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Original scientific paper

DESIGN AND DEVELOPMENT OF MECHATRONIC SYSTEM FOR ROOM TEMPERATURE REGULATION

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A b s t r a c t: This project describes a simple and efficient room temperature control system developed using a microcontroller, a DHT11 temperature and humidity sensor, a DC motor, and a motor driver. The DHT11 sensor continuously monitors the ambient temperature and sends the data to the microcontroller. Based on the temperature readings, the microcontroller adjusts the speed of the DC motor, which acts as a cooling unit. When the temperature exceeds a predefined upper limit, the microcontroller activates the DC motor to cool the room. When the temperature drops below the lower limit, the motor is turned off to conserve energy. The motor driver ensures the safe and efficient operation of the motor, ensuring compatibility with the microcontroller. This simple system offers an affordable and economical solution for regulating temperature in small spaces, demonstrating the practical application of basic electronics and microcontroller programming.

Key words: temperature; humidity; room temperature regulation; PID control

ДИЗАЈН И РАЗВОЈ НА МЕХАТРОНИЧКИ СИСТЕМ ЗА РЕГУЛАЦИЈА НА АМБИЕНТАЛНА ТЕМПЕРАТУРА

А п с т р а к т: Овој проект опишува едноставен и ефикасен систем за контрола на температурата во соба, развиен со користење на микроконтролер, DHT11 сензор за температура и влажност, DC-мотор и драјвер за моторот. Сензорот DHT11 континуирано ја мери амбиенталната температура и ги испраќа податоците до микроконтролерот. Врз основа на добиените мерења на температурата, микроконтролерот ја приспособува брзината на DC-моторот, кој служи како единица за ладење. Кога температурата ќе ја надмине претходно дефинираната горна граница, микроконтролерот го активира DC-моторот за да ја излади просторијата. Кога температурата ќе се намали под долната граница, моторот се исклучува за да се заштеди енергија. Драјверот за моторот овозможува безбедно и ефикасно работење на моторот, осигурувајќи компатибилност со микроконтролерот. Овој едноставен систем нуди достапно и економично решение за регулирање на температурата во мали простории, демонстрирајќи практична примена на основна електроника и програмирање на микроконтролери.

Клучни зборови: DHT11; температура; влажност; регулација на собна температура; PID контрола

1. INTRODUCTION

Temperature and humidity sensors are key components in engineering systems that require precise monitoring of environmental conditions. These sensors measure temperature and relative humidity, providing real-time data through continuous monitoring, and they are essential for maintaining controlled conditions in applications such as HVAC systems, industrial machinery, and agricultural equipment. These sensors are indispensable for optimizing thermal management, ensuring equipment reliability, and improving energy efficiency. Advances in sensor technology have resulted in compact, precise, and durable designs that can be easily integrated into mechanical systems.

Temperature sensors work by detecting changes in physical properties such as resistance, voltage, or current, which vary with temperature. These changes are then converted into electrical signals, which can be measured and interpreted to determine the temperature. Temperature sensors are classified into contact and non-contact measuring systems. Most instrumentation systems use contact-based measurement. Contact temperature measurement involves conducting heat from the surface of the object to the sensor. A portion of the body's thermal radiation is absorbed by the sensor and converted into a useful signal. Heat transfer from the centre of the sensor, which causes it to heat up, can lead to inevitable measurement errors. Non-contact temperature measurement systems are based on the principles of radiation thermometry, which has recently been used in medicine. The advantage of non-contact temperature measurement is that there is no heat absorption from the body or surface being measured. Various types of thermometers commonly used include mechanical, electrical, semiconductor devices, and thermal sensors [1].

In smart temperature sensor systems and microsystems (MEMS), integrated sensors are often used, combining sensing elements with the interface electronics required for communication, for example, with microcontrollers. The most common temperature sensing elements include transistors, thermocouples, and thermopiles, as these elements can be implemented using IC technology [2].

A humidity sensor works by detecting changes in the physical properties of a material when exposed to moisture in the air. These sensors are typically based on two main principles: resistance and capacitance. In resistive humidity sensors, the electrical resistance of a hygroscopic material changes as it absorbs moisture, and this change in resistance is directly related to relative humidity. A capacitive humidity sensor operates by measuring the change in capacitance of the sensor material when there is a change in ambient humidity. The sensor material is usually a dielectric material that absorbs water vapor from the air, altering its electrical properties. Capacitive sensors often use plastic or polymer as the dielectric material.

2. LITERATURE REVIEW

Traditional temperature measurement instruments are difficult to carry, expensive, and have limitations in monitoring specific locations (such as wounds or tumor ablation sites). Patient movement can also lead to inaccurate measurements. To address these issues, wearable, flexible, thin, and sensitive temperature sensors have become a research focus. The flexible temperature sensors use various materials. Common flexible substrates include polydimethylsiloxane (PDMS), polyimide (PI), polyurethane (PU), polyethylene terephthalate (PET), polyvinyl alcohol (PVA), polyvinyl butyral (PVB), paper, and silicone rubber. For better skin compatibility, biodegradable materials such as pectin, cotton, silk, and other cellulose-based materials are used. Heat-sensitive active materials include various carbon-based materials such as graphite (Gr) and graphene. Metallic materials like gold (Au), silver (Ag), copper (Cu), platinum (Pt), nickel (Ni), and aluminum (Al) are used for electrodes and wiring. Metal oxides such as vanadium dioxide (VO_2) and nickel oxide (NiO) are also important active materials. Polymers also serve as thermally sensitive materials, with hydrogels and carbon nanotubes increasing temperature sensitivity. Research has led to the development of flexible temperature sensors that can accurately monitor skin temperature, detect dehydration and heat stroke, and track wound healing progress. These sensors are integrated into fabrics, threads, and bandages, offering wireless data transmission capabilities. Results show that flexible temperature sensors can provide precise temperature monitoring [3].

The core material of a humidity sensor is its moisture-sensitive material. When the moisture-sensitive material interacts with humidity (through chemical action, biological action, or physical adsorption), its quality, thickness, and optical, mechanical, and electrochemical characteristics change, altering the impedance between detection electrodes. In this way, humidity information can be obtained by detecting the output signal of the impedance. Graphene is a new type of carbon material with a flexible, two-dimensional structure. Due to its excellent lattice stability and mechanical flexibility, graphene-based materials can be used in flexible humidity sensors. Since graphene oxide (GO) and reduced graphene oxide (rGO) are rich in oxygen-containing functional groups and have a large specific surface area for molecular adsorption, they have great potential for widespread application in flexible humidity sensors. With their high sensitivity, excellent flexibility, good elasticity, and stability, graphene-based flexible humidity sensors have significant potential for applications, including personal health monitoring. They can be placed on the human body or clothing to detect signals from human activity and obtain various physiological information. Graphene-based flexible humidity sensors can be classified into four categories: monitoring human respiration, monitoring skin humidity, detecting sweat, and detecting environmental humidity [4].

A sensor that combines both temperature and humidity measurements is the DHT11. The DHT11 temperature and humidity sensor can be used for automatic room temperature control using Arduino. The user sets the minimum and maximum reference temperature range via a keypad. The DHT11 sensor measures the room's ambient temperature and provides the result in degrees Celsius. The reference and measured values are displayed on an LCD. The Arduino microcontroller, as the system's processing unit, receives the measured data from the sensor and compares it with the set value. The results are as follows:

→ When the measured room temperature is lower than the minimum set value, the microcontroller activates the heating system.

→ If the measured room temperature is higher than the maximum set value, the fan is activated.

→ The fan speed is controlled via Pulse Width Modulation (PWM), depending on the difference between the sensor's measurement and the maximum set value. The greater the temperature difference, the higher the fan's duty cycle and speed.

→ Finally, if the measured room temperature is within the set range, all devices remain off [5].

3. SENSOR ANALYSIS METHODOLOGY

3.1. *Conceptual analysis of the measurement system using the DHT11 sensor*

Our measurement system consists of several key components working together to monitor and control the room's temperature as shown in Figure 1.

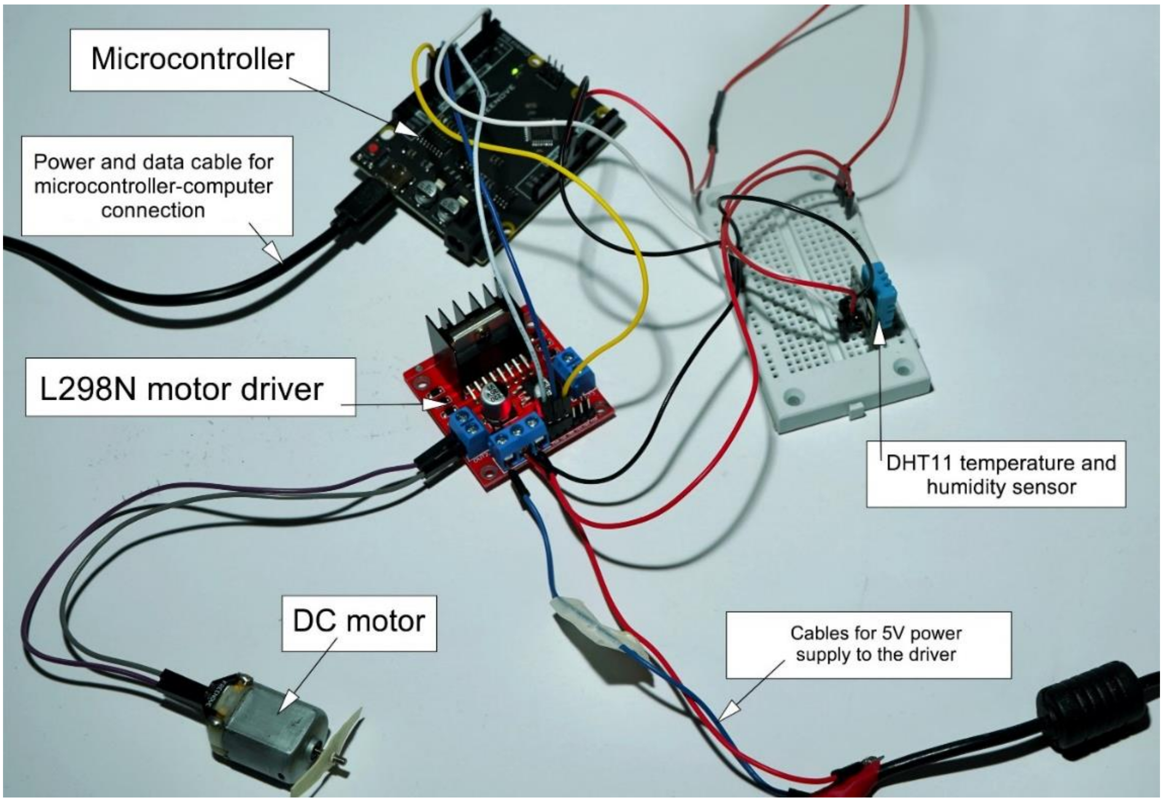

Fig. 1. All physical components illustrating the connection between them
1. **Microcontroller** – The central control unit, responsible for processing the DHT11 sensor data and controlling the DC motor.
2. **DHT11 sensor** – Measures ambient temperature and humidity, providing real-time data for temperature adjustment.
3. **DC motor** – Acts as a cooling unit or ventilation device. 4. **Motor driver (L298N)** – Ensures safe and efficient motor operation, as microcontrollers cannot directly supply the required voltage and current. 5. **Power supply** – Provides 5V power to the motor driver and other components.

The system operates as follows: The DHT11 sensor continuously monitors the temperature and humidity in the room, sending the data to the microcontroller, which uses PID control to continuously regulate the number of rotations to maintain 30 degrees Celsius in the room. The microcontroller generates a PWM signal and sends it to the driver, which controls the motor.

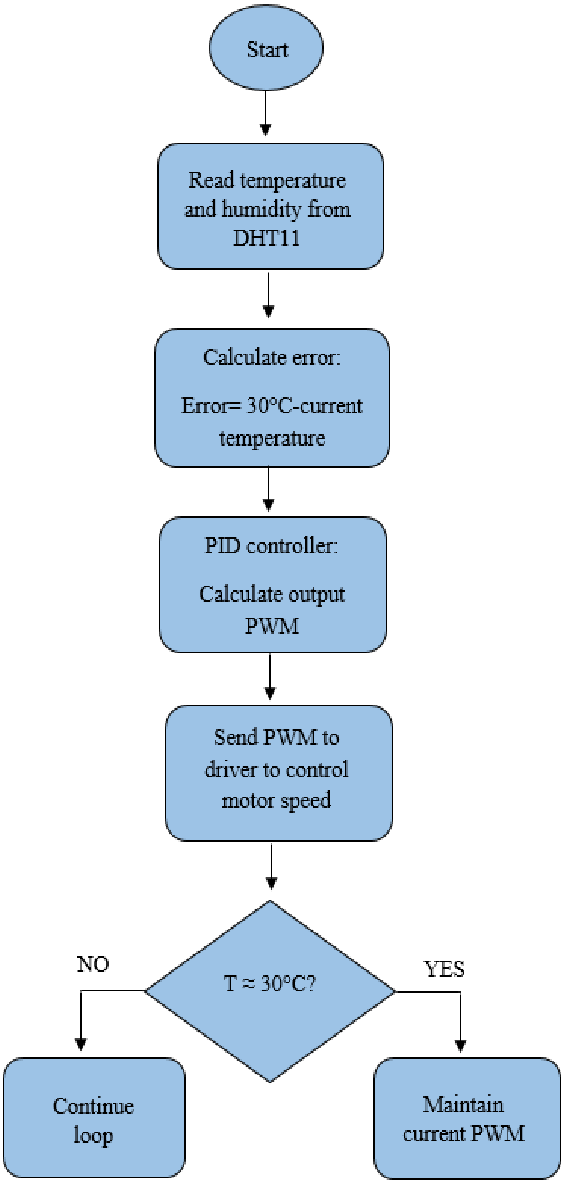

Fig. 2. Flowchart for fan speed control

The DHT11 sensor is used for measuring air temperature and humidity. This sensor is designed for applications with low power consumption, high stability, and compatibility with IoT-based systems. The DHT11 has a measurement accuracy of ±1°C for temperature and ±5% for relative humidity, making it an ideal choice for real-time environmental monitoring applications [6]. The DHT11 sensor measures humidity and temperature using a capacitive humidity sensor and a thermistor. The capacitive sensor detects changes in humidity by measuring the change in capacitance caused by moisture in the air. This change is converted into a digital signal. The thermistor changes its resistance based on temperature; the sensor reads this resistance and converts it into a temperature value. The sensor communicates with the microcontroller using a specific protocol, sending a total of 40 bits of data, which include humidity and temperature measurements along with a checksum for error detection. For example, the first 16 bits represent humidity, the next 16 bits represent temperature, and the last 8 bits serve as a verification check to ensure data integrity. Changes in resistance (for temperature) and capacitance (for humidity) are initially analog signals, but the DHT11 has a built-in microcontroller that converts these analog signals into digital data. The ADC process involves sampling the signals at regular intervals, then quantizing them into discrete values representing temperature and humidity levels. Once the microcontroller converts the analog data into digital values, it formats the data into a standardized output (usually a series of binary numbers) representing both temperature and humidity. The microcontroller reads the pulse widths of the signal sent by the DHT11, processes them to extract the temperature and humidity values, and converts these numbers into a readable format (e.g., Celsius for temperature and percentage for humidity).

3.2 *Analysis of sensor performance parameters*

Main static and dynamic characteristics of the sensor:

Humidity range: 20% to 90% RH

Temperature range: 0°C to 60°C

Humidity accuracy: ±5% RH

Temperature accuracy: ±2°C

Resolution: 8-bit for both humidity and temperature.

Sampling frequency: 1Hz

Power supply: 3.3V to 5.5V

Current consumption: 0.5 to 2.5 mA during operation, 100 to 150 μA in standby mode [7].

Response time: A few seconds for temperature, 5–30 seconds for humidity changes.

While the DHT11 performs well under typical weather conditions within its specifications, extreme environments such as condensation or lack of protection can degrade its accuracy and lifespan. For better performance in specific weather conditions, more durable sensors such as the DHT22 or BME280 can be used. These sensors offer a wider range and higher accuracy, and the BME280 also has a higher sampling frequency.

3.3. *Sensor applications*

The main applications of the DHT11 include agriculture (monitoring environmental conditions for optimal crop growth), pharmaceuticals (ensuring proper storage conditions for medications), biomedical applications (maintaining controlled environments for patient care and laboratory experiments), home automation (smart home climate control systems), and meteorological stations (collecting data for weather studies) [8].

4. RESULTS

The system was tested by setting up the hardware components and using the Arduino IDE to execute the instructions, along with MATLAB to display real-time graphs of the temperature (°C), humidity (%), and motor speed (RPM). When power is supplied to the system, the sensor begins measuring temperature and humidity. PID control is implemented in the microcontroller to regulate the fan speed and maintain a stable temperature.

It continuously compares the measured temperature to the desired setpoint (30°C) and calculates a control signal based on the error. The control signal determines the duty cycle of a PWM signal, which is then sent to the motor driver to adjust the fan speed.

The PID controller calculates the control output using three terms:

– *Proportional (P):* Reacts to the current error by applying an immediate correction.

– *Integral (I):* Accumulates past errors to eliminate steady-state deviations.

– *Derivative (D):* Predicts future errors and reduces sudden fluctuations.

The control signal is determined using the following formula:

$$u(t) = K_p e(t) + K_i \int_0^t e(t)\ dt + K_d \frac{de(t)}{dt}$$

where:

K_p is the proportional gain,

K_i is the integral gain,

K_d is the derivative gain,

$e(t)$ is the error.

This feedback control ensures that the system dynamically adjusts the fan speed to maintain the set temperature with minimal deviation.

For the purpose of visual representation of the collected data, three separate graphs for the humidity, temperature and RPM (revolutions per minute), are extracted as shown in Figure 3. Furthermore, based on the PID feedback control, it is conluded that the ouput(RPM) curve follows almost the same curve of the input (temperature). This gives us the opportunity to make certain post-processing calculations that allow us to dive deeper in understanding the meaning of the curves in the graphs themselves.

Table 1 represents the dots from Figure 4.

As shown in Figure 5 the orange line represents the behavior of the system: the ratio between RPM values and temperature values. The dotted black line is a linear trendline fitted to the orange line's data to give a simplified model of the relationship. The trendline is given as:

$$\text{RPM} = 138.98 \cdot \textit{temperature} - 934.36$$

The equation is in the form of a straight line $y = kx + b$ where y is RPM (dependent variable), x is the temperature, k is the slope and b is the y-intercept. From the trendline we can conclude that for each 1°C increase, the RPM increases by 138.98 on average since the slope has a value of 138.98. This shows a positive, strong correlation between the temperature and motor speed. The y-intercept has a value of –934.36 and it is important for defining the full line equation.

The trendline serves as a mathematical simplification of how the system behaves. In our case, it gives the ability to easily predict and estimate the RPM values for any given temperature within or slightly outside the range, which can help in controlling the system.

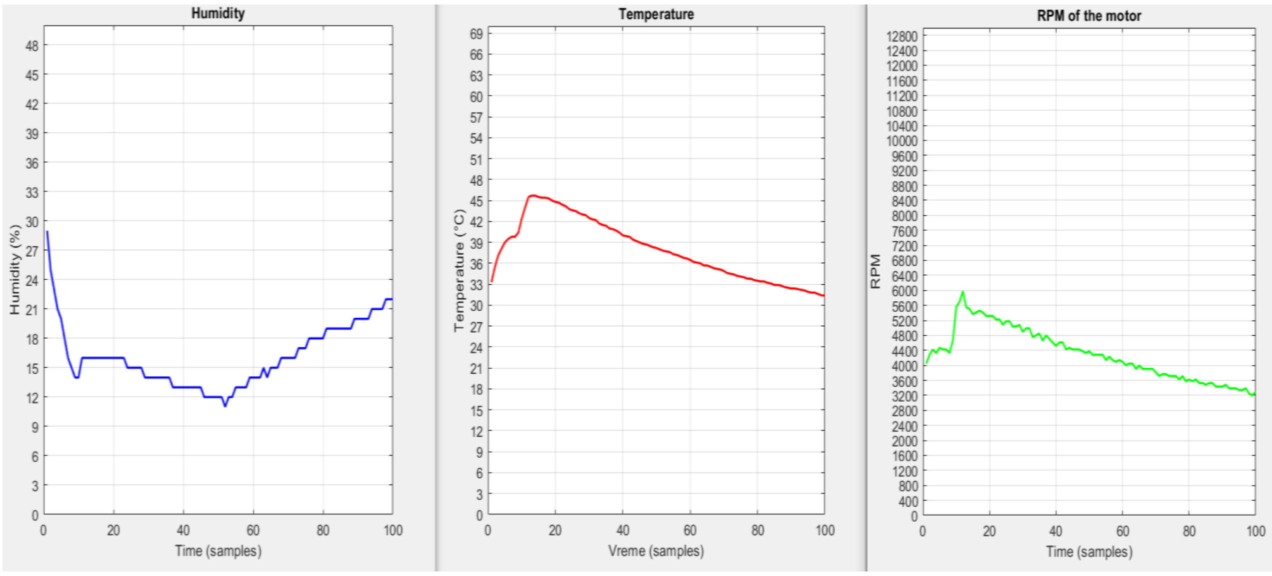

Fig. 3. Real-time graphs of the humidity, temperature and RPM and their influence on each other

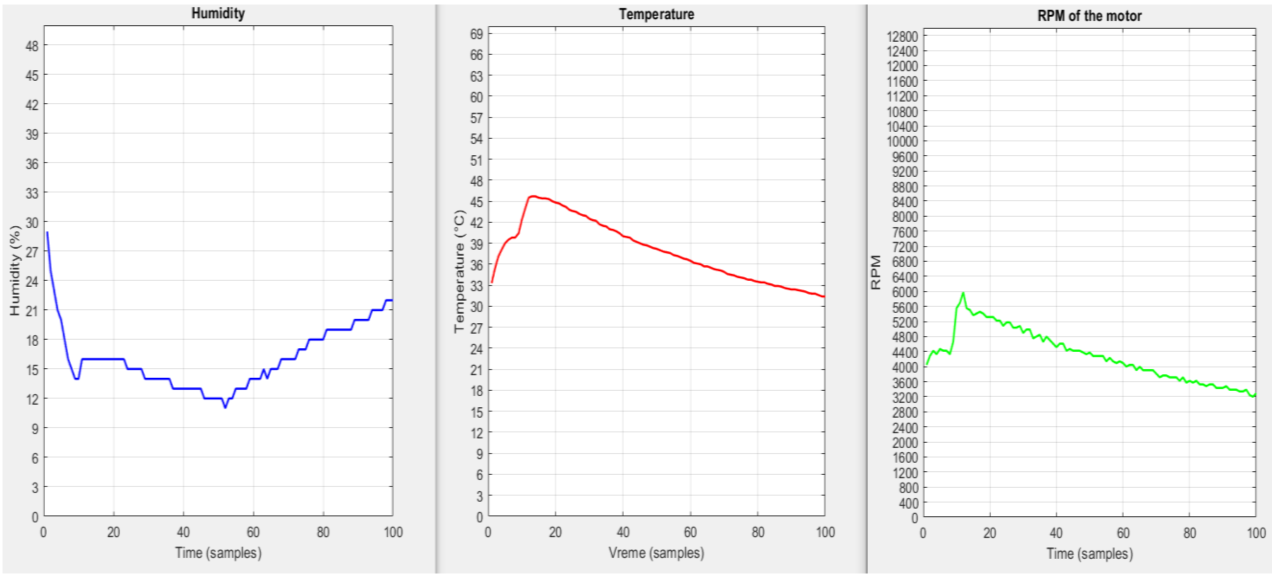

Fig. 4. The graphs with dotted points per 10 samples of the time axis

T a b l e 1

The dots from Figure 4

	A	B	C	D	E	F	G	H	I	J
Humidity (%)	29	14	16	14	13	11	14	16	18	20
Tepmperature (°C)	33	41.54	44.9	42.2	40.05	38.1	36.1	34.5	33.2	32.7
RPM	4000	4790	5400	4980	4500	4400	4110	3810	3600	3420
Ratio RPM/Temperature	121.21	115.42	120.27	118.01	111.1	115.49	113.,86	110.43	108.43	104.59

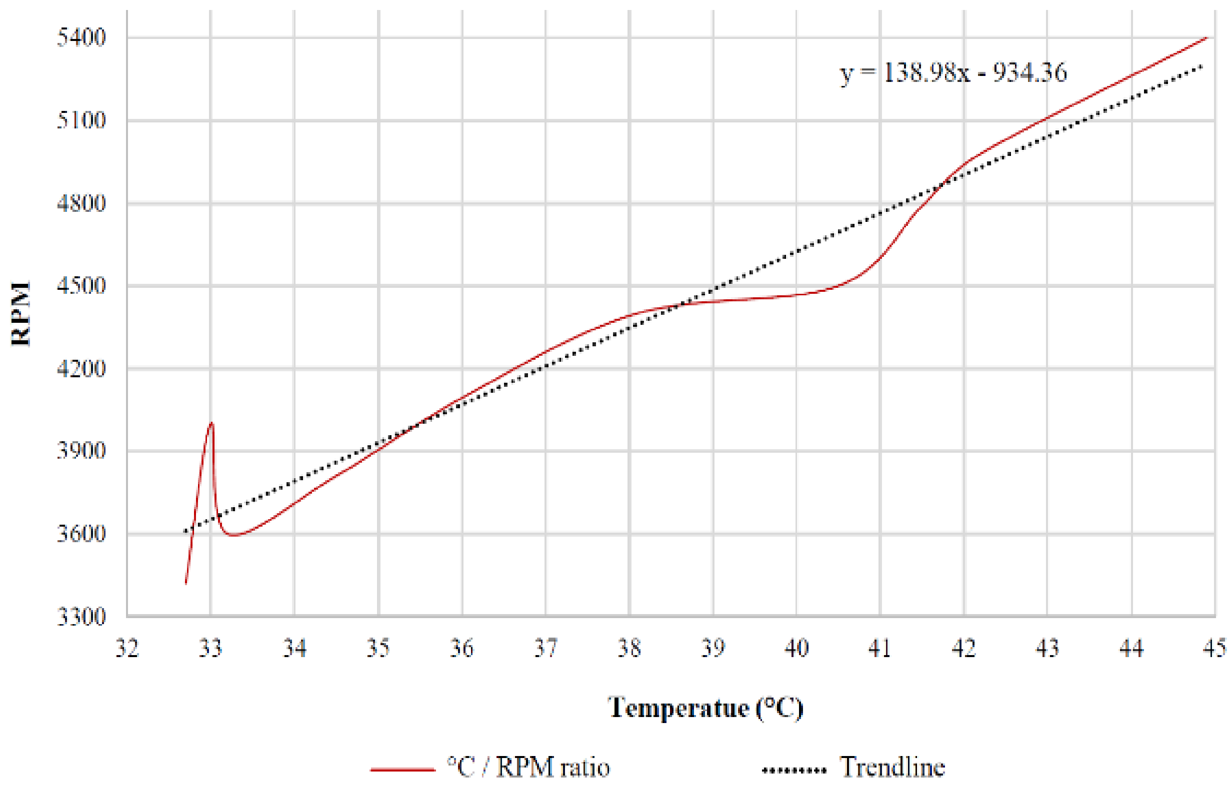

Fig. 5. Effect of temperature on motor speed (RPM) with linear trendline

5. CONCLUSION

The room temperature control system developed in this project successfully demonstrates how a simple combination of a microcontroller, a DHT11 sensor, a DC motor, and a motor driver can be effectively used to regulate ambient temperature. The system achieved its primary goal of maintaining the desired temperature by monitoring real-time temperature data and activating the motor when necessary. The project showcased the functionality of the motor driver, which safely amplifies the control signals from the microcontroller to power the motor, while the use of a PWM signal enabled a simple and efficient method for motor control. This system is energy-efficient, as the motor operates only when necessary, reducing power consumption and extending the motor's lifespan. Additionally, it is cost-effective and easy to implement, making it suitable for small rooms or environments where basic temperature regulation is required.

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