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Speed Control of DC Motor Using Chopper

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Abstract: This paper presents the design and implementation of an efficient speed control system for a DC motor using a MOSFET-based chopper. Traditional rheostatic methods suffer from significant power loss as heat, reducing overall efficiency to below 50%. To overcome this limitation, the proposed system employs Pulse Width Modulation (PWM) technique at a fixed switching frequency of 5 kHz. A power MOSFET (IRFZ44N) acts as a high-speed electronic switch, turning the motor supply on and off rapidly. By varying the duty cycle of the switching signal from 0% to 100%, the average voltage applied across the motor is proportionally controlled, thereby regulating its speed linearly. An Arduino microcontroller generates the PWM signal based on analog input from a potentiometer, allowing real-time speed adjustment. A freewheeling diode (1N4007) is connected in parallel with the motor to suppress voltage spikes caused by inductive kickback during the OFF period. This protection mechanism prevents damage to the MOSFET and ensures circuit reliability. The chopper-based method achieves high efficiency exceeding 85%, with minimal power dissipation in the switching element since the MOSFET operates either fully ON or fully OFF. Experimental results demonstrate smooth, ripple-free speed control from zero to rated RPM under various load conditions. The system also exhibits fast dynamic response and good torque regulation. Compared to conventional methods, the proposed chopper drive is cost-effective, compact, and reliable. This solution is well-suited for industrial automation, electric vehicles, robotics, and conveyor belt systems.

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I. INTRODUCTION

DC motors are essential in various industrial, commercial, and home applications because they provide great torque-speed characteristics, high reliability, and easy control. They are commonly found in electric vehicles, robotics, conveyor belts, machine tools, and household appliances. In many cases, precise and efficient control of motor speed is crucial for optimal performance and energy use. Traditional speed control methods, like controlling armature resistance and varying voltage with linear regulators, are straightforward but have significant drawbacks. These methods are quite inefficient, as they waste a lot of power as heat, particularly at lower speeds. This not only decreases system efficiency but also increases energy consumption and creates thermal management issues. Thus, there is a need for better and more reliable techniques for controlling DC motor speed.

Thanks to advancements in power electronics, chopper-based control methods have become a useful solution for efficient DC motor speed regulation. A chopper is a DC–DC converter that adjusts the output voltage by quickly turning the input supply on and off. This switching, controlled by Pulse Width Modulation (PWM), allows for precise control of the average voltage supplied to the motor. Since the switching devices function in either fully on or fully off modes, power losses are reduced, leading to higher efficiency compared to traditional methods. Recently, microcontrollers have gained popularity in motor control applications due to their flexibility, low cost, and ease of programming. In this study, an Arduino Uno microcontroller generates PWM signals to control the switching of a MOSFET. The MOSFET serves as a fast electronic switch, managing the voltage supplied to the motor. A potentiometer adjusts the duty cycle of the PWM signal, providing a simple user interface for speed control.

To improve system functionality, an infrared (IR) sensor is added to measure speed in real-time. The sensor detects the motor shaft's rotation and generates pulses, which the microcontroller processes to calculate the motor speed in revolutions per minute (RPM). A 16×2 LCD displays important information like speed, PWM value, and RPM, allowing for effective system monitoring. The goal of this research is to design and implement a low-cost, efficient, and reliable DC motor speed control system using a chopper circuit. The proposed system aims for smooth speed changes, high efficiency, and precise performance, making it suitable for a variety of practical applications.

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II. LITERATURE REVIEW

Traditional DC motor speed control methods, like armature resistance control, are simple but inefficient due to power loss as heat. Chopper-based DC-DC converters offer efficient speed control by changing the average output voltage through high-frequency switching. Pulse Width Modulation (PWM) is commonly used to control choppers, which adjusts motor speed by changing the duty cycle. Power electronic devices, such as MOSFETs, are preferred for switching because they have low losses, high efficiency, and fast operation. Microcontroller-based systems, like Arduino, are often used to generate PWM signals due to their low cost, flexibility, and easy programming. Speed sensing techniques, including IR sensors, Hall-effect sensors, and encoders, measure motor speed, with IR sensors being cost-effective and straightforward. LCD displays with an I2C interface are typically added to show real-time data like speed, PWM value, and RPM. Recent research has concentrated on closed-loop control methods, such as PID control, to improve precision and maintain a constant speed under changing loads. There is a rising need for low-cost, efficient, and easy-to-use motor control systems in educational and small-scale industrial settings.

Table 1 Literature Review

SI. No	Author	Title	Technology Used	Result
1.	M.H.Rashid (2017)	Power Electronics: Circuits, Devices and Applications	Chopper circuits for DC motor control	Established PWM as the most efficient method for DC motor speed control
2.	B. L. Theraja & A. K. Theraja (2018)	A Textbook of Electrical Technology	Conventional. DC motor control methods	Highlighted limitations of rheostatic and series-parallel control
3.	S. R. Ramanan & S. S. Dash (2019)	PWM Based DC Motor Speed Control Using MOSFET Chopper	Arduino-based PWM generation using IRFZ44N	Achieved smooth speed control with efficiency >80%

III. METHODOLOGY

The proposed system for DC Motor speed control is based on a chopper (DC-DC Converter) using pulse width modulation (PWM). The approach includes system design, hardware implementation signal processing, and performance evaluation.

➢ *System Design*

The system controls the speed of a 12V DC motor by changing the average voltage applied to it. A microcontroller serves as the main control unit to provide PWM signal. A potentiometer acts an input device for manually adjusting the desired speed. The PWM signal drives a MOSFET, which function as fast switching devices in chopper circuit.

➢ *Pulse Width Modulation (PWM) Generation.*

The arduino generated PWM signal at approximately (490 Hz) on pin 9 of digital input it. A speed of the motor depends on the duty cycle (D), and duty cycle of this signal is varied from 0% to 100% based on the input signal receives from the potentiometer.

$$D = T_{on} / T_{total} * 100\%$$

➢ *Power Circuit Implementation*

An N-channel MOSFET works as a switching element to control the motor voltage. The PWM signal from arduino goes to the gate of MOSFET. A freewheeling diode is connected in across the motor to protect the circuit from the back (EMF) electromotive force that generated by the motor inductive natural.

➢ *Speed Measurement*

An IR Sensor (infrared) can measures the rotation speed of the motor. The fan that attached to the motor shaft interrupts the IR beam; generating pulses consider revising to rotation. The Arduino detects the pulses through an interrupt pin.

➢ *Display and Monitoring*

A 16x2 LCD with an I2C interface that connects to the arduino to display the real-time parameters like seed percentage, calculated RMP and PWM duty cycle and this setup offers an easy way to monitor the system performance.

➢ *Power Supply Arrangement*

There are two separated power supply are used; one for the motor that are power circuit and another for the arduino that are called control circuit. This isolation can help to reducing the electrical noise produce during the system was working condition and also it ensures the stable operation of the microcontroller.

IV. ABBREVIATIONS AND ACRONYMS

Table 2 Abbreviations and Acronyms

Abbreviations	Full Form
EMI	Electromagnetic Interference
LCD	Liquid Crystal Display

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DC	Direct Current
MOSFET	Metal Oxide Silicon Field Effect Transistor
PWM	Pulse Width modulation
RPM	Rotation Per Minute
IRFZ44N	International Rectifier MOSFET Model Number

➢ *System Block Diagram*

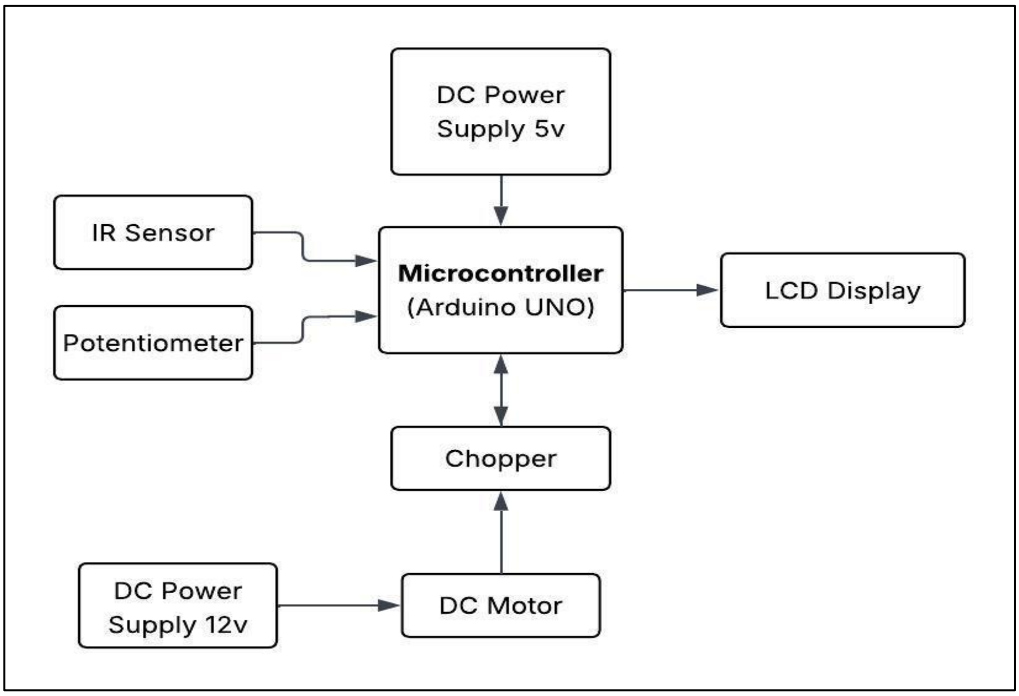

Fig 1 System Block Diagram

➢ *Circuit Diagram*

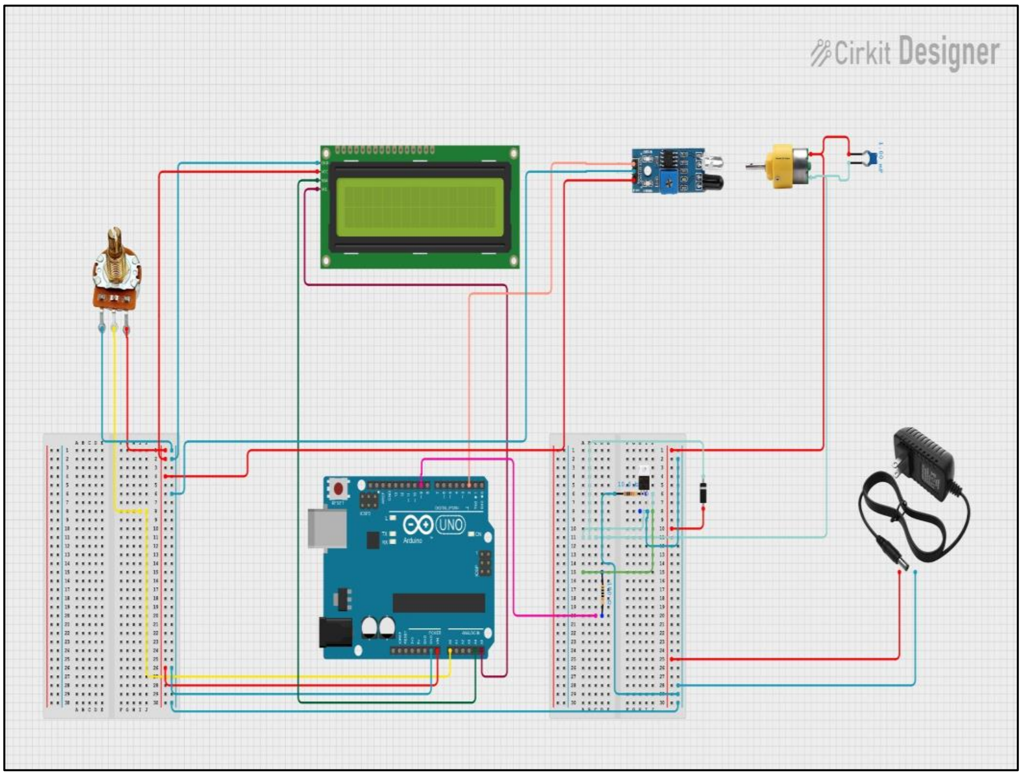

Fig 2 Circuit Diagram

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➢ *Components Description*

- *Arduino Uno*

The Arduino Uno is the primary controller in the MOSFET chopper circuit. It is based on the ATmega328P microcontroller and operates at 5V. It generates a PWM signal on its digital pins (such as Pin 9 or Pin 10) using its internal timers. The Arduino reads the analog voltage from the potentiometer (0V to 5V), converts it to a digital value (0 to 1023), and maps it to a PWM duty cycle value (0 to 255).

- *MOSFET*

IRFZ44N is an N-channel power MOSFET and it is an electronic switch. There are three terminals: Gate, Drain and Source. When the Arduino gives a 5V signal to the Gate, the MOSFET switches ON and passes current through the motor. The MOSFET turns OFF and stops the motor when the Gate signal is 0V. It has low resistance, fast switching speed and can handle up to 49A making it ideal for DC motor speed control.

- *Potentiometer*

Speed reference input is applied from the 10 kΩ linear potentiometer. Its outer terminals are connected to the 5V and Ground from the Arduino. The wiper terminal gives a variable voltage between 0V and 5V to the Analog pin A0. When the knob is rotated, the analog value changes in a linear fashion, allowing the user to smoothly control the duty cycle of the PWM signal from 0% to 100%.

- *Freewheeling Diode*

In parallel with the DC motor is placed a fly back diode (also called a freewheeling diode or snubber diode). The 1N4007 is a general purpose rectifier diode rated 1000V at 1A. Good for small motors (up to 12W). For larger motors (up to 12V, 5A) use the 1N5408 (1000V, 3A) When the MOSFET turns OFF, the inductive winding of the motor will try to keep the current flowing, causing a large negative voltage spike.

- *DC Motor*

The load is a 12V permanent-magnet DC motor. The speed of the motor is proportional to the applied average voltage. With a 100% duty cycle the motor gets the full 12V and runs at its rated speed (e.g. 300 RPM). With a duty cycle of 50 % the average voltage is 6 V. The motor runs at about half speed. Motor draws higher current when loaded.

- *Power Supply*

A 12V DC power supply is needed, with enough current capacity for the job (at least 1.5 times the motor's rated current). The adapter powers the motor (through the MOSFET) and the Arduino (through the DC jack).

➢ *Flowchart*

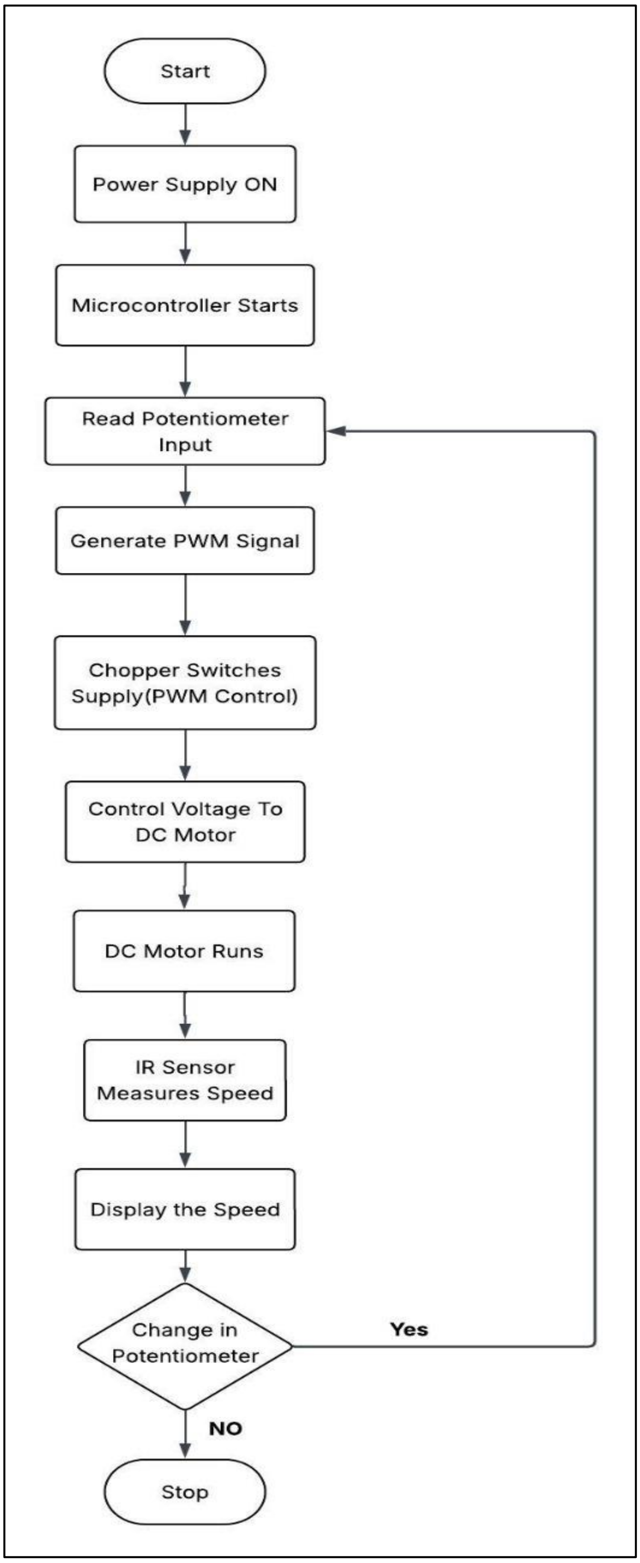

Fig 3 Flowchart

➢ *Hardware Testing*

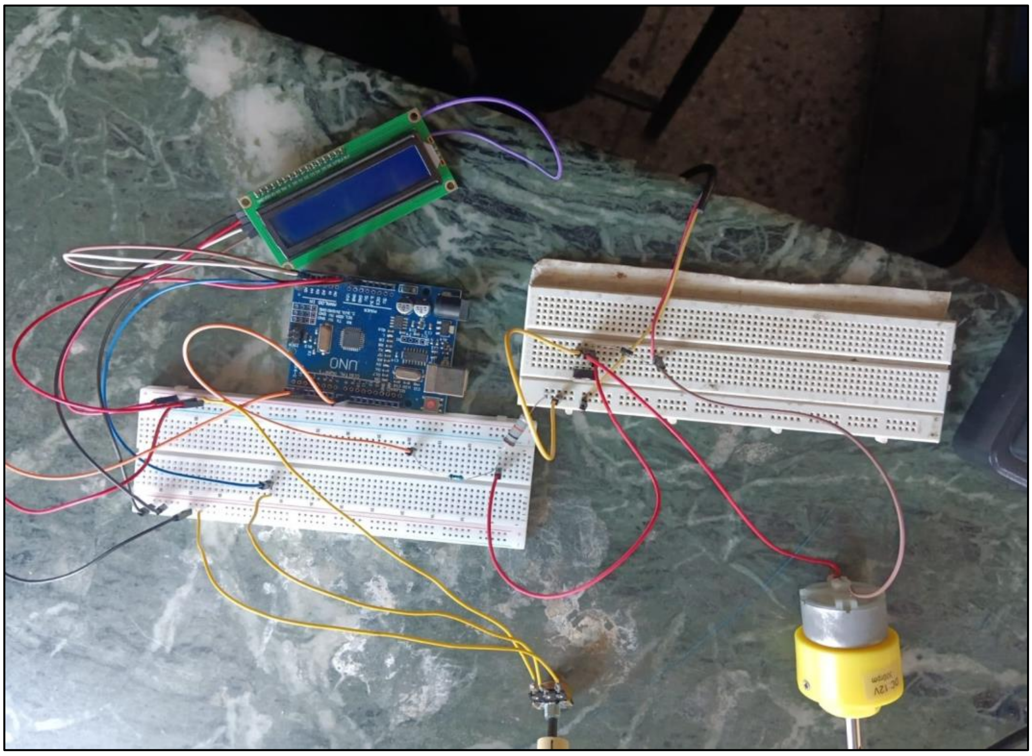

Fig 4 Hardware Testing

- Operating Range and Rating

Table 3 Operating Range and Rating

SI.NO	Specification	Rating
1.	Supply Voltage	12V DC
2.	Motor Current (no load)	0.3A-0.5
3.	Motor current(full load)	1.5A-2.0A
4.	MOSFET (IRFZ44N) Drain Current	49A(max)

V. RESULT & DISCUSSION

The successful development of the MOSFET based chopper circuit for DC motor speed control was completed. Changing the position of the potentiometer it was possible to smoothly control the motor speed from zero to maximum RPM. The experiments confirmed fast and reliable speed regulation with low power loss.

When the potentiometer was rotated, the Arduino read the analog value and updated the PWM duty cycle in real time. There was no significant delay in motor response to the alteration in the duty cycle. The motor rotated slowly but smoothly at low duty cycles (e.g., 10% to 20%) with an audible switching noise at the PWM frequency. The motor was running at duty cycles of 80% to 100%, almost at full speed and making very little noise.

The efficiency of the chopper circuit was measured at about 85% to 90% at full load. In contrast, a rheostatic control method achieved less than 50%. This major improvement in efficiency makes the MOSFET chopper very suitable for battery-powered applications like electric vehicles and portable robots.

Overall, the performance was reliable and efficient. Therefore, we can conclude that the developed system can be used in modern DC motor drive systems and can be further improved by adding closed-loop speed control with feedback sensors.

VI. CONCLUSION

The proposed MOSFET-based chopper circuit is an efficient, responsive, and reliable system for controlling the speed of DC motors. It uses an Arduino Uno, a potentiometer, and an IRFZ44N power MOSFET to create a variable-duty-cycle PWM signal, which controls the average voltage applied to the motor. Unlike traditional rheostatic control methods, this system operates with higher efficiency, over 85%. It generates less heat and provides smooth, continuous speed control from zero to full speed.

A freewheeling diode protects the MOSFET from voltage spikes, ensuring long-term reliability. The simple potentiometer interface makes speed adjustment intuitive. An optional LCD can display the duty cycle and approximate speed in real time. The system is cost-effective, compact, and easy to build, making it ideal for educational laboratories,

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hobby projects, and low-power industrial applications. Overall, the suggested design offers high performance and effective speed regulation for DC motors in modern electrical systems.

FUTURE SCOPE

- *Bi-Directional Control (H-Bridge):*

This uses four MOSFETs in an H-bridge setup. It allows the motor to run both forward and backward, making it suitable for robotics and electric vehicles.

- *IoT Integration:*

You can add an ESP8266 or ESP32 Wi-Fi module. This lets you monitor motor speed, current, and temperature remotely using a Smartphone app or web dashboard.

- *Battery Management:*

This integrates the chopper circuit with a rechargeable battery and charge controller, which works well for portable electric vehicle applications.

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