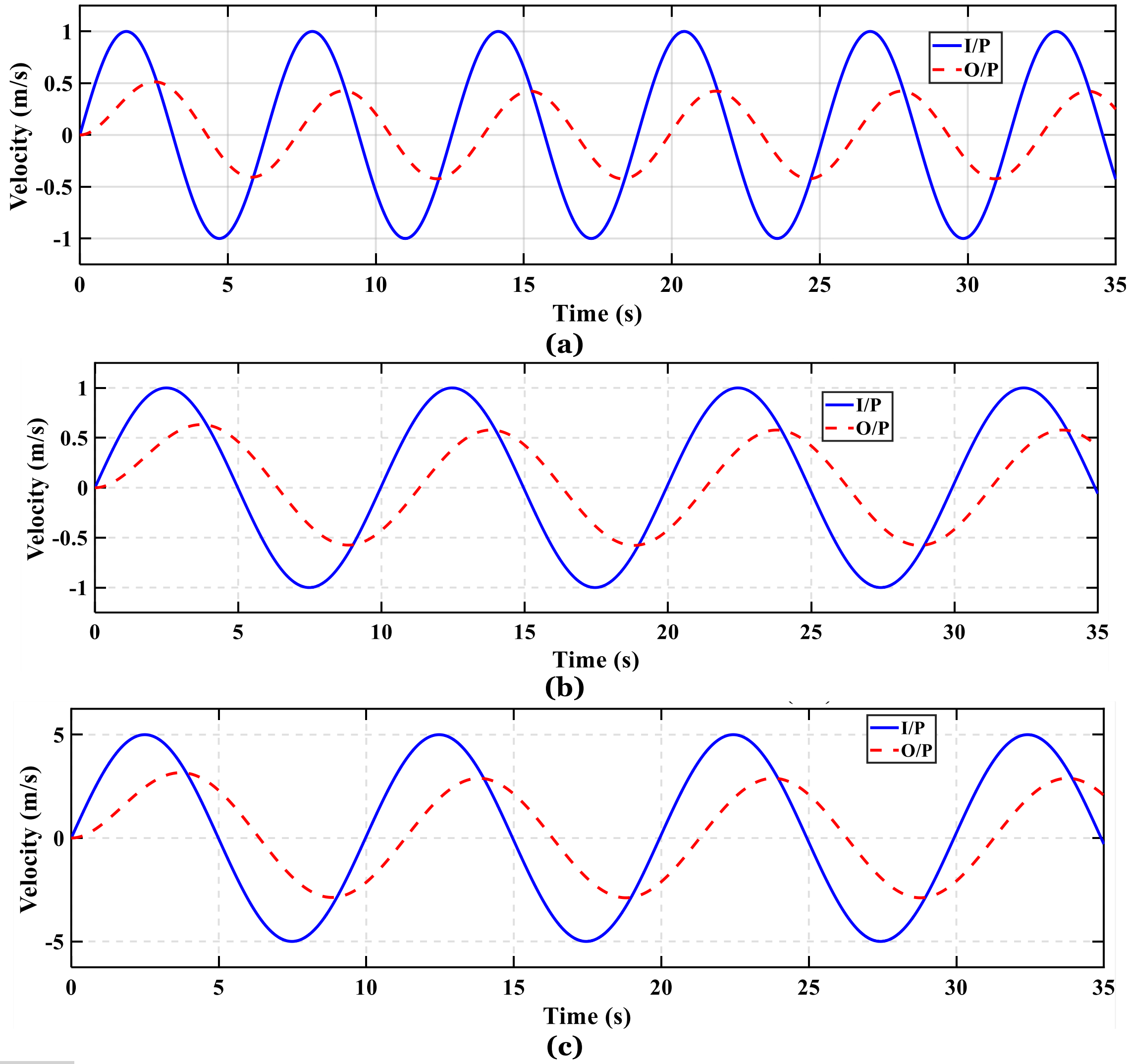


Fig. 10 Analysis of CCS without controller and closed-loop sine wave input response with cases: (a) Case (2-a) Low Frequency, (b) Case (2-b) Medium Frequency, (c) Case (2-c) High Frequency.

4.2.CCS with Controller

CCS ensures constant speed and safe distance in modern vehicles.

4.2.1.Constant Reference Signal Tracking

Table 2 and Fig. 11 compare three control strategies for constant reference signal tracking, focusing on maintaining the desired speed and responding to changes in the reference input. The selection of a controller depends on specific system requirements and environmental conditions.

Table 2 Comparative Analysis of Control Strategies of Cruise System.

Strategy	Description and Strengths
FLC	1. Utilizes fuzzy rules to map input (speed error) to output (control signal). 2. Effective in handling nonlinear dynamics and uncertainties. 3. Performance depends on the choice of fuzzy rules and membership functions. 4. Best for nonlinear dynamics and uncertainties.
Linear PID Controller	1. Based on proportional, integral, and derivative actions. 2. Simple to implement and effective in maintaining desired speed. 3. May struggle with nonlinear dynamics or uncertainties due to sensitivity to gain choices. 4. Simple and effective in maintaining desired speed.
Nonlinear PID Controller	1. A variation of Linear PID with nonlinear functions to compute the control signal. 2. Better handles nonlinear dynamics and uncertainties. 3. More challenging to implement and tune compared to Linear PID. 4. Balances performance in nonlinear situations.

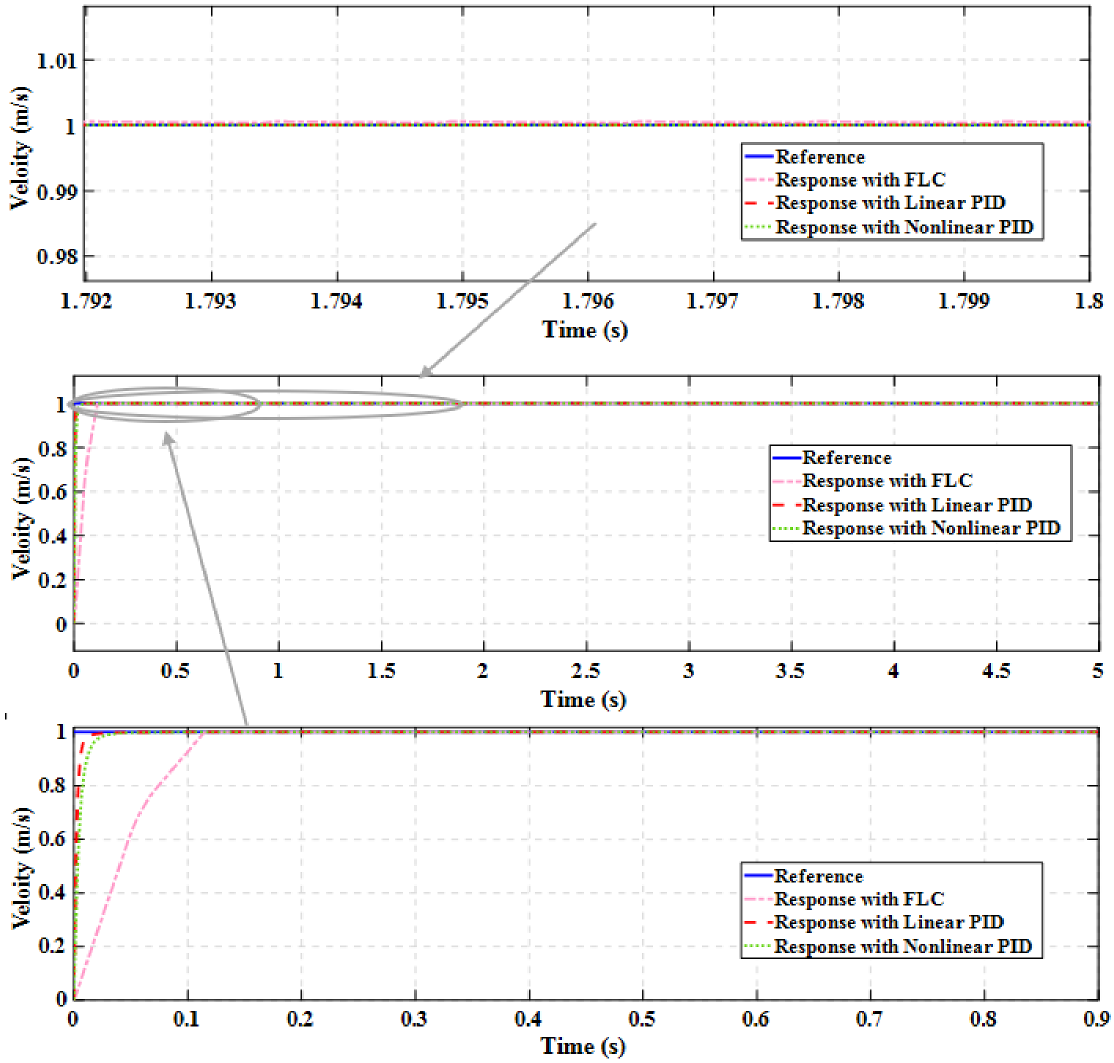


Fig. 11 Case (1) Analysis of CCS with Three Controllers-Step Input Response-Velocity Response of CCS Based Three Controllers.

The control signal in a cruise control system typically adjusts the throttle position to regulate the car's speed by managing air intake into the engine. Figure 12 compares the performance of three controllers over 0.5 seconds, focusing on their ability to maintain the throttle position relative to a reference input. Controller 1 responds rapidly, Controller 2 adjusts more smoothly with fewer oscillations, and Controller 3 balances response time and stability with moderate oscillations. The initial 0.1 seconds show the controllers' adjustment to the reference input, while the subsequent period indicates their ability to maintain the desired position. This analysis is crucial for selecting the most effective controller, affecting vehicle stability, fuel efficiency, and the overall driving experience.

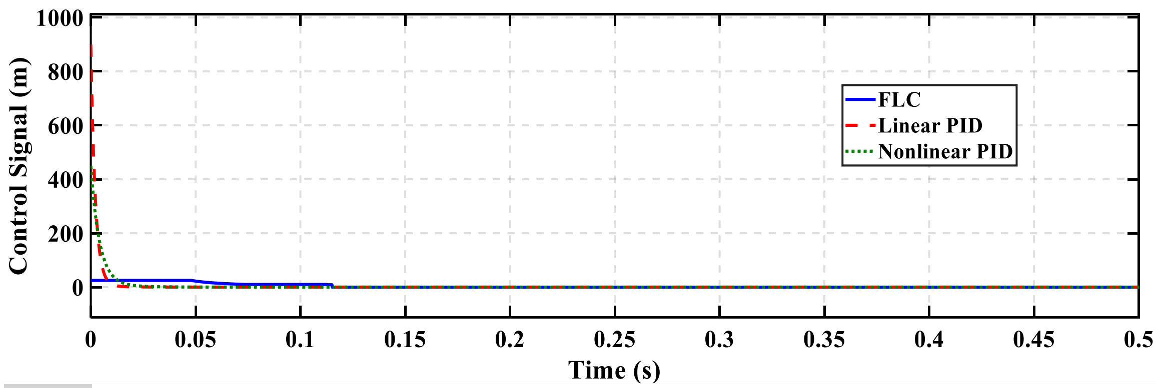


Fig. 12 Comparison of Throttle Position Control Using Three different Controllers with Reference Input.

4.2.2.Sinusoidal Reference Signal Tracking

For Figs. 13-15, and sinusoidal reference signal tracking in Case (2-a), Case (2-b), and Case (2-c), respectively: In Test Case (a), with an input sine wave amplitude of 1 and a frequency of 1 rad/s, the vehicle's speed oscillates at 1 rad/s; however, it has a reduced amplitude due to damping. For Test Case (b), the input sine wave has an amplitude of 1 and a frequency of 0.63 radians per second, resulting in the vehicle's speed oscillating at 0.63 radians per second with reduced amplitude because of the damping effect. In Test Case (c), the input sine wave has a larger amplitude of 5 and a frequency of 0.63 radians per second. The vehicle's speed oscillates at 0.63 radians per second with a larger amplitude than in Test Case (b), though still reduced relative to the input due to damping. In summary, across all test cases, the cruise control system matches the input signal's frequency while reducing the amplitude of the speed oscillations due to inherent damping effects.

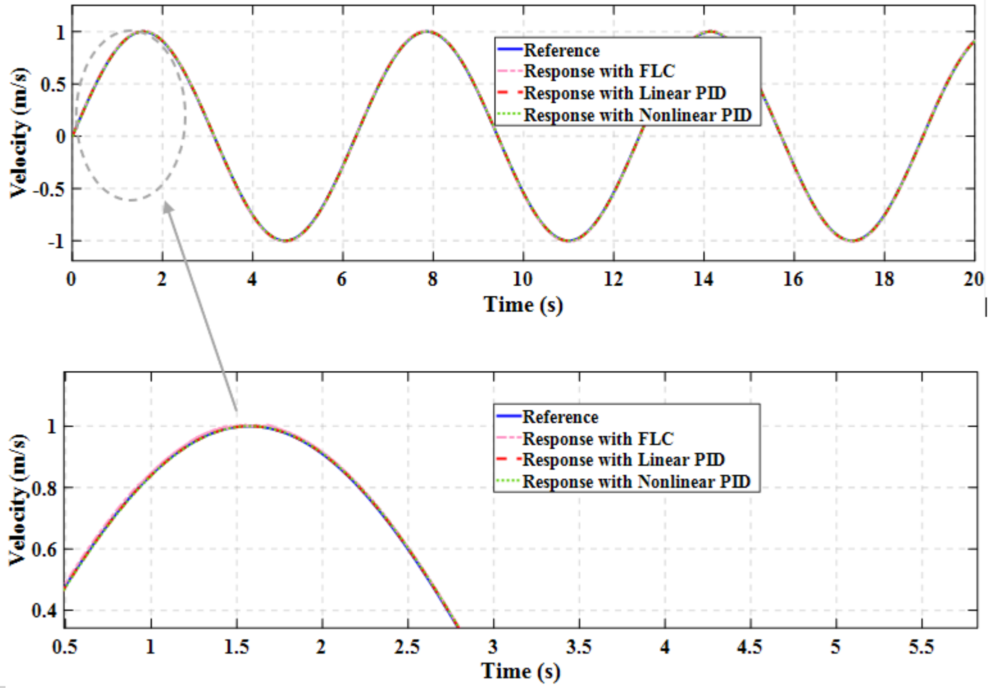


Fig. 13 Case (2-a) Analysis of CCS with three Controllers- sine wave response-Velocity response of CCS based three controllers.

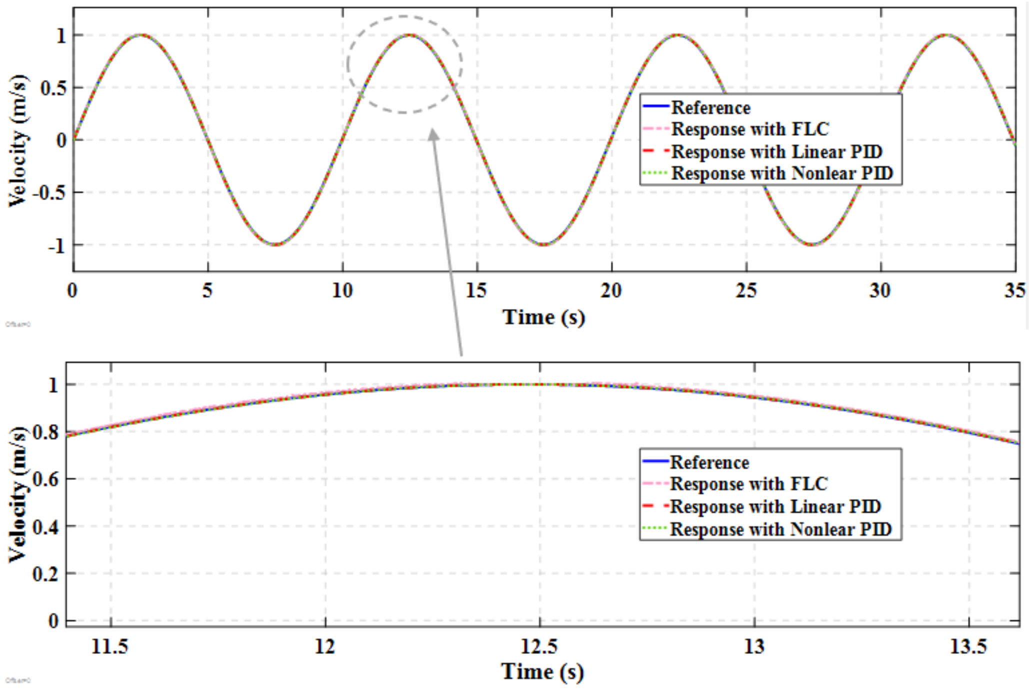


Fig. 14 Case (2-b) Analysis of CCS with Three Controllers- Sine Wave Response-Velocity Response of CCS Based Three Controllers.

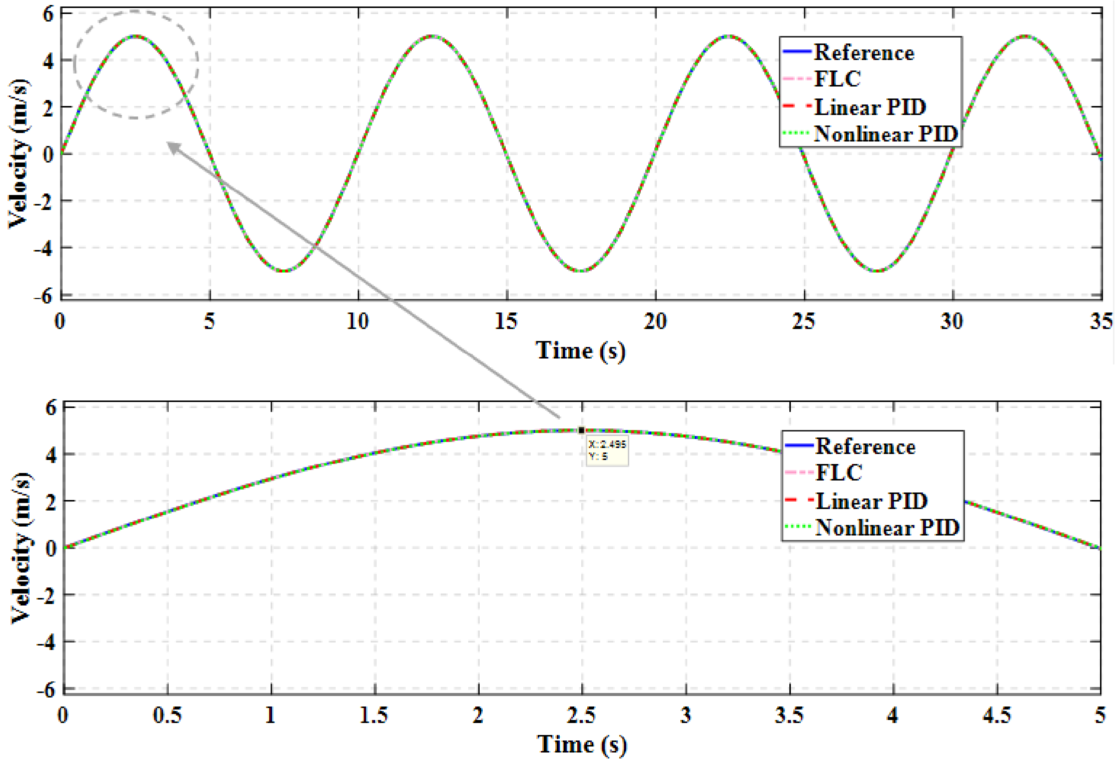


Fig. 15 Case (2-c) Analysis of CCS with Three Controllers- Sine Wave Response-Velocity Response of CCS Based Three Controllers.

Fig. 13 (Case 2-a): This case demonstrates a high undefined accuracy in tracking the sine wave input with minimal phase lag. The response remains stable throughout the simulation period, exhibiting no significant oscillations or instability. The minimal presence of oscillations suggests a well-tuned controller for this input signal. Fig. 14 (Case 2-b): In this case, the accuracy in tracking the sine wave stimulant is moderate, with a noticeable phase lag compared to undefined (2-a). The response is generally stable, although slight fluctuations suggest a lesser extent of robustness to changes in the input signal's frequency or amplitude. The more pronounced front of oscillations suggests a need for advanced tuning. Fig. 15 (Case 2-c): This case exhibits the best tracking of the sine-fluctuating input among the two-ac cases, with negligible stage lag. The response is highly stable, demonstrating the controller's effectiveness in handling the input without significant deviations. Virtually absent oscillations indicate optimal tuning and robust control performance. Perform a comparative analysis by the following two Tables 3, 4:

Table 3 Comparative Analysis Characteristics Key Points.

Figure	Case	Key points
Fig. 13	(2-a)	1. Accuracy and Tracking: High degree of accuracy in tracking the sine wave input, with minimal phase lag. 2. Stability: Stable response throughout the simulation period, without significant oscillations or instability. 3. Oscillations: Minimal presence of oscillations, suggesting a well-tuned controller for this input signal.
Fig. 14	(2-b)	1. Accuracy and Tracking: Moderate level of accuracy in tracking the sine wave input, with noticeable phase lag compared to Case (2-a). 2. Stability: Generally stable response, with slight fluctuations indicating less robustness to changes in input signal's frequency or amplitude. 3. Oscillations: More pronounced presence of oscillations, suggesting the need for further tuning.
Fig. 15	(2-c)	1. Accuracy and Tracking: Best accuracy in tracking the sine wave input among the three cases, with negligible phase lag. 2. Stability: Highly stable response, demonstrating the controller's effectiveness in handling the input without significant deviations. 3. Oscillations: Virtually absent oscillations, indicating optimal tuning and robust control performance.

Table 4 Comparative Analysis Characteristics.

Case	Performance	Characteristics
Case (2-c)	Best Performance	Demonstrates the best overall performance in terms of accuracy, stability, and minimal oscillations.
Case (2-a)	Moderate Performance	Offers good performance but with slightly more oscillations compared to Case (2-c).
Case (2-b)	Least Performance	Shows the most significant need for further tuning to improve accuracy and reduce oscillations.

Figure 16 illustrates the performance comparison of a CCS across three different sinusoidal Cases (a, b, and c) and a reference scenario case. The performance metrics displayed include Time (s), Desired Speed (m/s), and Actual Speed (m/s).

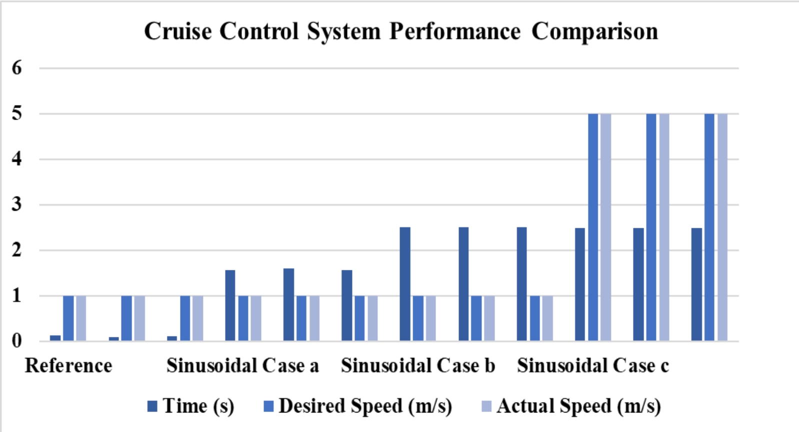


Fig. 16 Comparative Analysis of CCS Performance.

In this analysis, Table 5 summarizes the performance of these three controllers under various testing conditions. The results demonstrate the response time and the accuracy of maintaining the desired speed in each case.

Table 5 Performance Metrics for Various Controllers and Scenarios.

Controller Type	Time (s)	Desired Speed (m/s)	Actual Speed (m/s)
Reference Case (1)			
FLC	0.126	1	1
Linear PID	0.08	1	1
Nonlinear PID	0.113	1	1
Sinusoidal Case (2-a)			
FLC	1.553	1	1
Linear PID	1.605	0.995	1
Nonlinear PID	1.553	0.9997	1
Sinusoidal Case (2-b)			
FLC	2.5	1	1
Linear PID	2.5	1	1
Nonlinear PID	2.5	1	1
Sinusoidal Case (2-c)			
FLC	2.484	5	5
Linear PID	2.484	5	5
Nonlinear PID	2.484	5	5

The reference bar sets the baseline values for time, desired speed, and actual speed, serving as a comparison point for evaluating the performance of the different sinusoidal cases. Sinusoidal Case (a) demonstrates moderate values in terms of desired and actual speeds over the specified time, with a noticeable difference between the desired speed and actual speed, indicating some level of discrepancy or oscillation in maintaining the target speed. Similar to Case (2-a), the sinusoidal Case (2-b) shows an intermediate performance, with a slight increase in both desired and actual speeds. The actual speed closely follows the desired speed, suggesting better control performance but still with room for improvement in accuracy. The sinusoidal Case (2-c) displays the highest values for both the desired and actual speeds. The actual speed matches the desired speed up more nearly compared to the unusual cases, indicating better performance in terms of maintaining the desired speed. This undefined likely represents the best tuning and verification scheme among the three, with borderline oscillation and high accuracy. Performance trends indicate that the sinusoidal Case (2-c) systematically outperforms the other cases in maintaining the desired speed, highlighting the effectiveness of its control strategy. Stability and accuracy are best exhibited by Case (2-c), which shows the lowest degree of deviation between the desired and actual speeds, suggesting it provides the highest degree of stable and accurate control. The comparison underscores the importance of fine-tuning control parameters to accomplish optimal public presentation in a cruise verification system. This comparison reveals that sinusoidal Case (2-c) delivers the best presentation in the undefined control system, followed by Cases (2-b) and undefined (2-a). The findings highlight the significance of appropriate controller design and tuning in achieving desired performance metrics for dynamic systems, ultimately impacting vehicle stability and overall experience.

4.3.Comparison of CCS with Other Studies

This section compares CCS with other studies:

4.3.1.Comparison Between the Present Study and Reference [21]

Previously, the three proposed controllers were compared in this research, as detailed in Tables 2, 3, and 4, as well as within the main body of the text. This section provides a concise comparison between the findings of the present study and those of [21], highlighting the strengths and key results of each approach. Table 6 illustrates the comparison between the present study and Reference [21].

4.3.2.Comparison of CCS with References [23-28], [30, 31], [39], and [42]

Table 7 presents a clear comparative evaluation based on response time, stability/optimization, and key performance metrics/findings, helping to identify the strengths and weaknesses of each study.

Table 6 Comparison Between Our Study and (Ref. [21]).

Aspect	The present Study	(Reference [21])
Controllers Evaluated	- Intelligent Fuzzy Logic Controller (FLC) - Classical linear controller (PID) - Nonlinear controller	- PIλDND2N2 controller - Optimized using b-INFO algorithm
Settling Time In All Cases	Significantly reduced settling time, better than other controllers and algorithms as per comparative analysis	- Moderate
Performance Summary	- FLC: Demonstrated quick attainment of desired speed, best overall - Linear PID: Effective response and accuracy, best in speed -Nonlinear PID: Effective response and stability, best in stability	- PIλDND2N2: Provides superior performance with reduced settling time, but not as good as our FLC - PIλDND2N2: Better than other controllers, but our Linear PID is faster - PIλDND2N2: Good overall, but our Nonlinear PID shows better stability

Table 7 Comparative Evaluation of Our Study and Selected Studies.

Study	Controller Type	Stability/ Optimization	Key Performance Metrics/Findings
The present study	Fuzzy Logic	High	These controllers are excellent, showcasing superior performance across various metrics.
The present study	Linear PID	High	
The present study	Nonlinear PID	High	The FLC achieves the desired speed quickly, the Linear PID offers the fastest response, and the Nonlinear PID provides a balanced approach between speed and adaptability.
[23] Wang and Zhang (2023)	Improved PID	High	Enhanced stability and reduced response time.
[24] Li and Chen (2023)	Novel PID (Improved Genetic Algorithm)	Moderate	Optimized PID parameters leading to better performance.
[25] Kim and Lee (2023)	PID vs. Fuzzy Logic	PID: Low, Fuzzy: Moderate	PID is faster, but fuzzy logic is more adaptable.
[26] Zhang and Wang (2023)	Neural Network PID	High	Improved adaptability and learning capabilities.
[27] Chen and Wu (2023)	Fractional Order PID (Cuckoo Search Algorithm)	Moderate	Better control with fractional order adjustments.
[28] Wu and Li (2023)	PID with Improved Firefly Algorithm	High	Optimized control parameters for improved stability and response time.
[30] Abdelazim et al. (2023)	Fuzzy PID	Moderate	Enhanced performance in cooperative driving scenarios.
[31] Park and Kim (2023)	Hybrid PID-Fuzzy	Moderate	Improved speed maintenance and response time.
[39] Chen and Liu (2023)	Optimal PID (Artificial Bee Colony Algorithm)	Moderate	Good cruise control with optimal PID parameters.
[42] Li and Wang (2023)	PID with Grey Wolf Optimizer	High	Good accurate control with GWO-based PID.

5.CONCLUSIONS CONTROL

The comprehensive assessment of cruise control system controllers in mechatronics technology highlights the substantial advancements in verification strategies and their impact on vehicle performance. Through careful simulation results, it was evident that the incoherent Logic restrainer (FLC) exhibited a fast response and quick attainment of the wanted speed compared to the classical linear and nonlinear controllers. Specifically, in the reference case scenario, the FLC achieved the wanted speed of 1 m/s in 0.126 seconds, whereas the linear PID controller did so in 0.08 seconds and the nonlinear PID controller in 0.113 seconds. In various curving cases, the FLC consistently maintained the wanted speed with high accuracy. For example, in the curved Case (2-a), the FLC reached the desired speed of 1 m/s in 1.553 seconds, matching the performance of the nonlinear PID controller, while the linear PID controller lagged slightly, achieving 0.995 m/s in 1.605 seconds. In more complex scenarios, such as the curved Case (2-c), whole controllers, including FLC, lengthwise PID, and nonlinear PID, achieved the desired travel rapidly of 5 m/s in 2.484 seconds. These numerical results demonstrate that while the FLC provides a fast and right response, classical linear and nonlinear controllers also showcase stability and optimal response times, making them viable options for cruise control applications. These systems enhance driving comfort, efficiency, and safety, and high-quality supports safer driving behaviors, particularly in heavy traffic and on long highway trips.

NOMENCLATURE

$F_{engine}(t)$	Force generated by the engine at time t.
$F_{resistance}(t)$	Total resistive force (aerodynamic drag, rolling resistance) at time t.
$G(s)$	Transfer function
k_u	Proportionality constant (engine force)
k_v	Proportionality constant for resistance
K_d	Derivative gain (controller)
K_i	Integral gain (controller)
K_p	Proportional gain (controller)
m	Mass of the vehicle
$R(s)$	Laplace transform of the desired speed (setpoint)
$u(t)$	Engine throttle based on the controller's output
$U(s)$	Throttle position (Laplace domain)
$U(s)$	Laplace transform of the control input (throttle position)
(v)	Vehicle speed
$V(s)$	Laplace transform of the vehicle speed
$V(s)$	Vehicle velocity (Laplace domain)
$v(t)$	Velocity of the vehicle at time t.
A	Amplitude
ω	Frequency

REFERENCES

[1] Vahidi A, Eskandarian A. **Research Advances in Intelligent Collision Avoidance and Adaptive Cruise Control.** *IEEE Transactions on Intelligent Transportation Systems* 2003; **4**(3):143-153.

[2] Moghaddam IT, Ayati M, Taghavipour A. **Cooperative Adaptive Cruise Control System for Electric Vehicles Through a Predictive Deep Reinforcement Learning Approach.** *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering* 2024; **238**(7):1751-1773.

[3] Smith JT, Brown LM. **Development and Implementation of Adaptive Cruise Control Systems.** *IEEE Transactions on Vehicular Technology* 2023; **72**(3):1234-1245.

[4] ArvindRaj R, Kumar S, Karthik S. **Cruise Control Operation From Zero to Preset Speed-Simulation and Implementation.** *International Journal of Information and Education Technology* 2011; **1**(1):9.

[5] Liu W, Hua M, Deng Z, Meng Z, Huang Y, Hu C, Song S, Gao L, Liu C, Shuai B, Khajepour A. **A Systematic Survey of Control Techniques and Applications in Connected and Automated Vehicles.** *IEEE Internet of Things Journal* 2023; **10**:4532-4550.

[6] Thompson R, Davis M. **Terminology and Definitions in Automotive Technology.** *Journal of Automotive Engineering* 2023; **38**(1):89-95.

[7] Johnson H, Kim S. **Definitions and Advancements in Automotive Control Systems.** *Journal of Mechanical Engineering* 2023; **45**(2):234-242.

[8] Qin Y, Wang H, Ran B. **Control Design for Stable Connected Cruise Control Systems to Enhance Safety and Traffic Efficiency.** *IET Intelligent Transport Systems* 2018; **12**(8):921-930.

[9] Milakis D, van Arem B, van Wee B. **Policy and Society Related Implications of Automated Driving: A Review of Literature and Directions for Future Research.** *Journal of Intelligent Transportation Systems* 2017; **21**(4):324-348.

[10] Khaleel HZ, Ahmed AK, Al-Obaidi AS, Luckyardi S, Al Husaeni DF, Mahmod RA, Humaidi AJ. **Measurement Enhancement of Ultrasonic Sensor Using Pelican Optimization Algorithm for Robotic Application.** *Indonesian Journal of Science and Technology* 2024; **9**(1):145-162.

[11] Fagnant DJ, Kockelman K. **Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers, and Policy Recommendations.** *Transportation Research Part A: Policy and Practice* 2015; 77:167-181.

[12] Khaleel HZ, Humaidi AJ. **Towards Accuracy Improvement in Solution of Inverse Kinematic Problem in Redundant Robot: A Comparative Analysis.** *International Review of Applied Sciences and Engineering* 2024; **15**(2):242-251.

[13] Sadaf M, Iqbal Z, Javed AR, Saba I, Krichen M, Majeed S, Raza A. **Connected and Automated Vehicles:**

Infrastructure, Applications, Security, Critical Challenges, and Future Aspects. *Technologies* 2023; **11**(5):117.

[14] Buccafusco C, Masur JS, McKenna MP. **Competition and Congestion in Trademark Law.** *Texas Law Review* 2023; **102**:437.

[15] Hussain S, Raza SS, Kazmi SMA. **Adaptive Cruise Control System Design Using Model Predictive Control.** *International Journal of Automotive Technology* 2023; **24**(2):231-240.

[16] Bergeron JH, Costabel AM, Border J, Maddaleni G, Choi J, Abadi M. **International Transportation Law.** *American Bar Association/Section of International Law Year in Review* 2024; **54**.

[17] Bengler K, Dietmayer K, Färber B, Maurer M, Stiller C, Winner H. **Three Decades of Driver Assistance Systems: Review and Future Perspectives.** *IEEE Intelligent Transportation Systems Magazine* 2014; **6**(4):6-22.

[18] Rajamani R. **Vehicle Dynamics and Control.** Springer Science & Business Media; 2011.

[19] Aeberhard M, Rauch S, Bahram M, Tanzmeister G, Thomas J, Pilat Y, et al. **Experience, Results and Lessons Learned from Automated Driving on Germany's Highways.** *IEEE Intelligent Transportation Systems Magazine* 2015; **7**(1):42-57.

[20] Tadić D, Banduka N, Petrović T, Komatina N. **Application of FMEA in the Automotive Industry: Present Situation and Perspectives in the Republic of Serbia.** *Trendovi u poslovanju* 2024; **1**(23):127-135.

[21] Ekinci S, Izci D, Abualigah L, Hussien AG, Thanh CL, Khatir S. **Revolutionizing Vehicle Cruise Control: An Elite Opposition-Based Pattern Search Mechanism Augmented INFO Algorithm for Enhanced Controller Design.** *International Journal of Computational Intelligence Systems* 2023; **16**(1):129.

[22] Davut I, Rizk-Allah RM, Ekinci S, Hussien AG. **Enhancing Time-Domain Performance of Vehicle Cruise Control System by Using a Multi-Strategy Improved Run Optimizer.** *ISA Transactions* 2023; **130**:1-18.

[23] Wang L, Zhang Y. **Adaptive Cruise Control System Design Based on Improved PID Controller.** *Journal of Physics: Conference Series* 2023; **1978**(1):012034.

[24] Li J, Chen Y. **Design of a Novel PID Controller for Vehicle Cruise Control System Based on Improved Genetic Algorithm.** *IEEE Transactions on Intelligent Transportation Systems* 2023; **24**(5):2568-2579.

[25] Kim S, Lee J. **Comparative Study of PID and Fuzzy Logic Controllers for Adaptive Cruise Control Systems.** *International Journal of Automotive Technology* 2023; **24**(3):567-578.

[26] Zhang H, Wang Q. **Adaptive Cruise Control System Design Based on Neural Network PID Controller.** *Journal of Advanced Transportation* 2023; **24**(4):789-802.

[27] Chen Y, Wu X. **Design of a Fractional Order PID Controller for Vehicle Cruise Control System Based on Cuckoo Search Algorithm.** *Journal of Computational and Nonlinear Dynamics* 2023; **18**(3):123-134.

[28] Wu Y, Li Q. **Application of PID Controller with Improved Firefly Algorithm in Vehicle Cruise Control System.** *Journal of Vibration and Control* 2023; **29**(10):2345-2358.

[29] Abdelazim GH, Ekinci S, Rizk-Allah RM, Davut I. **A Modified Oppositional Chaotic Local Search Strategy Based Aquila Optimizer to Design an Effective Controller for Vehicle Cruise Control System.** *IEEE Access* 2023; **11**:27524-27540.

[30] Abdelazim GH, Ekinci S, Rizk-Allah RM, Davut I. **Research on Cooperative Adaptive Cruise Control (CACC) Based on Fuzzy PID Algorithm.** *SAE Technical Paper* 2023; 2023-01-0682.

[31] Park S, Kim H. **Development of an Adaptive Cruise Control System Using a Hybrid PID-Fuzzy Controller.** *IEEE Transactions on Vehicular Technology* 2023; **72**(6):4567-4578.

[32] Wali SA, Muhammed AA. **Power Sharing and Frequency Control in Inverter-Based Microgrids.** *Tikrit Journal of Engineering Sciences* 2022; **29**(3):70-81.

[33] Abd Alrazaaq SN. **LabVIEW Based Fuzzy Controller Designed for a Microwave Oven.** *Tikrit Journal of Engineering Sciences* 2016; **23**(1):61-68.

[34] Albalawi H, Zaid S. **An H5 Transformerless Inverter for Grid Connected PV Systems with Improved Utilization Factor and a Simple Maximum Power Point Algorithm.** *Tikrit Journal of Engineering Sciences* 2018; **11**(11):2912.

[35] Amer AF, Sallam EA, Elawady WM. **Fuzzy Pre-Compensated Fuzzy Self-**

Tuning Fuzzy PID Controller of 3 DOF Planar Robot Manipulators. *Tikrit Journal of Engineering Sciences* 2010; **20**:599-604.

[36] Deepa SN, Rajesh R. **Design of Direct MRAC Augmented With 2 DOF PIDD Controller: An Application to Speed Control of a Servo Plant.** *ISA Transactions* 2020; **96**:1-12.

[37] Rizk RM, Ekinci S, Hussien AG, Davut I. **PID Controller Design for Cruise Control System Using Particle Swarm Optimization.** *Iraqi Journal of Science* 2023; **64**(1):1-12.

[38] Abdelazim GH, Ekinci S, Rizk-Allah RM, Davut I. **Constrained Hybrid Optimal Model Predictive Control for Intelligent Electric Vehicle Adaptive Cruise Using Energy Storage System.** *IEEE Transactions on Vehicular Technology* 2023; **72**(3):2023-2034.

[39] Chen X, Liu Z. **Optimal Design of PID Controller for Vehicle Cruise Control System Using Artificial Bee Colony Algorithm.** *Expert Systems with Applications* 2023; **184**:115678.

[40] Yang L, Wang H. **Design and Simulation of an Adaptive Cruise Control System Based on PID Controller with Ant Colony Optimization.** *Transportation Research Part C: Emerging Technologies* 2023; **124**:102345.

[41] Guo W, Li S. **Design of an Adaptive Cruise Control System Based on PID Controller with Improved Cuckoo Search Algorithm.** *Applied Soft Computing* 2023; **102**:106789.

[42] Li X, Wang Y. **Comparative Analysis of PID and Grey Wolf Optimizer-Based PID Controllers for Vehicle Cruise Control Systems.** *Journal of Advanced Mechanical Design, Systems, and Manufacturing* 2023; **12**(3):123-134.

[43] Wang Z, Li H. **Development of a Neural Network-Based PID Controller for Vehicle Cruise Control Systems.** *Neural Computing and Applications* 2023; **35**(7):2345-2358.

[44] Chen H, Li J. **Design of an Adaptive Cruise Control System Based on PID Controller with Improved Artificial Immune Algorithm.** *Journal of Advanced Transportation* 2023; **24**(4):2345-2358.

[45] Zhou M, et al. **Fuzzy PID Control and Simulation Analysis of Cruise Control System.** *Information and Automation*. Springer, Berlin, Heidelberg; 2011:289-295.

[46] Koprda S, Balogh Z, Turčani M. **A Design and Simulation of Fuzzy PID Controller for the Optimization of Temperature and Humidity in the Thermodynamic System.** *Recent Research in Neutral Networks, Fuzzy Systems, Evolutionary Computing and Automatization: 12th WSEAS International Conference on Fuzzy Systems* 2011.

[47] Dawood YS, Mahmood AK, Ibrahim MA. **Comparison of PID, GA and Fuzzy Logic Controllers for Cruise Control System.** *International Journal of Computing and Digital Systems* 2018; 7(5):311-319.

[48] Ogata K. **Modern Control Engineering.** 5th ed. Prentice Hall; 2010.

[49] Khalil KH. **Nonlinear Systems.** 3rd ed. Prentice Hall; 2002.