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# The Utilization of Fuzzy Logic Controllers in Steering Control Systems for Electric Ambulance Golf Carts

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ABSTRACT

This study investigates methods to improve steering control for electric ambulance golf carts by conducting a comparative analysis of fuzzy logic controllers. The research assesses four control systems, PD controller, fuzzy PD controller, fuzzy PD+I controller, and PBC and PD+I type fuzzy logic controller, to determine their effectiveness in enhancing steering control. Simulink simulations are employed to evaluate the performance of these controllers under various conditions. Results indicate that the PBC and PD+I type fuzzy logic controller demonstrates superior performance, showing significant reductions in both rise time and settling time with minimal overshoot compared to other controllers. The findings underscore the potential of fuzzy logic controllers in enhancing steering control for electric vehicles. Future research should explore alternative control strategies and assess controller robustness under diverse operating conditions.



## 1. Introduction

Electric golf carts [1] serve diverse roles in various environments. They are commonly used in shopping malls to assist elderly patrons in navigating long distances. Similarly, educational institutions rely on them for transporting students, faculty, and attendees during events or activities, either through acquisition or rental services. In medical facilities, electric ambulances based on golf carts expedite patient transfer between buildings, streamlining treatment procedures and emergency responses. Universities also employ electric golf carts for intra-campus transportation, improving accessibility for the academic community. Additionally, places of worship, museums, and tourist destinations utilize electric golf carts to offer convenient transportation options for visitors, ensuring a pleasant experience for all. In summary, electric golf carts play a crucial role in enhancing mobility and accessibility across diverse settings, solidifying their significance in modern society.

Research and development in steering systems for electric vehicles [2] have advanced significantly. For instance, structured controllers have been devised for electric power steering (EPS) systems, with a focus on improving stability, robustness, and bandwidth while keeping complexity manageable [3]. Conversely, strategies for vehicle stability control in dual-motor drive electric vehicles incorporate real-time recognition of driver turning intentions with modified reference models and predictive control theory, resulting in comprehensive mechanisms for enhancing vehicle stability.

The predominant approach in steering system development in this field typically commences with the design of system architectures based on DC motor-driven mechanisms for steering angle manipulation, as evidenced by foundational studies [4]. In general, in initial electric system development or motor control, utilizing Arduino for programming can be a hardware development possibility. This has been studied and utilized in numerous research projects [5]-[19], particularly in motor control applications [20]-[27]. These systems often employ proportional-integral-derivative (PID) control systems, which are praised for their simplicity and effectiveness in maintaining system stability. Various methods, such as PID tuning rules like Ziegler-Nichols (Z-N), Cohen-Coon (C-C), and Chien, Hrones & Reswick (CHR), are investigated to enhance system efficiency [28]-[46].

Fuzzy logic controller systems [47] have undergone extensive development and utilization across diverse fields. For example, in the design of motor control systems for the ball and beam system, researchers have investigated various approaches such as neural fuzzy control [48], hybrid fuzzy PID controllers [49], and adaptive neuro-fuzzy techniques [50]. These systems often incorporate both type-I and type-II fuzzy logic controllers [51], with the latter incorporating an additional layer known as Footprint of Uncertainty values (FOU). While both types find application in scenarios like self-balancing wheelchairs, interval type-II fuzzy control has demonstrated slightly superior performance, particularly in real-world testing across varying terrains. The design process for fuzzy controllers involves identifying variables, defining linguistic terms, establishing rules, inference processing, and defuzzification. These controllers have found success in numerous industries, including air conditioning, traffic control, robotics, and financial modeling. Furthermore, research in this domain encompasses the development of adaptive fuzzy systems, fuzzy PID controllers, optimal control, and adaptive sliding mode techniques for applications in motor control and robotic arm operations. Despite extensive research, a comprehensive comparison between Type-1 and interval Type-2 fuzzy logic systems in different environments is lacking. For example, studying fuzzy logic controllers in self-balancing wheelchairs [52] under ideal and real-world conditions could provide valuable insights. Consideration of performance indicators such as overshoot, rise time, settling time, and displacement highlights the unique capabilities of Type-2 systems, particularly in managing uncertainty and noise for improved system stability.

This study focuses on control system design, specifically examining PD control and fuzzy logic controllers, which are commonly used in motor control applications. These control methodologies are implemented in the steering control system to determine the most suitable control system for regulating the degree of steering shaft rotation according to specific application requirements.

The research contribution lies in the comparative analysis of various control systems' effectiveness, including PD controller, fuzzy PD controller, fuzzy PD+I controller, and PBC and PD+I type fuzzy logic controller. Through simulations, the study assesses the strengths and weaknesses of each control system across different setpoints. The findings aim to offer valuable insights for decision-making in the future design of steering control systems.

## 2. Method

In this section, the research methodology for experimenting with the design of a system modeling method will be explained. It will delve into system modeling and the design of fuzzy logic control systems, comparing various techniques such as fuzzy PD controller, fuzzy PD+I controller, and proportional back calculation and PD+I type fuzzy logic controller. These comparisons will be presented in the following sequence.

### 2.1. Transfer Function of Steering Control Systems

The concept of developing an electric steering wheel system for golf carts and adapting it for medical purposes reflects an innovative approach in design. Currently, golf carts are utilized in hospitals and other facilities to facilitate patient transportation, showcasing their versatility. These carts play a vital role in various settings, ranging from large venues like schools to smaller environments such as shops or tourist spots. They assist elderly individuals in malls and aid in patient mobility within medical facilities. Golf carts serve as efficient tools, saving time and providing convenience for both users and service providers, particularly in navigating short distances and confined spaces, as illustrated in the model golf cart depicted in Fig. 1.

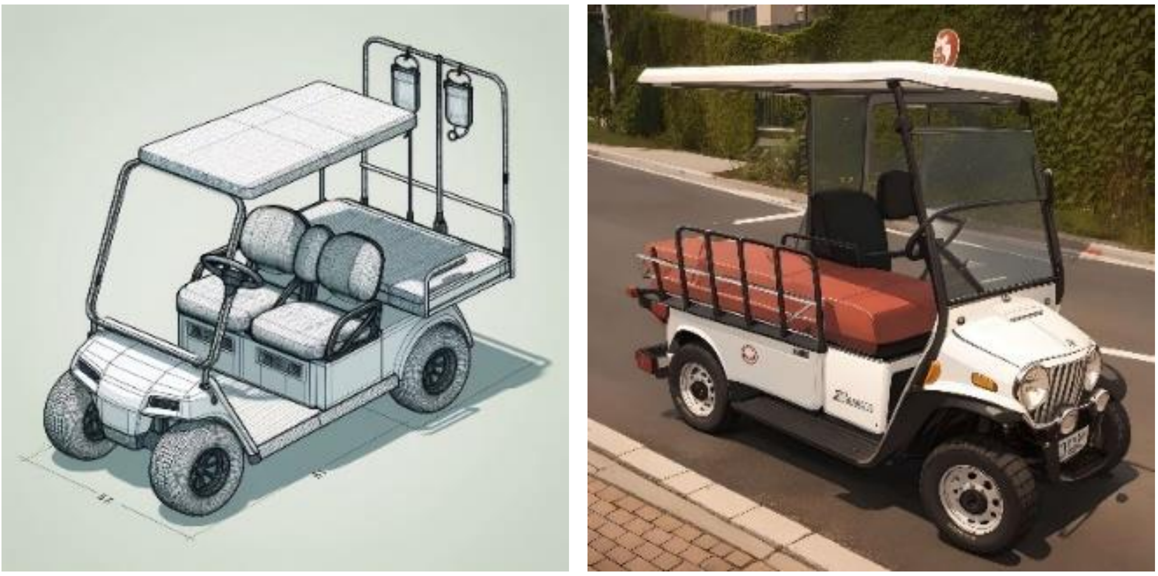

**Fig. 1.** The electric ambulance golf cart model

The electric hydraulic power steering systems' configuration, depicted in Fig. 2, delineates the steering control mechanisms utilized in electric ambulance golf carts. Typically, these systems integrate a DC motor as the actuator, tasked with producing rotary motion to directly drive the gear pump. The generated back electromotive force (Back EMF) by this motor functions as a generator output, proportionate to the motor's angular velocity. Initially, upon motor activation, the Back EMF registers zero, indicating full driving voltage received by the coil. Consequently, during motor standstill, it draws maximum current. The transfer function of a DC brush motor, articulated by R. Barua and colleagues [54] and denoted by (1), establishes the correlation between input voltage ($V$) and output angular rotation rate ($\dot{\theta}$). The parameters employed in the equations of this system, gleaned from the research [54], are outlined in Table 1 and (2) to furnish data for the development of the control system in this investigation.

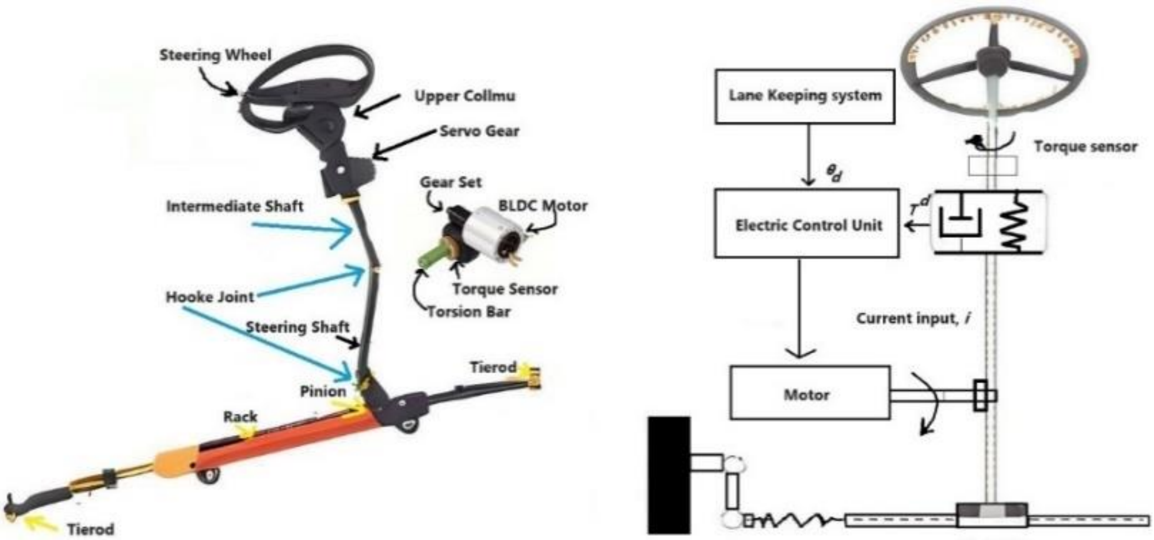


**Fig. 2.** The structure of steering control systems for electric ambulance golf carts

$$\frac{\dot{\theta}}{V} = \frac{k_t}{jLs^2 + (jR + bL)s + (bR + k_e k_t)} \tag{1}$$

**Table 1.** Physical parameters for simulation results

| Detail | Parameter | Value | Unit |
|---|---|---|---|
| The armature resistance | $R$ | 0.26 | ohm |
| Moment of inertia of the motor | $J$ | 0.000117 | kg.m$^2$/ s$^2$ |
| Damping ratio of the mechanical system | $b$ | 0.00147 | Nms |
| Electromotive force constant (Steering torque = 5.23 Nm) | $k_t$ | 0.033 | Nm/Amp |
| Motor constant | $k_e$ | 0.009 | Nm/Amp |
| Electric inductance | $L$ | 0.117 | H |

$$G(s) = \frac{0.033}{0.0000137s^2 + 0.0002s + 0.00068} \tag{2}$$

Fig. 3 depicts the block diagram structure of steering control systems, considering the structure from Fig. 2 for system design. To evaluate the control system structure, the motor equation system in (2) will be expressed in radians per second (rad/sec). This unit can be converted to rotations per second by multiplying by $0.159$. This conversion is utilized in researching steering control systems, where each rotation corresponds to one degree of steering shaft rotation, adjusting the vehicle's orientation. It serves as an initial step in examining the design of steering control system structures.

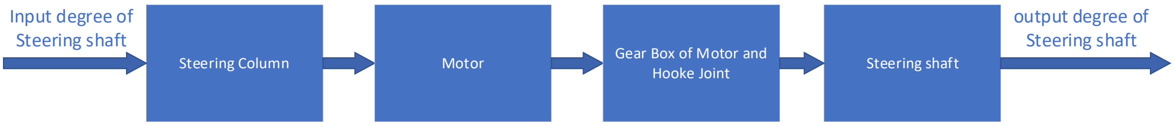


**Fig. 3.** Illustrates the structural block diagram of steering control systems

## 2.2. Feedback Control Design

In designing closed-loop control systems for various applications, it is common practice to design systems with adjustable control signal values, allowing for flexibility in controlling systems. This constitutes closed-loop control design. Typically, designing such closed-loop control systems imposes limitations on selecting appropriate parameter values for control because it's not feasible to predict the values of rise time, overshoot, and settling time by simply altering these parameters. Instead, designers rely on studying the system's response when adjusting these parameters.

In PID control, three linearly combinable control signals are utilized: the proportional action (P-action), which is proportional to the error signal ($e$), the integral action (I-action), which integrates the past error signal ($\int e\, dt$), and the derivative action (D-action), which considers the rate of change of the error ($\frac{dx}{dt}$ or $\dot{e}$). This section discusses the process of tuning a mixed-error PID control system, which can be represented by the closed-loop control system shown in Fig. 4 and expressed in (3).

$$u_j(k) = K_p e_j(k) + K_i \sum_{k-N}^{k} e_j(k) + K_d \left(e_j(k) - e_j(k-1)\right) \tag{3}$$

This research design involved studying the design of a fuzzy PD controller by utilizing the PD controller to determine the membership function of the system, based on research conducted by P. Chotikunnan et al. [53]. The design specified a gain value of $K_p$ at $0.2$ and $K_d$ at $0.015$, with $K_i$ set to $0$. This was done to enable the system's sampled data to predict the membership function of the system. To determine the system's gain value, manual tuning was employed to find the system's parameter values.

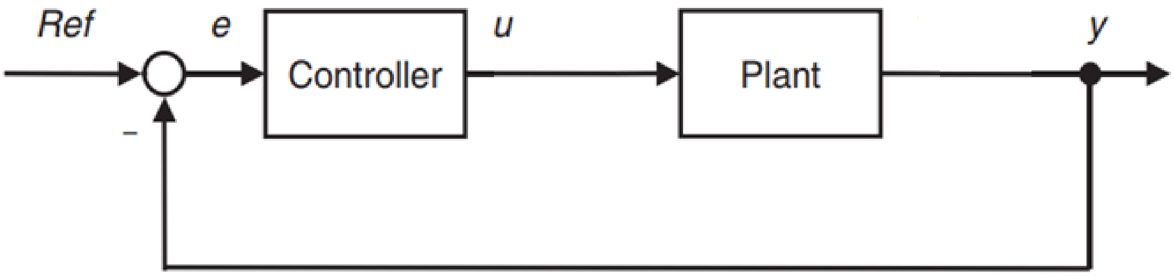


**Fig. 4.** Feedback control

### 2.3. Fuzzy Controller

Fuzzy logic controllers are sophisticated systems capable of efficiently managing complex and nonlinear systems. The design process of a fuzzy controller involves several essential steps, including identifying input and output variables, defining linguistic variables, establishing fuzzy rules, utilizing the fuzzy inference engine for rule processing and output generation, and applying defuzzification to convert fuzzy outputs into crisp outputs. Across the research studies, there is a consistent and coherent application of fuzzy logic controller (FLC) technology to effectively and diversely address or enhance systems within their respective domains. For example, FLC is employed to aid in obstacle avoidance for wheeled soccer robots, resulting in effective obstacle avoidance and reduced response time compared to non-FLC methods [55]. Furthermore, a digital system is developed for early hypoxemia prediction using fuzzy logic technology, facilitating the early detection of hypoxemia crucial for preemptive health interventions [56]. FLC is also integrated into a smart drip irrigation system for chili cultivation to optimize water supply and enhance crop yield [57]. Additionally, distance functions in fuzzy C-means clustering are examined, utilizing fuzzy logic technology for data analysis and clustering in complex systems [58]. The utilization of fuzzy logic in these research endeavors highlights its role in managing uncertainty and complexity in decision-making processes. These applications span various domains, including robot navigation, health monitoring, agricultural automation, and data clustering, demonstrating the versatility and effectiveness of fuzzy logic technology.

This section focuses on Mamdani models with two inputs and one output, each comprising 5 rules for input 1 and input 2, and 9 rules for the output, illustrated in Fig. 5 and Fig. 6, respectively. Table 2 presents the rules utilized in these models. The fuzzy system estimation employs the equation provided in (4), where $y_{mam}$ denotes centroid defuzzification. Centroid defuzzification determines the center of gravity of the fuzzy set along the x-axis, calculated using the following formula, where $\mu(x_i)$ represents the membership value for point $x_i$ in the universe of discourse.

$$y_{mam}(x_i) = \frac{\sum_i \mu(x_i)x_i}{\sum_i \mu(x_i)} \tag{4}$$

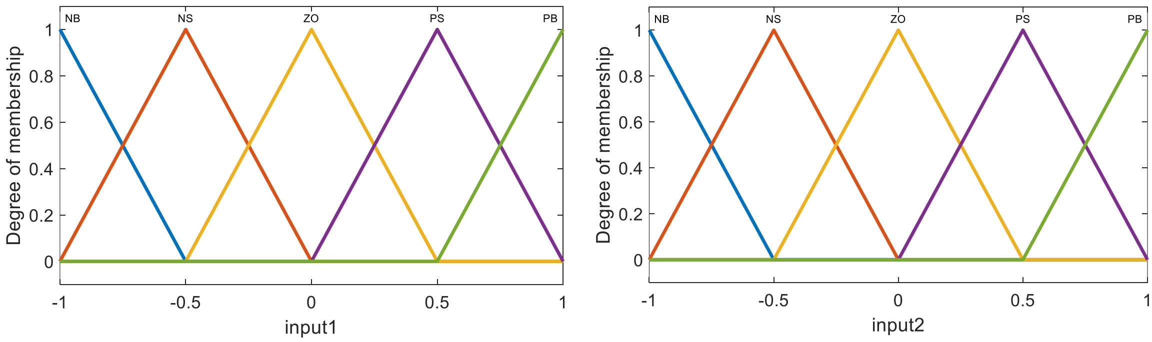


**Fig. 5.** Membership Function of input 1 and input 2 in fuzzy logic control

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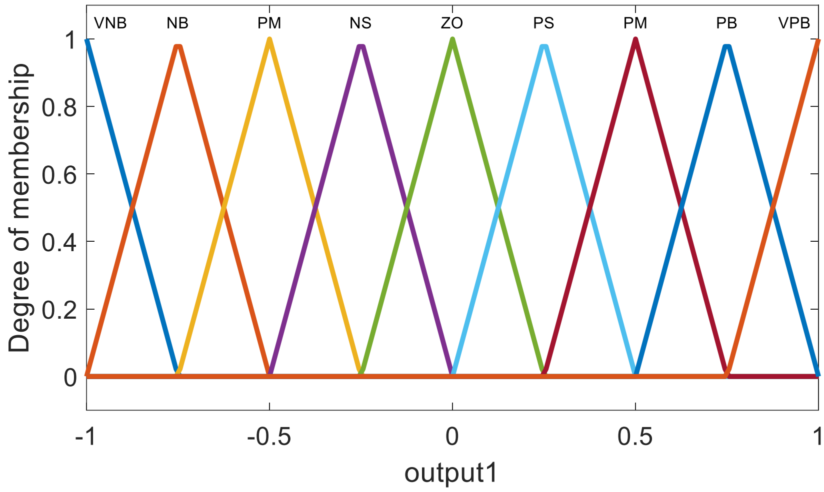


**Fig. 6.** Membership function of output in fuzzy logic control

**Table 2.** Membership function of the steering control systems

| | | $\breve{L}_{\dot{e}}$ | | | | |
|---|---|---|---|---|---|---|
| | | **NB** | **NS** | **ZO** | **PS** | **PB** |
| | NB | VNB | VNB | VNB | VNB | NM |
| | NS | NM | NM | NB | NB | NM |
| $\breve{L}_e$ | ZO | NS | NS | ZO | PS | PS |
| | PS | PM | PB | PB | PM | PM |
| | PB | PM | VPB | VPB | VPB | PB |

Table 2 presents the optimized membership functions for the steering control system, achieved through optimizing membership function tuning. This process is crucial in configuring membership functions for fuzzy logic control systems. P. Chotikunnan et al. [53] investigated this optimization, utilizing data from a closed control system with a PD controller to design membership function tuning for fuzzy control. The aim was to apply these techniques to steering control systems.

This research utilized training algorithms to derive the membership function, leveraging data storage techniques within a control system. MATLAB/Simulink programs were employed for feedback control, as shown in Fig. 7 and Fig. 8, illustrating the electric steering control system utilizing PID control. In this study, $K_p$ was set to 0.2, $K_i$ to 0, and $K_d$ to 0.015 for control.

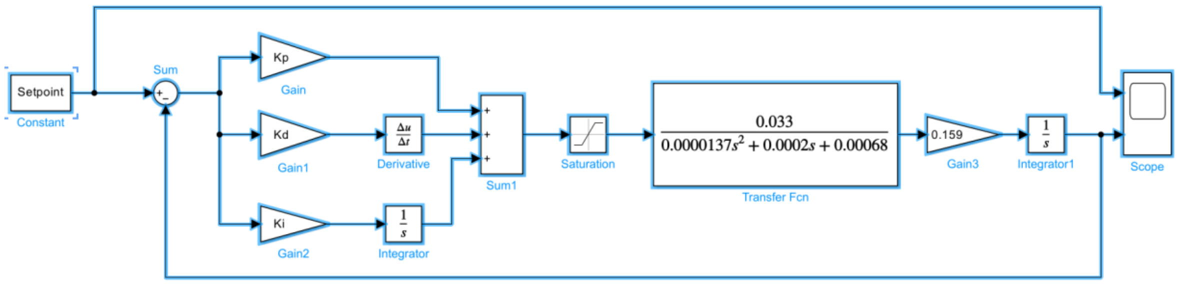


**Fig. 7.** The structure of Simulink program using the PID controller

To enhance the controller's performance in the system, optimization of membership function tuning was implemented in the design of fuzzy logic controllers. The PD control method was utilized to learn the system and determine the membership function. The membership function values were determined by gathering data from the feedback control using a program depicted in Fig. 8. This program facilitated data collection for membership function determination by generating a smooth function signal with a predefined setpoint. In Fig. 9, specific parameter values for the sine wave function are outlined. Subsequently, this signal is fed into the control system requiring the membership function of fuzzy logic. Data, including the error ($e$), the derivative of the error ($\dot{e}$), and the control input ($\breve{o}$), is collected from the feedback control system, as depicted in Fig. 10.

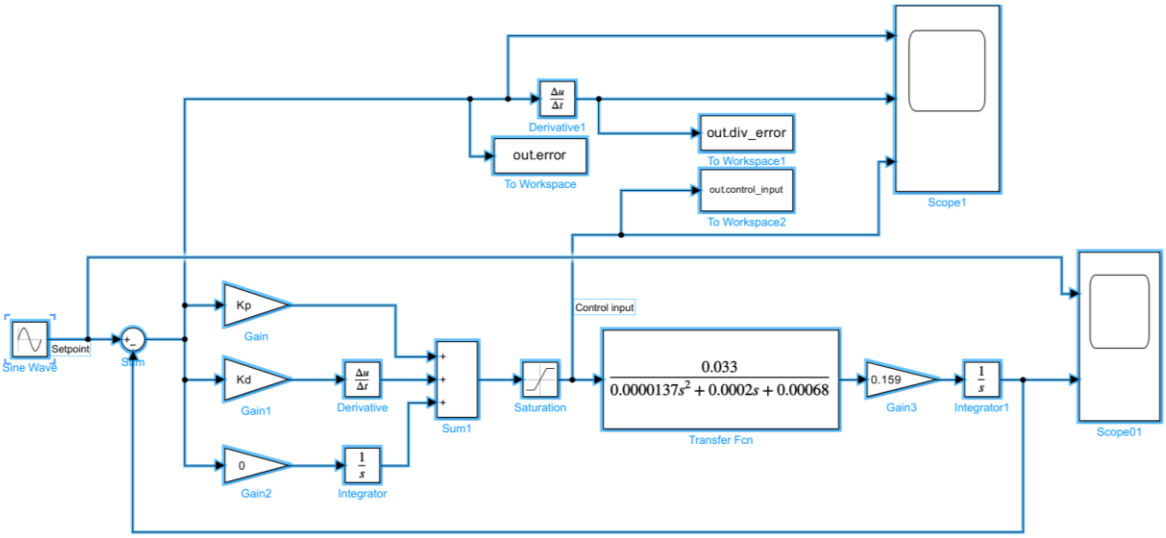


**Fig. 8.** Simulink was utilized to collect data from the feedback control

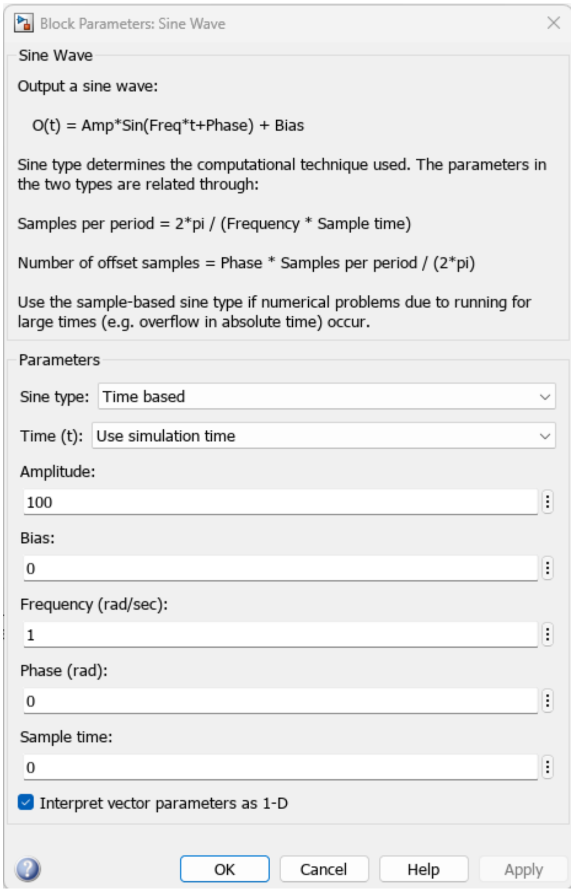


**Fig. 9.** Parameters of the sine function for data collection

Fig. 10 depicts the system's input and output values, while Fig. 11 shows the signal values obtained from the design of multiple polynomial regression using the Bisquare weight method tuned

FLC. This process implements optimized membership function tuning, following the methodology outlined by P. Chotikunnan et al. [27], to determine membership function values. The values obtained from Fig. 11 are used in finding the equation method through a membership function optimization process, resulting in constant values. These constant values are then substituted into the membership function table, as presented in Table 2, following the methodology by P. Chotikunnan et al. [27].

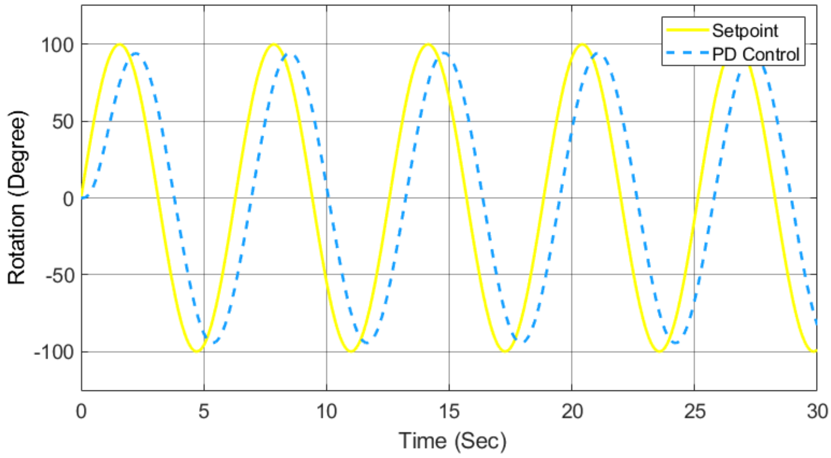


**Fig. 10.** System response using the PD controller

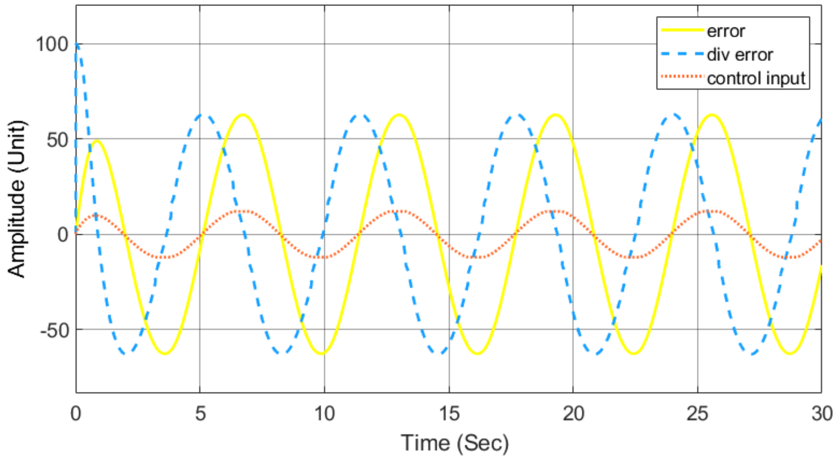


**Fig. 11.** Data collected from the feedback control system

### 2.3.1. Fuzzy PD Controller

Fuzzy logic controllers find wide application in systems like the steering control of electric ambulance golf carts, depicted in Fig. 1, effectively managing rotation and stability. System dynamics introduce delays between control signal changes and output adjustments, affecting controller responsiveness. Time-delay in PD controllers impacts error correction proportionally. Predictive action in PD controllers anticipates future errors, enhancing closed-loop system stability. Discontinuous-time PD controllers use this action to improve efficiency. The PID controller system equation, as derived from (3), can be modified to fit the PD controller format, as shown in (5).

$$u(k) = \left(K_p e(k) + K_d e(k) - e(k-1)\right) \tag{5}$$

$$\dot{e}(n) \approx e(n) - e(n-1) \tag{6}$$

The PD controller, with the differential term involving the difference between $e(n-1)$ and $e(n)$, can be expressed in the form of $\dot{e}(k)$ as shown in (6).

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Comparing the Fuzzy PD controller system for approximating system values can utilize (4) to estimate the system's response. (4) can be transformed into (7) to represent the system, which can be further explained in Fig. 12. Considering input 1 as the error value $e$ passed through the gain value $GE$ before being used for estimation in Fig. 5, the Membership Function of input 1 and input 2 represents the value of the error derivative $\dot{e}$ or the difference in error values in the system. By substituting $GCE$ with the gain value derived from the output of the closed-loop control system, the control signal $U(k)$ at step time $(k)$ becomes a nonlinear function of both error and error derivative changes, as depicted in (7), where the value of $GU$ represents the amplification rate to amplify the signal from $U(k)$.

$$U(k) = f(GE * e(k), GCE * \dot{e}(k)) * GU \tag{7}$$

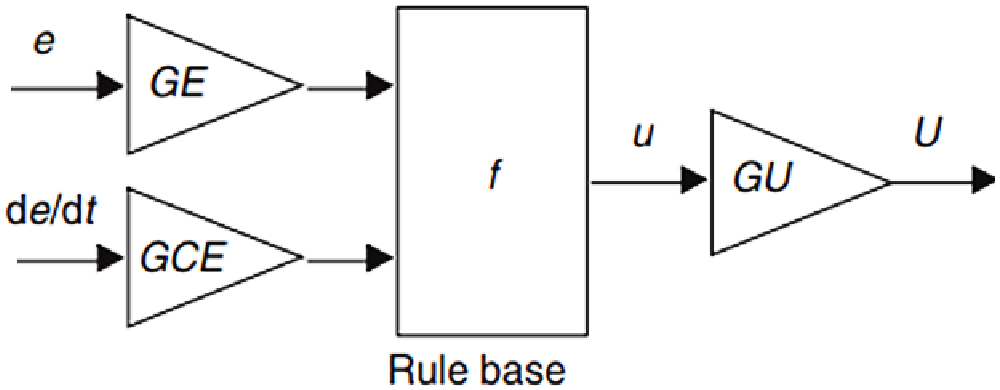


**Fig. 12.** Fuzzy PD controller

The block diagram illustrated in Fig. 12 can be used to design the implementation of a fuzzy logic system for controlling the stability and mobility of the system. Various parameters are employed in the diagram depicted in Fig. 13, with $GE$ and $GCE$ set as $KFI$ values. These parameters are programmed into Simulink as follows, $KFI$ is set to 1/40, $KFO$ is set to 12, “saturation” and “saturation1” are set to ±1, and “saturation2” is set to ±12. These parameter values can be determined through optimized membership function tuning or adjusted manually to achieve optimal performance. $KFI$ represents the signal gain value of the input signal, while $KFO$ represents the signal gain value of the output signal. It's worth noting that while $KFO$ is typically set to 12, indicating the maximum signal the system can send to control the steering system, its value may vary based on the specific design requirements of the system. To determine the system's Gain value, manual tuning was employed to find the system's parameter values.

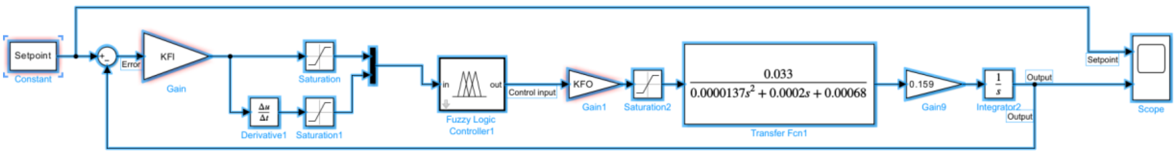


**Fig. 13.** Simulink block diagram of a fuzzy logic controller

### 2.3.2. Fuzzy PD+I Controller

The design of the fuzzy PD+I controller entails creating a conventional fuzzy PD controller and integrating an integral term to address continuous errors in the closed-loop system's steady state. Integrative actions are necessary to correct errors, regardless of their size, ensuring the controller always returns to the reference in a steady state. While a PID controller utilizes three input signals error, integral of the error, and derivative of the error operating with a rule base featuring three basic inputs can be complex. However, by incorporating the Integral (I) term into a fuzzy PD controller, it simplifies system design complexity.

In utilizing the Fuzzy PD+I Controller, values from (3) can be rearranged to form (8), with GIE representing the gain in the summation of error terms. In (8) can then be transformed into a simplified block diagram format, as depicted in Fig. 14.

$$U(k) = \left[ f(GE * e(k), GCE * \dot{e}(k)) + GIE \sum_{k-N}^{k} e_j(k) \right] * GU \tag{8}$$

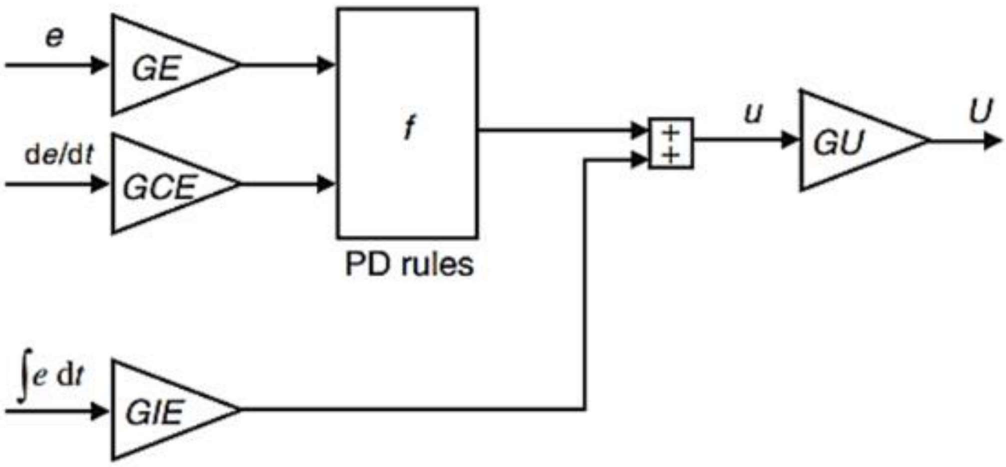


**Fig. 14.** Fuzzy PID controller

From Fig. 14, a system design incorporating a fuzzy PD rule base in the fuzzy PD+I controller can be envisioned, as shown in Fig. 15. In this system, the gain values of $GE$ are specified as $F_{kp}$=0.8, $GIE$ as $F_{ki}$=0.125, and $GCE$ as $F_{kd}$=1.5. To determine the system's Gain value, manual tuning was employed to find the system's parameter values and These values can be adjusted as required.

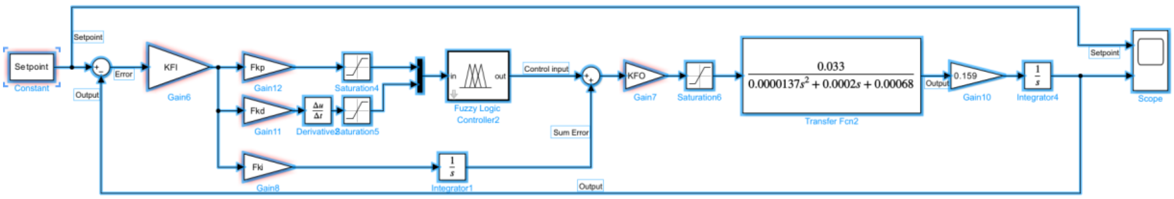


**Fig. 15.** Simulink block diagram of a PBC and PD-I type fuzzy logic control

### 2.3.3. Proportional Back Calculation and PD+I Type Fuzzy Logic Controller

The design of the proportional back calculation and PD+I type fuzzy logic controller, or PBC and PD+I type fuzzy logic controller, involves creating a conventional fuzzy PD+I controller and introducing a proportional component to address errors within the system. This method is employed to mitigate occasional system overshoots or extended settling times when approaching the setpoint. Typically, anti-windup mechanisms are utilized to counteract these effects. One common approach is conditional integration and back calculation. Conditional integration disables the PID derivative term when an indicator suggests that integrator action is causing accumulation. The simplest anti-windup method involves checking the controller output against a limit and deactivating the integrator if the output exceeds the limit. However, back calculation for anti-windup involves adding feedback reinforcement to the derivative term, activating when integrator action disrupts the main feedback loop, with an additional parameter for adjusting the back calculation rate.

In this context, the equation for approximation can be derived as (9), building upon (8) with additional terms for receiving the signals $U(k-1)$ via the amplification rate $Kci$ and $y(k-1)$ via the amplification rate $Kop$. This is illustrated in the block diagram shown in Fig. 16.

$$U(k) = \left[ f\big(GE * e(k), GCE * \dot{e}(k)\big) + GIE \sum_{k-N}^{k} e_j(k) + U(k-1) * (Kci) + y(k-1) * (Kop) \right] * GU \tag{9}$$

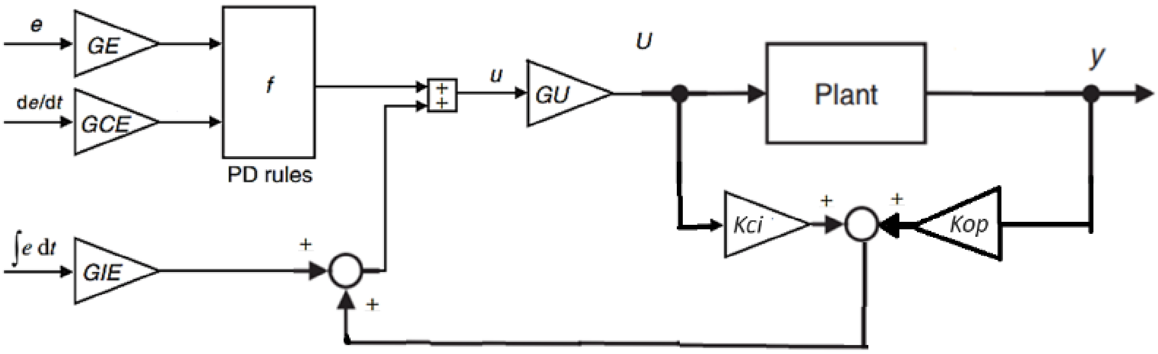


**Fig. 16.** Proportional back calculation and PD+I type fuzzy logic controller

From Fig. 16, a Simulink program can be designed as illustrated in Fig. 17. This Simulink program facilitates the simulation and analysis of proportional back calculation within a fuzzy logic system, effectively reducing the time required to reach the system's setpoint, as depicted in Fig. 17. The designed proportional back calculation utilizes the system's control input and output signals to compensate for internal errors. The specified gain values for the system are as follows, $Fkp$ =0.8, $Fkd$ =0.25, $Fki$ =1.5, $Kci$ =0.040, and $Kop$ =-0.002. To determine the system's Gain value, manual tuning was employed to find the system's parameter values and These values can be adjusted as required.

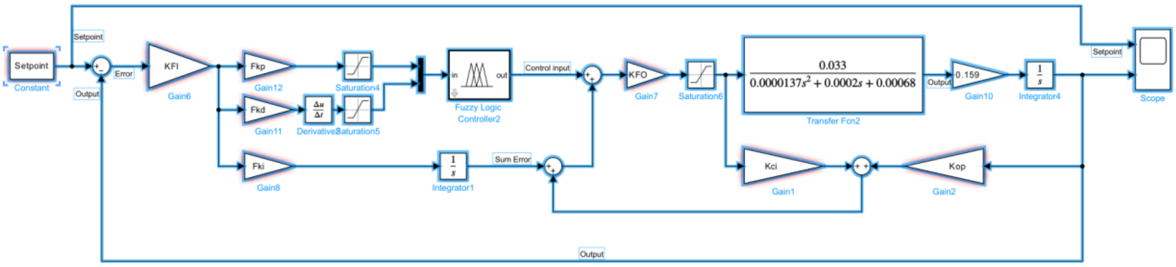


**Fig. 17.** Simulink block diagram of a PBC and PD-I type fuzzy logic control

## 3. Results and Discussion

To comprehensively assess the performance of four control systems - PD controller, fuzzy PD controller, fuzzy PD+I controller, and PBC and PD+I type fuzzy logic controller - a systematic simulation testing approach is devised. This approach utilizes Simulink to create test simulations, focusing on evaluating the controllers' effectiveness under diverse conditions. Specifically, the testing includes two system simulations with setpoints of 10 degrees and 20 degrees for the degree of steering shaft rotation. The rise time is determined at 5%, and settling time at 3% of the setpoint entry, with each test standardized to a duration of 3 seconds. Manual tuning is employed to determine the system's Gain value, as detailed in sections 2.3.1, 2.3.2, and 2.3.3. The configuration of these control systems is illustrated in accompanying figures: the PD controller in Fig. 7, the fuzzy PD controller in Fig. 13, the fuzzy PD+I controller in Fig. 15, and the PBC and PD+I type fuzzy logic controller in Fig. 17. Each figure serves as a reference for understanding the design and setup of the respective control systems in the simulation testing. Furthermore, Fig. 18 demonstrates the integration of these control systems into Simulink for system simulation purposes. The analysis of the systems involves examining the values of rise time, settling time, and %OS observed within the system.

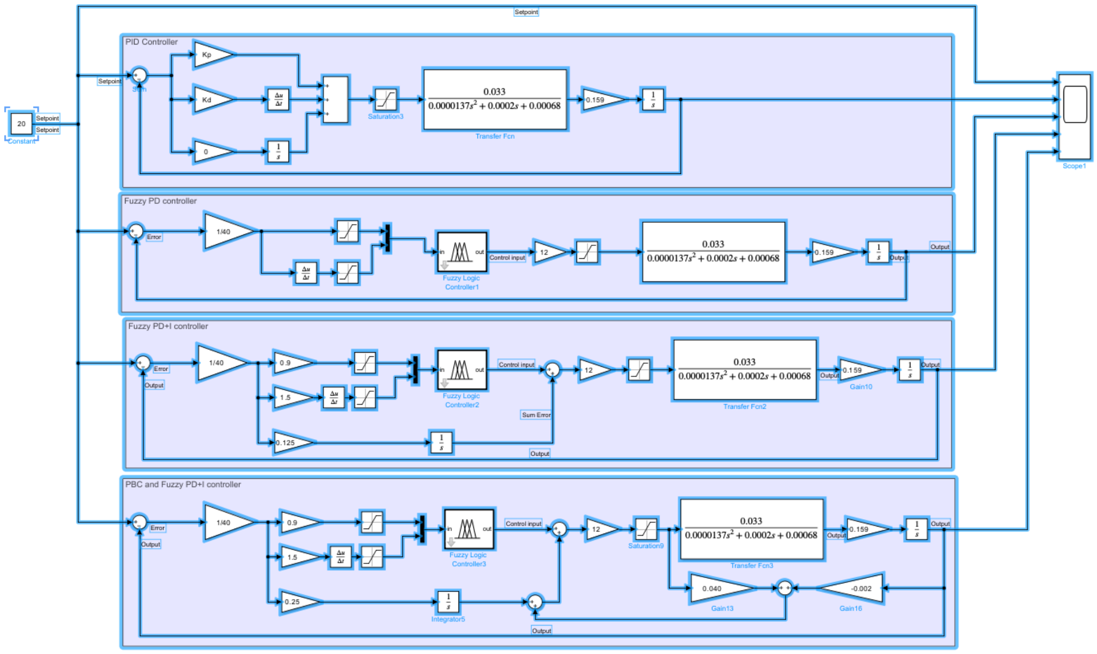


**Fig. 18.** Overview of Simulink block diagram for testing in simulation of the steering control systems

In the first simulation, as depicted in Fig. 19, the control systems were assessed at a setpoint of 10 degrees. The objective of the system testing was to evaluate the performance of the controllers in controlling the system when the setpoint was set at 10 degrees. It was observed that the PD controller exhibited a rise time of 1.39 seconds and a settling time of 1.50 seconds, with a minimal overshoot of only 0.8%. Furthermore, the results highlighted the effectiveness of the fuzzy PD controller, which demonstrated faster rise time and settling time compared to the PD controller, with no overshoot occurring (0.00%). When testing the fuzzy PD+I controller, it was found to effectively control the system, albeit with a slightly higher overshoot compared to the fuzzy PD controller, but still within acceptable levels (2.50%). Lastly, the testing of the PBC and PD+I type fuzzy logic controller yielded significant success, as it achieved the shortest rise time and settling time while maintaining the lowest level of overshoot (1.80%). These findings contribute to bolstering confidence in the efficient control capabilities of this type of controller. From the results of the aforementioned system simulation tests, interpretations can be derived from Fig. 19 and Fig. 20, which can be summarized in Table 3 and Table 4 as follows.

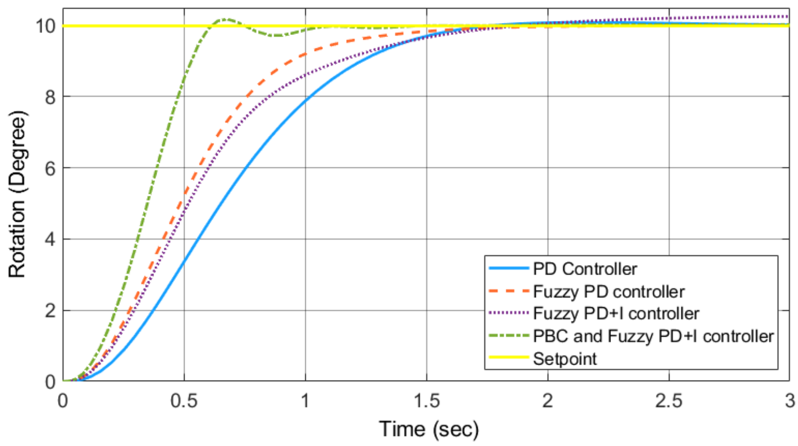


**Fig. 19.** Simulation results of the first simulation test of the system

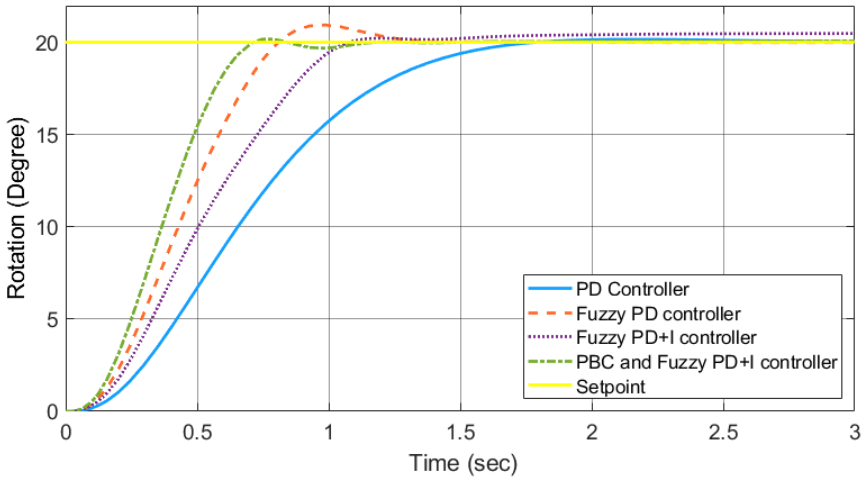


**Fig. 20.** Simulation results of the second simulation test of the system

**Table 3.** Controller performance in setpoint 10 degree

| Controller | Risetime (Sec) | Setting time (Sec) | % OS (%) |
|---|---|---|---|
| PD Controller | 1.39 | 1.50 | 0.8 |
| Fuzzy PD Controller | 1.13 | 1.30 | 0.00 |
| Fuzzy PD+I Controller | 1.38 | 1.52 | 2.50 |
| PBC and PD+I type Fuzzy Logic Controller | 0.57 | 0.59 | 1.80 |

**Table 4.** Controller performance in setpoint 20 degree

| Controller | Risetime (Sec) | Setting time (Sec) | % OS (%) |
|---|---|---|---|
| PD Controller | 1.40 | 1.50 | 0.95 |
| Fuzzy PD Controller | 0.74 | 1.12 | 4.75 |
| Fuzzy PD+I Controller | 0.96 | 0.98 | 1.10 |
| PBC and PD+I type Fuzzy Logic Controller | 0.64 | 0.66 | 1.00 |

The comparative analysis of the experimental results presented in Table 3 and Table 4 is particularly intriguing as it involved testing under two different setpoint values (10 degrees and 20 degrees). This allowed for a better understanding of the controller performance in varying system conditions. Due to the challenge of designing a fuzzy logic control system, it is crucial to ensure effective control within the range of control inputs covered by the membership functions' rules to achieve optimal performance. Therefore, the control of the degree of steering shaft rotation is demonstrated at setpoints of 10 degrees and 20 degrees, respectively. From the results in Table 3, when the setpoint was 10 degrees, all types of controllers performed efficiently with short rise time and settling time. The PBC and PD+I type fuzzy logic controller demonstrated the highest effectiveness in reducing rise time and settling time while maintaining the lowest level of overshoot. Conversely, when the setpoint was increased to 20 degrees in Table 4, all controllers continued to operate effectively. However, both the fuzzy PD controller and fuzzy PD+I controller showed significant reductions in rise time and settling time. It's worth noting that with the increase in setpoint to 20 degrees, there was an increase in overshoot. The fuzzy PD controller exhibited the highest overshoot at 4.75%, while the PBC and PD+I type fuzzy logic controller maintained the lowest level of overshoot at 1.00%. Overall, this comparative analysis provides valuable insights into the performance of different controllers under varying setpoint conditions, highlighting their strengths and weaknesses in controlling the system. It is observed that the PBC and PD+I type Fuzzy Logic Controller system exhibits the best rise time and settling time compared to the other control systems under comparison. However, this comes at the expense of experiencing overshoot within the system. On the other hand, the normal operation of the fuzzy PD controller system has a minimal or no chance of overshoot within the range of the degree of steering shaft rotation at 10 degrees. However, if the difference is set to 20 degrees, the overshoot occurrence is significantly higher in this control system compared to others.

## 4. Conclusion

This research aimed to enhance electric ambulance golf cart steering control through a comparative study of fuzzy logic controllers. The objective was to investigate and evaluate the performance of control systems utilizing fuzzy logic techniques to improve steering control. By comparing various controllers under different test scenarios, the aim was to enhance steering control capabilities in diverse conditions. The experimental results demonstrated the effectiveness of fuzzy logic controllers in reducing both rise time and settling time of the steering system across all test scenarios. Specifically, the evaluation included PD controller, fuzzy PD controller, fuzzy PD+I controller, and PBC and PD+I type fuzzy logic controller. Notably, the PBC and PD+I type fuzzy logic controller exhibited superior performance in both scenarios, showcasing significant improvements in reducing rise time and settling time with minimal overshoot. This underscores its potential for effective steering control. While this study provides valuable insights into the capabilities of fuzzy logic controllers for steering control, it is important to acknowledge its limitations. Future research should address these limitations and explore other control system designs to further improve the performance of controlling the degree of steering shaft rotation. This may include exploring alternative control strategies, evaluating the robustness of controllers under various operating conditions, and conducting field experiments to validate findings in real-world settings. In summary, this research aimed to demonstrate the effectiveness of fuzzy logic controllers in application to steering control for electric vehicles. Additionally, it tested the design of proportional back calculation and PD+I type fuzzy logic controller to examine if it can control better than PD type fuzzy logic systems, aligning with the objectives of the control system design.

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