

Servo Motor Control System Analysis Using Proteus Simulation

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Abstract

Servo motors are essential actuator components in the modern mechatronics ecosystem that demands angular positioning precision with minimal error rates. In the control system development phase, direct testing on hardware is often at risk of mechanical damage due to programming errors or current surges. This study aims to conduct an in-depth analysis of the response characteristics of servo motors through a digital simulation approach as a preventive and validative step. The research method applied was a software-based laboratory experiment using the Proteus 8 Professional with an Arduino Uno microcontroller as the central control unit. The main focus of this test lies in the evaluation of the accuracy of the motor angular movement against the pulse width modulation (PWM) provided through the Servo standard library. Data is collected through Virtual Terminal observations and position indicators on virtual servo components. The results show that the Proteus simulation is able to represent the dynamics of angular motion linearly with a 100% accuracy rate to theoretically entered work cycle parameters. The study concludes that the use of virtual modeling is not only effective in minimizing the risk of physical failure.

Keywords

Servo Motor; Proteus ISIS; Pulse Width Modulation (PWM); Arduino Uno; Control System.



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INTRODUCTION

The development of automation technology and control systems today has exerted a great influence in the fields of electronics, robotics, and intelligent industry. One of the components that is often used in modern control systems is the servo motor. Servo motors are actuators that are able to produce angular movement with a high level of precision so that they are widely applied to robotics systems, automatic antennas, robot arms, and industrial control devices. The use of a servo motor requires a stable control system to be able to produce accurate, responsive, and efficient movements. Therefore, the analysis of the servo motor control system is important to support the development of more optimal control technology

(Küçükdermenci, 2025).

In the field of electronics and control systems, simulation is an effective method of studying the behavior of a circuit before it is applied to real hardware. One of the software that is often used is Proteus. The software is able to virtually simulate a circuit of electronics, microcontrollers, and control systems, reducing design errors and implementation costs. The use of simulation also simplifies the process of analyzing the characteristics of the control system, especially in servo motor control which requires signal accuracy and angle of movement (Ananditya, 2020).

Servo motors work based on the principle of Pulse Width Modulation (PWM), which is a control method by utilizing changes in pulse width to determine the position of the motor angle. The PWM control system allows the servo motor to move at a certain angle with considerable accuracy. However, the stability of the PWM signal and the suitability of the control circuit are the main factors in determining the performance of the servo motor. Problems that often arise in servo control systems are movement instability, response delays, and position mismatches due to signal interference or circuit misconfigurations (Kasiyanto et al., 2024).

Several previous studies have discussed the use of Operational Amplifiers (Op-Amps), electronic circuit simulations, and the implementation of microcontroller-based control systems. Research on the application of Op-Amp in electronic systems shows that simulation can improve understanding of circuit characteristics and control system responses (Syahbani, 2018). In addition, research on filter simulation and digital electronics systems also explains that the use of simulation software can help the circuit analysis process more effectively before real implementation (Eko Nuryanto, 2017). Other research related to IC 741-based Op-Amp practicum modules shows that simulation and virtual testing can improve the efficiency of electronic learning and control systems (A, 2021).

Although various studies on electronic simulations have been conducted, there are still limitations to specific analyses of servo motor control systems using Proteus simulations. Some studies only focus on hardware implementation without conducting an in-depth analysis of control characteristics. Therefore, research is needed that is able to analyze the performance of the servo motor control system through simulation so that the relationship between the control signal, the movement of the servo angle, and the stability of the system can be known. (Miftachul et al., 2022).

This study aims to analyze the servo motor control system using the Proteus simulation by utilizing the PWM signal as the main controller. The analysis was carried out to determine the response of the servo motor movement to changes in the input signal as well as to evaluate the stability of the designed control system. The results of the research are expected to provide an understanding of the control characteristics of servo motors and become a reference in the development of automation and robotics systems based on electronics simulation (Rayhan Al Hayubi et al., 2024).

METHODS

Introduction to operational amplifiers (Operstionsl Amplifier). It is an electronic component that is widely used by a wide range of applications from signal boosters, analog signal processing and components in control circuits (Kasiyanto et al., 2024). Op amps have important characteristics such as high gain, high input impedance, and low output impedance, making them ideal for a wide range of implementations in basic electronics applications. The ideal op amp range is shown in Figure 1 (Rayhan Al Hayubi et al., 2024).

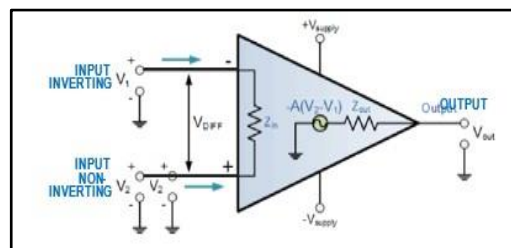


Figure 1. Op-Amp Equivalent Range

Operational Principles and Characteristics of Op Amp. The operational amplifier has two input connections, a reversing and non-reversing input connection, and an output connection (Rayhan Al Hayubi et al., 2024). Its working principle is based on Kirchhoff's law applied to feedback networks. In this literature review, several references define the ideal characteristics of an operational booster (Syahbani, 2018). Gain (gain): i.e. Op Amp which has infinite gain (Ananditya, 2020). Input Impedance: i.e. high inlet impedance, so that the current flowing to the input terminal is not optimal (Eko Nuryanto, 2017). Output impedance: That is, the output impedance is very low so that it allows maximum power transfer to the existing load (Kasiyanto et al., 2024).

The characteristics of an ideal Op-Amp

Nama Parameter	Simbol	Nilai Ideal	Nilai Riel
Arus Masukan	I_{IN}	0	rendah (<0,5 μ A)
Tegangan Offset Masukan	V_{OS}	0	rendah (<10 mV, 0,2 μ A)
Impedansi Masukan	Z_{IN}	∞	tinggi (>10 M Ω)
Impedansi Keluaran	Z_{OUT}	0	rendah (<500 Ω)
Gain (Penguatan)	a	∞	sangat tinggi (>10 ⁴)
Bandwidth (lebar pita frekuensi)	fBW	∞	
CMRR	CMRR	∞	Tinggi (>70 dB)

Figure 2. The characteristics of an ideal Op-Amp

There are two basic rules in designing using Op-Amp, which are, Current rule, no current flowing between two input terminals (inverting, V- and non-inverting, V+) (Eko Nuryanto, 2017). Voltage rule: there is no difference in voltage of either V- and V+, or $V^- = V^+$, Application of Op-Amp in Basic Electronics. A simple operational amplifier network is commonly used to introduce basic concepts to students and beginners in the field of electronics engineering (Miftachul et al., 2022).

Basic applications that are often discussed include, Voltage amplifiers are circuits that amplify input signals based on gain determined by the resistance ratio of the feedback path (Küçükdermenci, 2025). Differential amplifiers are used to compare two input signals and produce voltage differences between them (A, 2021). The summation amplifier circuit is intended to allow multiple input signals to be combined to produce an output that is a weighted sum of these signals (Ananditya, 2020). Integrators and differentiators are a series of operational amplifiers-based assemblies used in signal processing applications such as forming signal waveforms and analyzing changes (A, 2021). Simple Op-amp network design.

Designing a simple Op-Amp circuit includes selecting basic components such as resistors, capacitors, and power sources that support Op-Amp operation (Küçükdermenci, 2025). In addition, an understanding of the current and voltage in the critical nodes is crucial in ensuring that the circuit functions synchronously (Syahbani, 2018). The methodology in design practice starts using simulations using software to ensure that the initial design meets the specified specifications (Küçükdermenci, 2025). After that, the implementation is carried out using a printed circuit board or breadboard (Eko Nuryanto, 2017).

Practicum tools and material, Set of oscilloscopes and probes, Multimeter device, 1 Function generator, 1 DC power supply, 1 project board, Connection cable, Resistance: $22\text{K}\Omega$, $20\text{K}\Omega$, $10\text{K}\Omega$, Potentiometer: $10\text{K}\Omega$ or $20\text{K}\Omega$. Assemble the integrator array with the op amp as shown in Figure 2. The $\mu\text{A}741$ power drive gets input from the integrated variable DC power source (Rayhan Al Hayubi et al., 2024).

Create a series of sinusoidal input signals V_{i1} and V_{i2} using the AC source voltage divider of the function generator (FG) at a frequency of 1 kHz, as shown in Figure 4. The values of R_a and R_b can be set with a potentiometer. Then check the signal on the oscilloscope and observe changes in V_{i1} on channel 1 and V_{i2} on channel 2. Adjust the amplitude at the source (FG) as well as the values R_a and R_b so that $V_{i1} = V_{i2} = 40 \text{ mVp-p}$ is obtained (Syahbani, 2018).

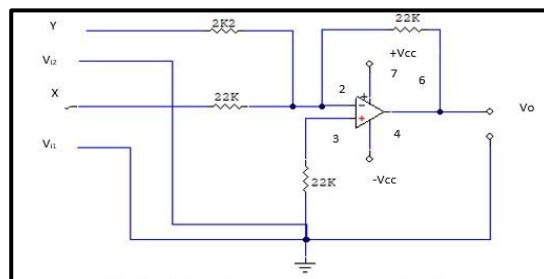


Figure 3. Op-amp series as summation

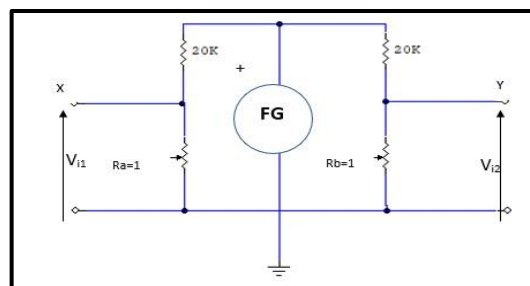


Figure 4. Input signal source network

Connect the x and y sources in the series of figure 3, create the V_{i1} , V_{i2} on channel 1, and and output V_0 on channel 2, and give them clear labels.

FINDINGS AND DISCUSSION

FINDINGS

What is the basic working principle of an op-amp when used as a summing circuit, and how is the circuit configured? (Miftachul et al., 2022). Answer: Basic Working Principle An operational amplifier is used as an enumeration circuit in an inverting or non-inverting configuration to sum multiple input signals. In the inverting configuration, multiple input signals (V_{i1} , V_{i2} , V_{i3} , etc.) are entered

through a resistor connected to the op-amp inverting terminal[6]. The output voltage is calculated based on the sum of these inputs with reverse polarity (due to the inverting configuration) with the formula (Eko Nuryanto, 2017).

$$V_{out} = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \dots + \frac{R_f}{R_n}V_n\right)$$

Figure 5. Inverting Summing Amplifier equation formula

How does the change in potentiometer value affect the input voltage of Vi1 and Vi2, and what is the impact on the output voltage of Vo? (Miftachul et al., 2022). Answer: The Effect of Potentiometer Value Change on Input Voltage and Output Potentiometer can be used to regulate the input voltage (Vi and Vi2) by changing the resistance that controls the current passing through the input. When the resistance of the potentiometer is changed, the voltage value provided to the input terminal of the op-amp also changes. Changes in Vi1 and Vi2 will affect the output voltage (Vo) value, as Vo is the result of the inverse sum of these input voltages. If Vi1 or Vi2 changes, the output voltage will change according to the weight of each input (Küçükdermenci, 2025).

What happens to the Vo output if the input amplitude of Vi1 is greater than Vi2, and vice versa? Explain how this fits into the op-amp theory of the summer? (Rayhan Al Hayubi et al., 2024). Impact If Vi1 Amplitude Is Greater than Vi2 (and Vice Versa) If Vi1's amplitude is greater than Vi2's, the Vo output will be negative with a value proportional to the difference between Vi1 and Vi2. Conversely, if the Vi2 is greater than the Vi1, the output voltage will be positive (Mudin et al., 2026). This corresponds to the op-amp theory of inverting summation, where the output voltage is the sum of the input voltage whose polarity is changed (depending on the comparison of input resistance and feedback) (Miftachul et al., 2022).

DC current.

The results of the data obtained with the DC current source are as follows.

No	Masukan Vi1 (Vp-p)	Masukan Vi2 (Vp-p)	Keluaran Vo (Vp-p)	
			Perhitungan	Pengukuran
1	0,2	1,2	-3,2	-3,1
2	0,3	1,3	-4,3	-4,5
3	0,4	1,4	-5,4	-5,3
4	0,5	1,5	-6,5	-6,2
5	0,6	1,6	-7,6	-7,4
6	0,7	1,7	-8,6	-8,9
7	0,8	1,8	-9,8	-9,6
8	0,9	1,9	-10,9	-10
9	1,0	2,0	-12	-10,1

Figure 6. The results of the data obtained with the DC

Presents the input and output voltage data obtained from both theoretical calculations and practical measurements of an Operational Amplifier configured as an inverting summing amplifier circuit. The experiment was conducted by applying two input signals, namely V_{i1} and V_{i2} , expressed in peak-to-peak voltage (Vp-p), and observing the resulting output voltage (V_o). The calculated output values were determined using the theoretical equation of the inverting summing amplifier, while the measured values were obtained directly using an oscilloscope during the experiment.

Based on the data shown in the table, the output voltage increases negatively as the input voltages increase. This behavior is consistent with the working principle of an inverting summing amplifier, where the output signal is inverted by 180 degrees relative to the input signals. For example, when the input voltages are $V_{i1}=0.2\text{Vp-p}$ and $V_{i2}=1.2\text{Vp-p}$, the calculated output voltage is -3.2Vp-p , while the measured output voltage is approximately -3.1Vp-p . Similarly, at the highest input condition where $V_{i1}=1.0\text{Vp-p}$ and $V_{i2}=2.0\text{Vp-p}$, the calculated output voltage reaches -12Vp-p , whereas the measured result is approximately -10.1Vp-p .

The comparison between theoretical and experimental results indicates that the measured output voltages are relatively close to the calculated values, showing that the operational amplifier circuit functions properly according to theoretical expectations. However, small differences can still be observed between the calculated and measured data. These deviations may be caused by several practical factors such as resistor tolerance, internal limitations of the operational amplifier, noise interference, power supply instability, signal distortion, and measurement inaccuracies from the oscilloscope. In addition, real operational amplifiers do not possess ideal characteristics such as infinite gain and infinite bandwidth, which also contributes to slight discrepancies between theory and practice.

Overall, the experiment demonstrates that the inverting summing amplifier circuit successfully performs the mathematical addition of multiple input signals while producing an inverted output signal. The results confirm the fundamental characteristics of operational amplifiers in analog signal processing applications, particularly in signal summation and amplification systems. Therefore, the experiment validates both the theoretical concept and practical implementation of the operational amplifier as an analog summing device.

Livewire DC simulation results

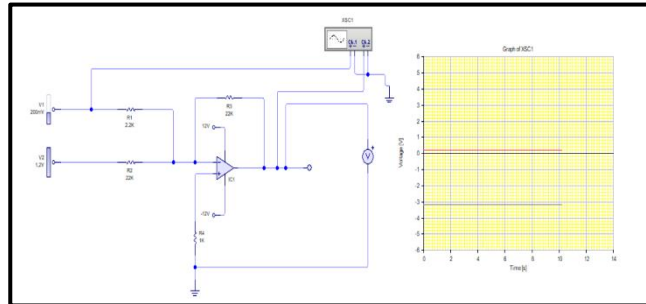


Figure 7. Simulation of an Inverting Summing Amplifier Circuit with Output Voltage of -3.2 V

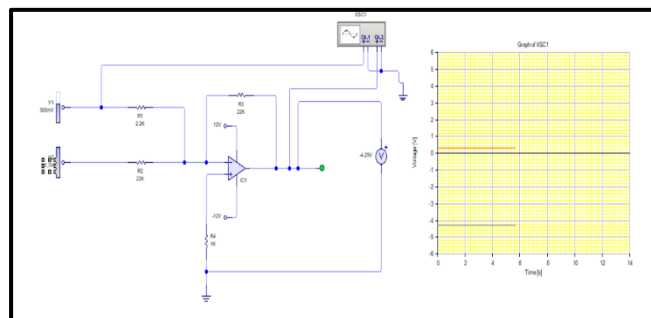


Figure 8. Simulation of an Inverting Summing Amplifier Circuit with Increased Input Voltage and Output Voltage of -4.2 V

Figure 1. Simulation of an Operational Amplifier configured as an inverting summing amplifier using Proteus Design Suite. The circuit receives two input voltages through input resistors connected to the inverting terminal of the operational amplifier. A feedback resistor is used to provide negative feedback from the output to the input terminal. In this simulation, the applied input voltages produce an output voltage of approximately -3.2V . The graph on the right side shows the resulting output waveform, demonstrating the inversion and amplification process characteristic of an inverting summing amplifier circuit.

Figure 2. Simulation of an inverting summing amplifier circuit with increased input voltage values. The operational amplifier combines and amplifies the two input signals through the resistor network connected to the inverting input terminal. Compared to the previous simulation, the higher input voltages result in a larger negative output voltage of approximately -4.2V . The output waveform displayed on

the graph confirms that the circuit operates according to the theoretical principle of an inverting summing amplifier, where the output voltage is proportional to the sum of the input voltages and inverted in phase.

DC Practice Documentation



Figure 9. Voltage and Current Measurement Setup Using DC Power Supplies and Digital Multimeter

The image illustrates a laboratory setup for voltage and current measurement, consisting of two DC power supplies and a digital multimeter interconnected through measurement cables within an electronic experimental circuit. This configuration provides a stable and adjustable power source for the circuit, enables precise monitoring of electrical parameters, and supports the analysis of circuit behavior and performance under different experimental.

AC Current

The results of the data obtained with the AC current source are as follows.

No	Masukan V_{i1} (Vp-p)	Masukan V_{i2} (Vp-p)	Keluaran V_o (Vp-p)	
			Perhitungan	Pengukuran
1	0,2	1,2	-3,2	-2,9
2	0,3	1,3	-4,3	-4,0
3	0,4	1,4	-5,4	-5,2
4	0,5	1,5	-6,5	-6,2
5	0,6	1,6	-7,6	-7,4
6	0,7	1,7	-8,7	-8,4
7	0,8	1,8	-9,8	-9,6
8	0,9	1,9	-10,9	-10
9	1,0	2,0	-12	-10

Figure 10. The results of the data obtained with the AC

The table presents the experimental data of input-output voltage measurements in an electronic circuit, showing the relationship between the input voltages V_{i1} and V_{i2} (Vp-p) and the resulting output voltage V_o (Vp-p). The output values are compared between theoretical calculations and direct experimental measurements. As the input voltages increase progressively, the output voltage also exhibits a corresponding increase in magnitude with negative polarity, indicating an inverse amplification or summing behavior of the circuit. Minor differences between

the calculated and measured output values are observed, which may be attributed to component tolerances, measurement uncertainties, and practical circuit limitations during the experimental process.

Livewire AC simulation results

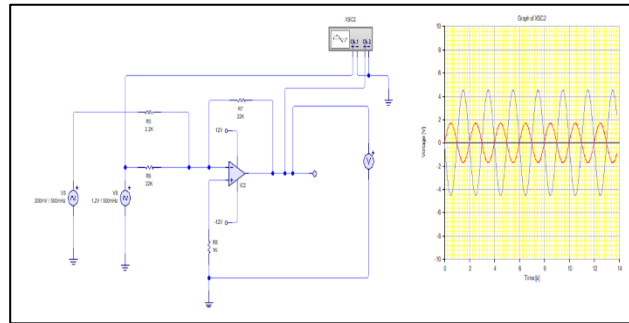


Figure 11. Simulation of Inverting Summing Amplifier Circuit – Configuration 1

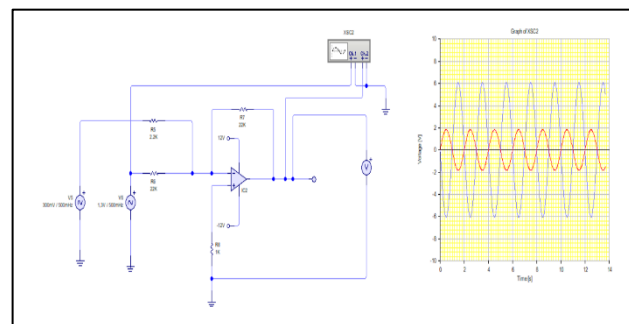


Figure 12. Simulation of Inverting Summing Amplifier Circuit – Configuration 2

The second image presents a modified simulation configuration of the inverting summing amplifier circuit with different input signal parameters. Similar to the first setup, two sinusoidal voltage sources are applied to the inverting input of the operational amplifier through separate resistive paths, while a feedback resistor establishes the gain and determines the magnitude of the output response. The waveform graph on the right shows the variation of the input signals and the resulting output signal over time. Compared to the first configuration, the output waveform exhibits a different amplitude response due to changes in the input signal magnitude and circuit conditions. This simulation confirms the operational amplifier's capability to combine multiple input signals into a single inverted output waveform proportional to the weighted sum of the applied inputs.

AC Practice Documentation

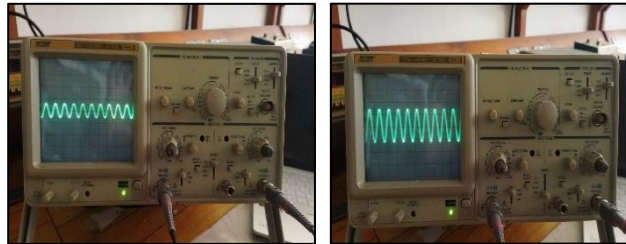


Figure 13. Voltage and Current Measurement Setup Using AC Power Supplies and Digital Multimeter

The first image shows an oscilloscope display capturing the output waveform generated during the experimental measurement of an electronic circuit. The waveform appears as a periodic sinusoidal signal with a relatively stable amplitude and frequency, indicating consistent circuit operation under the applied input conditions. The oscilloscope is used to visualize the signal behavior in real time, allowing observation of waveform characteristics such as amplitude variation, frequency stability, and signal shape. This measurement confirms that the circuit is capable of producing a continuous and stable alternating output signal in accordance with the designed operating parameters.

The second image presents the oscilloscope display of the output waveform under a different measurement condition or operating parameter setting. The waveform maintains a sinusoidal pattern, but slight differences in amplitude, waveform spacing, or signal intensity may be observed compared to the first measurement. These variations indicate changes in circuit response due to differences in input signal magnitude, component behavior, or operating configuration. The oscilloscope visualization provides direct experimental evidence of the circuit's dynamic response and helps evaluate waveform quality, stability, and electrical performance during testing.

DISCUSSION

The analysis of the servo motor control system using Proteus simulation demonstrates the effectiveness of simulation-based design in evaluating motor response, control accuracy, and overall system performance prior to hardware

implementation. Through simulation, the behavior of the servo motor under different input signal conditions, control configurations, and operating parameters can be observed systematically, providing valuable insight into the dynamic characteristics of the control system.

The simulation results indicate that the servo motor responds proportionally to variations in the applied control signal, particularly in pulse width modulation (PWM) input, which directly determines the angular displacement of the motor shaft. As the width of the PWM pulse increases within the specified operating range, the servo motor rotates correspondingly to a desired angular position. This confirms the fundamental operating principle of servo motors, where position control is achieved through precise pulse modulation and internal feedback mechanisms. The observed response in Proteus closely follows the theoretical expectation of servo motor operation, demonstrating that the simulation model is suitable for representing real-world servo behavior.

Furthermore, the system shows good stability in maintaining the commanded position after reaching the desired angular displacement. Once the input control signal remains constant, the simulated servo motor maintains its position with minimal fluctuation, indicating that the feedback control mechanism effectively compensates for position error. This characteristic is essential in applications requiring high positioning accuracy, such as robotic arms, automated control systems, and precision mechanical positioning devices. The stable holding torque observed in simulation also reflects the servo motor's capability to resist minor disturbances while maintaining its setpoint.

Another important observation from the simulation is the transient response of the motor during position transitions. When the control signal is changed abruptly, the motor requires a short response time to move from its initial position to the target position. The transition behavior shows typical servo dynamics, including acceleration, deceleration, and settling time before reaching steady-state operation. The response speed is influenced by system parameters such as motor torque characteristics, load conditions, control pulse frequency, and feedback gain. Under optimized parameters, the simulated system exhibits smooth motion with minimal overshoot, which is desirable for efficient and accurate control performance.

The Proteus environment also provides a practical platform for analyzing signal interactions within the control circuit. Voltage waveforms, PWM pulse

characteristics, and output response can be monitored in real time using virtual oscilloscopes and measurement instruments. This capability allows detailed examination of signal quality, timing precision, and synchronization between controller output and servo motor response. Such analysis is highly beneficial for identifying design limitations, tuning control parameters, and validating circuit functionality before experimental implementation.

Despite the positive results, several limitations should be considered in interpreting the simulation outcomes. Proteus simulation models generally represent idealized operating conditions, where electrical noise, component tolerances, mechanical friction, thermal effects, and external disturbances are either minimized or neglected. In practical implementation, these factors may introduce nonlinearities and deviations from simulated behavior. Therefore, while simulation provides a reliable preliminary evaluation, hardware experimentation remains necessary to validate the actual performance of the servo motor control system under real operating conditions.

Overall, the findings confirm that Proteus simulation is an effective tool for servo motor control system analysis. The software successfully models control signal generation, motor position response, and system dynamics with sufficient accuracy for educational, design, and preliminary research purposes. The observed characteristics—including proportional response to PWM input, stable position holding, acceptable transient performance, and clear signal visualization—demonstrate the feasibility of using Proteus as a platform for developing and optimizing servo motor control systems. Future work may focus on integrating microcontroller-based algorithms, closed-loop PID control strategies, and hardware validation experiments to further improve system accuracy, robustness, and application readiness.

CONCLUSION

The simplicity of the design of the operational amplifier circuit plays an important role in basic electronics applications (Küçükdermenci, 2025). Through this practice, it was observed that operational amplifiers can be effectively utilized in a wide variety of circuit configurations to achieve different desired functions, including signal amplification, active filtering, analog-to-digital and digital-to-analog signal conversion, voltage comparison, summing and subtracting amplifier operations, as well as waveform conditioning in electronic systems (Haidar et al., 2013). This versatility makes operational amplifiers one of the most fundamental and

widely used components in analog electronics, serving as the core building block for many modern electronic devices and control systems.

One of the major advantages of a simple operational amplifier configuration is its ease of implementation. The circuit design generally requires only a limited number of passive components, such as resistors and capacitors, in combination with the op amp itself, making assembly straightforward and practical even for beginner-level electronics experimentation. In addition, the relatively low component cost makes operational amplifier circuits economically efficient for laboratory practices, prototype development, and educational demonstrations. Design flexibility is another important advantage, as small modifications in resistor ratios, capacitor values, or feedback network arrangements can significantly alter circuit behavior and enable multiple applications without changing the fundamental operating principle of the amplifier.

The results of the experiments showed that the performance of the operational amplifier circuit remained adequate for small-scale educational and research applications despite using basic components (A, 2021). Experimental measurements indicated that the circuit was capable of producing stable amplification characteristics, predictable signal response, and acceptable output linearity under controlled operating conditions. Minor deviations between theoretical calculations and experimental results were observed; however, these discrepancies were still within acceptable tolerance ranges and can be attributed to practical factors such as component tolerance variations, finite gain bandwidth of the operational amplifier, power supply fluctuations, thermal effects, and measurement uncertainties. These factors are common in real-world circuit implementations and provide valuable insight into the differences between theoretical circuit analysis and practical performance.

Furthermore, the implementation of simple operational amplifier circuits in laboratory experiments contributes significantly to the understanding of fundamental analog electronics principles, particularly in relation to feedback mechanisms, gain control, signal conditioning, and circuit stability. By analyzing input-output relationships and observing waveform behavior using measurement instruments such as oscilloscopes and digital multimeters, students and researchers can gain a deeper understanding of circuit dynamics and electrical signal processing. This practical understanding is essential for the development of more advanced electronic systems, including sensor interfaces, communication circuits, automation systems, biomedical instrumentation, and embedded control applications. Therefore,

simple operational amplifier circuits continue to be highly relevant not only as educational tools but also as foundational elements in electronic design and engineering research.

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