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Design and Construction of a Speed Control for Direct Current fan using Temperature Sensor

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Abstract
Unregulated fan speed results to excessive power wastage and over exposure to cold leading to various sicknesses especially in tropic regions like Northern Nigeria. This study designed and constructed a speed control for direct current fan using a temperature monitoring sensor. Simulation of the circuit was carried out using Proteus 8.0 and a prototype was constructed on a Vero board and tested for continuity and functionality. Results shows that the constructed device performed according to the design specifications, with an automatic increase in fan speed due to temperature increase and decreasing fan speed as the temperature falls with a smooth switching action. The recording output of the temperature sensor against the tachometer yielded a linear relationship which indicates the sensitivity of the device. The speed control can provide comfort to both domestic and industrial users especially when the temperature is considerably high and at night when the user is asleep.

Keywords: Speed Controller, Direct Current Fan, ATMega8 Microcontroller, Proteus Design Suit, Temperature Sensor, Implementation

1. Introduction

An electric fan is a device used to produce flow of air for the purpose of providing comfortable ventilation. They are designed to create breeze and circulate the air in a region so as to provide the necessary cooling, especially during hot weather condition [1]. While an electric fan circulates the air around its environment, an air-conditioning system changes the temperature of the air in its environment [2]. The fan creates its cooling effect based on the speed at which its blades rotate; hence, the speed controller is a very important part of a fan. Usually, the speed of the fan blades is controlled manually by turning the knob on the regulator. This non-innovative feature may not be very suitable when certain level of air circulation is to be maintained in various types of buildings and enclosed spaces, and when ensuring efficient use of energy [3]. Older DC fans used mechanical brushes, which can cause increased electromagnetic interference (EMI) along with dust particles due to mechanical wear throughout the system. Over time, the fan would wear and eventually fail. Brushless fans have replaced these mechanical brushes with electronic sensors and switches that now perform the necessary commutation and increase the lifetime and the reliability of these fans [4]. Brushless DC fans are called "brushless" because the electric motor within the fan is commutated electronically which makes them highly reliable with ease to use. With the improvement in machinery, smart systems are being introduced every day. In the present time microcontrollers play a vital role in the development of the smart systems [5].

A temperature controller is a closed loop control system which senses the temperature of the environment and compares it with a user-fed threshold temperature value and changes the speed of the fan so as to increase or reduce accordingly between the minimum and maximum speed values [4, 6, 3]. In an automatic temperature-controlled system, the independent variable (temperature) is measured by a suitable sensor such as a thermocouple, thermistor or thermostat and converts it to a signal accepted by the controller. The controller compares the signal to the desired temperature (set point) and activates the final control device. The final control device alters the dependent variable (fan speed) to change the quantity of heat being taken or added to the process [1, 7]. Therefore, an automatic temperature control system has the ability to monitor and control the temperature of a specified space without human intervention based on pre-defined setting by the user of the system.

In the case of Nigeria, over exposure to cold due to high-speed fan for long period of time has been an issue especially in the Northern region where harsh temperature is experienced. This has led to several people diagnosed with various kinds of sickness such as pneumonia, rheumatism, frost bite, gastroenteritis, bronchitis, trench foot, hypothermia, cough, seasonal flue, sore throat, cold and catarrh. Loss of electrical energy in DC fan motor operation has also been an issue due to the use of traditional fans that operate at one speed even when the room temperature changes because the speed has to be manually changed. Turning ON and OFF fans in some homes or buildings is often a serious problem as these fans are mostly left ON even when the user leaves the room, thereby consuming unnecessary power. With the high rising cost of electricity in Nigeria, power saving has become essential as such automatic controlled fan becomes very important. Therefore, the objective of this study is to design and construct an automatic speed controller circuit for a DC fan application using a microcontroller and a temperature sensor. The advantages of such a system are less energy usage, saves time and maintains a consistently convenience and comfortable environment for the user. It finds application in places like hospitals to provide the necessary cooling for the sick patients that cannot stand up regularly to change the speed of the cooling fan, homes of handicapped and old aged people, since it requires no human effort to function.

2. Materials and methods

2.1 Materials

The materials and their specification that were used for the implementation of an automatic speed controller for direct current fan using a temperature sensor includes microcontroller ATMega8p, 220V/12V transformer, 11.0592MHz programmable board, 33pF quartz crystal, LM35 temperature sensor, 16x2 LCD display, 32 pot, 2N2222 ADC0804, DC motor, press button, CP45 transistor, 1N4007 diode, DT117A digital tachometer, and assorted resistors and capacitors.

2.2 Methods

The methods for implementation of the automatic speed controller for direct current fan using a temperature sensor was carried out in four (4) parts to include hardware design analysis, software design method, hardware construction and circuit analysis (testing) method. The block diagram is shown in Fig 1.

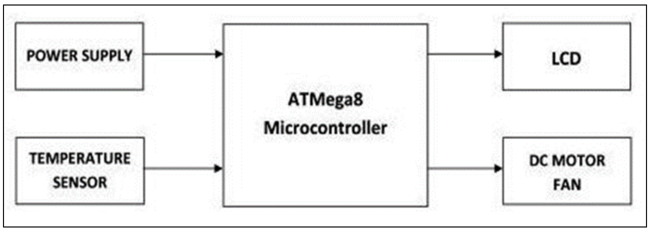


Fig 1: Block diagram of the proposed speed-controlled dc fan system

2.2.1 Hardware Design Method

The design of the DC fan speed controller circuit was carried out according to the block diagram in Fig 1. Block I represent the power/ signal pickup unit which house the input and distribution of power to the circuit system. Block II is the temperature sensor. Block III is the microcontroller which is also the heart/ brain of the whole system that works/ operates according to temperature sensing. Block IV is the output driver (motor) which operates in such a way that it increases with increase in temperature. Block V is the LCD which displays the surrounding temperature, time and data.

2.2.1.1 The Power Supply Unit

Power supplies designed for use was equipped with an input voltage selector switch that allowed the user to configure the unit for use on local power grid. In the lower voltage range, around 12V, this switch is turned on changing the power grid voltage rectifier into a voltage circuit design. As a result, the large primary filter capacitor behind that rectifier was split up into two capacitors wired in series, balanced with the resistors. The circuit diagram of a 12V dual power supply is as shown in Fig 2.

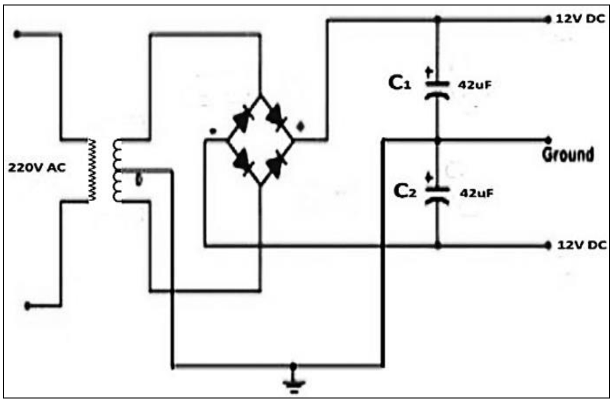


Fig 2: 12V power supply

The energy consumption limiting in power section base on capacitors (C) to the output voltage can be calculated as follows:

$$\text{Energy (E)} = \text{power (P)} \times \text{time} \quad (1)$$

$$P = IV \quad (2)$$

$$E = IVt \quad (3)$$

$$\text{Quantity of charge } Q = It \quad (4)$$

$$Q = CV \quad (5)$$

Therefore, energy consumption in a circuit based on two capacitors is

$$E = \frac{1}{2} \times CV^2 \quad (6)$$

2.2.1.2 The Temperature Sensor Unit

Speed control of fan based on room temperature, the Circuit diagram of the Temperature sensor of dc Fan Speed Control is monitoring with Mega8 Microcontroller & LM35 Temperature sensor is shown in Fig 3. Microcontroller which is heart of the circuit as it controls all functions. LM35 is a precision integrated circuit whose output voltage is linearly proportional to Celsius (Centigrade) temperature. It to operate over a -2°C to 70°C temperature range. The output voltage of the LM35 will vary at a rate of 10mV per degree Celsius. Since, the range of the LM35 temperature sensor is from - 2°C to +70°C. To measure this full range of temperatures that is from negative range to positive range, the circuit design need to include connection of an external resistor between the data pin and a negative supply of V_{CC}.

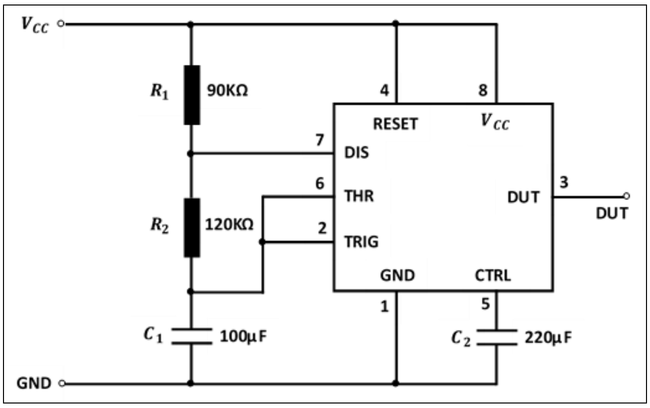


Fig 3: LM35 Temperature Sensor Unit

The input voltage can be expressed such that temperature obtained is based on the resistors and capacitors of the circuit as follows:

$$V_{in} = \frac{R_1 \times V_{out}}{R_1 + R_2} \tag{7}$$

Quantity of charges which current Q flow in the circuit in 1 second is given by equations 4 and 5. If V is the voltage across the circuit, then from Ohms Law, V = IR, where R is a resistor in the circuit. Therefore,

$$t = CR \tag{8}$$

Where C is the capacitance of the capacitor in the circuit, and t is the time constant.

2.2.1.3 The Microcontroller Unit

The Arduino programmable circuit board with IDE software which uses simplified version of C++ was used. In this work, the Arduino Uno ATMega8p was used and programmed to continuously read temperature from its surroundings. The temperature sensor acts as a transducer which converts the sensed temperature to electrical value. It was also programmed to monitor time and date which is displayed on the LCD. Fig 4 is the circuit diagram of the microcontroller unit.

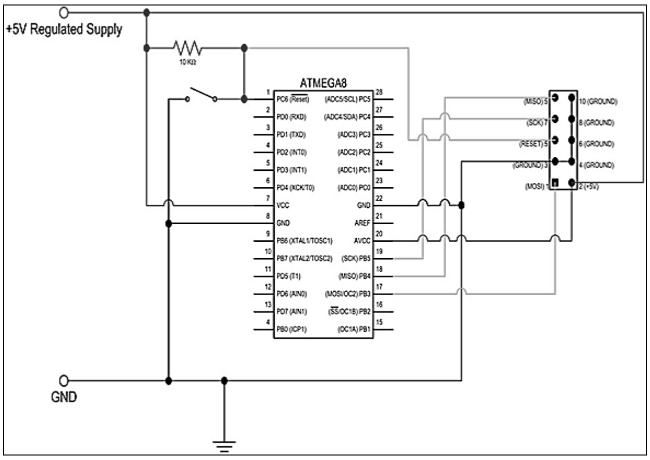


Fig 4: Atmega8p Microcontroller Unit

The current flowing in a circuit I

$$I = \frac{V_{out}}{R} \tag{9}$$

Where the power output is calculated using Eq. (2).

2.2.1.4 The LCD Unit

An LCD (Liquid Crystal Display) screen is an electronic display module which has a wide range of applications. A 16x2 LCD display is very basic module and is very commonly used in various devices and circuits. It can display 16 characters per line and there are 2 such lines. Each character is displayed in 5x7 pixel matrix and is capable of displaying 224 different characters and symbols. It has two registers, namely, command register which stores various commands and data register which stores data to be displayed. The LCD was used to display temperature, time and calendar. Fig 4 shows the 16x2 LCD unit.

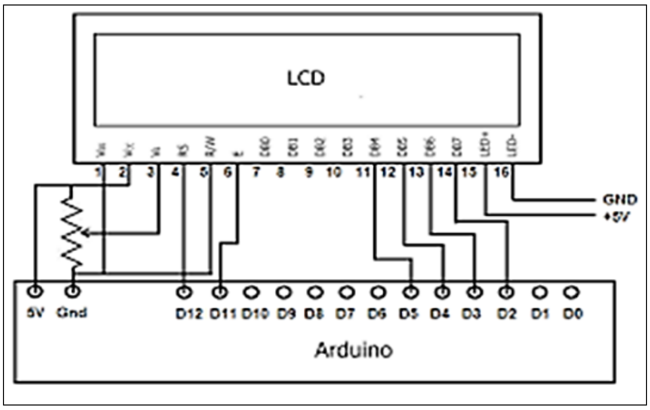


Fig 5: Pinout for the LCD Unit

2.2.1.5 The Motor Output Driver Unit

The DC motors are often designed to be used in dc fan applications due to their easy speed controllability, high efficiency and long-life time expectation. Nearly all types of DC fan motors designed to have some internal mechanism, either electromechanical or electronic, to periodically change the direction of current in part of the motor. The most common types rely on the force produced by magnetic fields. The motor in this study was designed electronically, to convert dc electrical energy into mechanical energy. The circuit diagram of the motor output driver is shown in Fig 6.

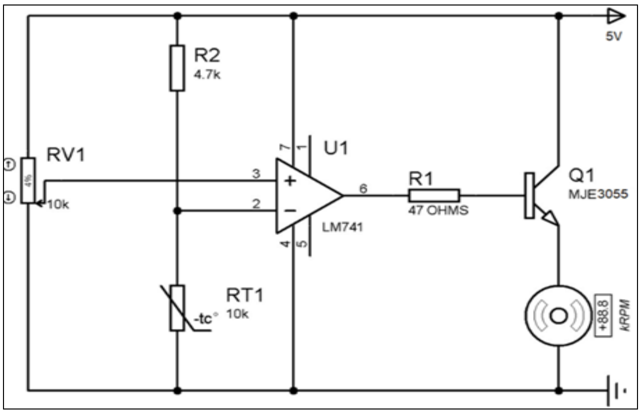


Fig 6: The dc motor output driver unit

The motor driver is directly output is proportional to the temperature, as the temperature increase the motor speed must equally increase. That cycle continues to repeat with the power since there is not capacitor for alternately charging and discharging. The resulting output power is given as:

$$P = IV_{in} \quad (10)$$

Substituting this in Eq. (2) and (7) the power output is given as:

$$P = \frac{V_{in}^2}{R_1} \quad (11)$$

2.2.2 Software Design Method
The software design for the system includes simulation, flowchart, algorithm, and choice of programming language.

2.2.2.1 Simulation Method
The simulation of the automatic speed controller using a temperature sensor was carried out in stages according to the block diagram presented in Fig 1. The circuit was simulated using Proteus ver8.0 software.

2.2.2.2 The Flow Chart
The flow chart for the automatic speed controller using a temperature sensor is shown in Fig 7.

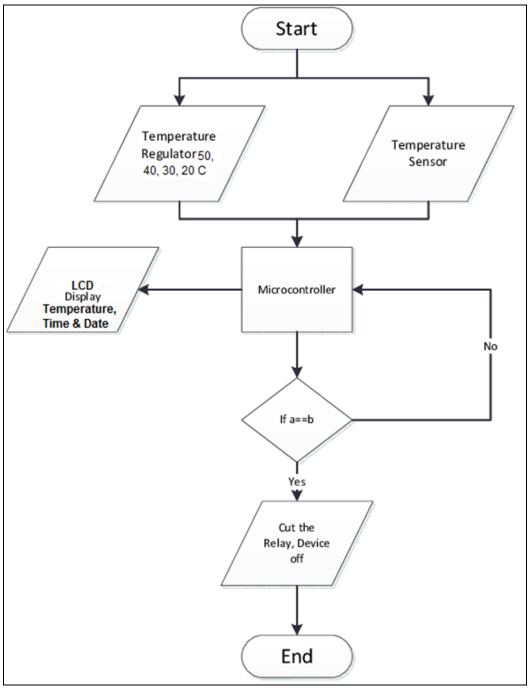


Fig 7: Flowchart for the proposed automatic speed controller

2.2.2.3 Algorithm
The algorithm that explains the flowchart is given as follows:
1. Start
2. Initialize the system
3. Set the date and time
4. If the temperature is greater than minimum, activate the relay (fan speed high)
5. Else, deactivate the relay (Fan speed low)
6. Stop.

2.2.2.4 Choice of Programming Language
The choice of programming language in this work is the C language. This is widely used in programming language for embedded microcontrollers. Coding of the system was done in assembly language.

2.2.3 Hardware Construction Method
The circuit construction was carried out in stages according to the specification of the design and simulation, following the block diagram in Fig 1. The components were first assembled on electronics breadboard to ensure proper terminal connections and then transferred on to a Vero board for permanent soldering. However, too much Lead was avoided to prevent clumsiness and bridging of the components.

2.2.4 Circuit Testing Method
Components testing was carried out before fixing them on the Vero Board. The various units were isolated and tested independently for continuity test. Then the whole system was cascaded and tested to ensure proper functionality of the system, and loading and impedance mismatch from one stage and another. Power ON test were also carried out during construction to ensure that no components in the circuit undergo heating when the device is in use. Also, performance evaluation was carried out on different temperatures and the duty cycle was measured using a tachometer. The result was output test was used to calculate the frequency (Hz) and the angular speed (rad/s) as follows:

$$F = \frac{D}{t}\ Hz \quad (12)$$

$$\omega = 2\pi F\ rad/s \quad (13)$$

Where D is the duty cycle, and ω is the angular speed in rad/s.

3. Results
3.1 Design Analysis
3.1.1 Power Supply
Given that C = 42µF, from Eq. (6), the energy consumption as a result of power supply is:

$$E = \frac{1}{2} \times 940 \times 10^{-3} \times 12^2 = 67.68J$$

3.1.2 The LM 35 Temperature Sensor
Given that R1 = 90kΩ, R2 = 120kΩ, and V_{out} = 12V. Then from Eq. (7), we have:

$$V_{in} = \frac{90 \times 12}{90+120} = 5.1v$$

If C1 = 100µF, and C2 =220µF, then from Eq. (8), the sensor timing constant is:

$$t_1 = C_1R_1 = 100 \times 10^{-6} \times 90 \times 10^3 = 9sec$$

$$t_2 = C_2R_2 = 220 \times 10^{-6} \times 90 \times 120^3 = 26.4sec$$

$$t = t_1 + t_2 = 9 + 26.4 = 35.4sec$$

3.1.3 The Microcontroller
Given that the output voltage V_{out} = 12V and R =10kΩ, from Eq. (9), the current flowing in the circuit is:

$$I = \frac{V_{out}}{R} = \frac{12}{10\times10^3} = 1.2 \times 10^{-3} = 1.2mA$$

The power supplied is calculated from Eq. (2) as:

$$P = IV = 1.2 \times 10^{-3} \times 12 = 1.44 \times 10^{-2} watt$$

3.1.4 The Motor output

From Eq. (7), the input voltage is obtained as:

$$V_{in} = \frac{14 \times 12}{14+14} = \frac{168}{24} = 7v$$

The power output is obtained from Eq. (11) as:

$$P = \frac{V_{in}^2}{R_1} = \frac{7 \times 7}{14} = \frac{49}{14} = 3.5watts$$

3.1.5 The General Principle of the Circuit

The principle of operation of the designed circuit diagram consists of major components including power unit, Atmega8 Microcontroller, 16×2 LCD Display, LM35 Temperature Sensor, and DC Motor. At the power unit, the input mains power 220V AC is stepped down by the transformer to a 12V DC which is further rectified via the rectifier to a pulsating DC and then smoothened by the smoothening capacitor. The smooth 12V DC goes out in two ways; one directly to the relay unit and the other to the microcontroller unit through the voltage regulator which ensures only 5V DC goes into that unit. LED indicates the flow of 5V and 12V DC into their respective units. The basic connections with respect to microcontroller include watch, reset and EA. Watch consists of an 8.2MHz crystal and two 220µF capacitors. The reset circuit consists of a 10µF capacitor 10kΩ resistor and a press button were now the connections with respect to other components. For the LCD to display temperature, time and calendar a 10kΩ pot is connected to contrast adjust pin. The three control pins of the LCD are connected to the pins P3.6, GND and P3.7. The 8 data pins of the LCD are connected to PORT 1 of the microcontroller. The basic connections with respect to ADC are explained in its configuration. The 8 digital outputs of the ADC must be connected to PORT 2 of the microcontroller. The next component we are going to connect is LM35. Connect the data pin of the LM35 to the analog input pin i.e., Pin 6 of ADC. Finally, we need to connect the relay circuit consisting of resistor, transistor and relay to the PORT 0 of the microcontroller with PORT 0 pulled-up externally. Connect the input of relay i.e., base of the transistor to P0.0 pin of the microcontroller. The complete circuit of the automatic speed controller using temperature sensor is shown in Fig 8.

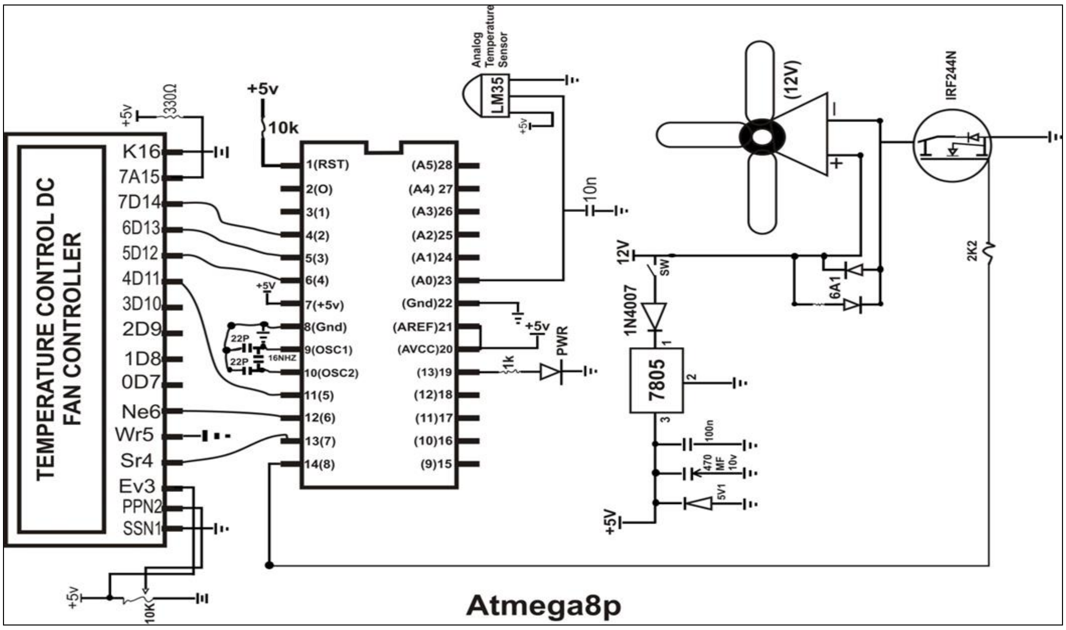


Fig 8: Complete designed circuit diagram of automatic speed controller

3.2 Simulation Results

The simulation was carried out in stages according to the block diagram in Fig 1 and the results are presented in Fig 9, 10 and 11. Fig 9 presents the general simulated circuit of the automatic speed controller system, while Fig 10 and 11 presents the behavior of the circuit when sensing temperature to adjust speed of the fan and the display of time and date.

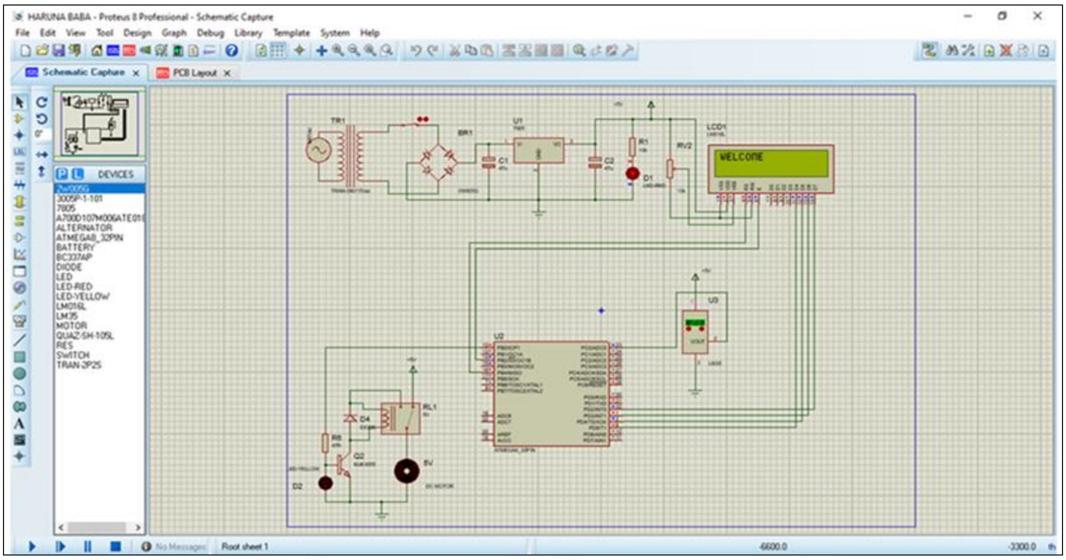


Fig 9: Simulated general circuit at initialization state

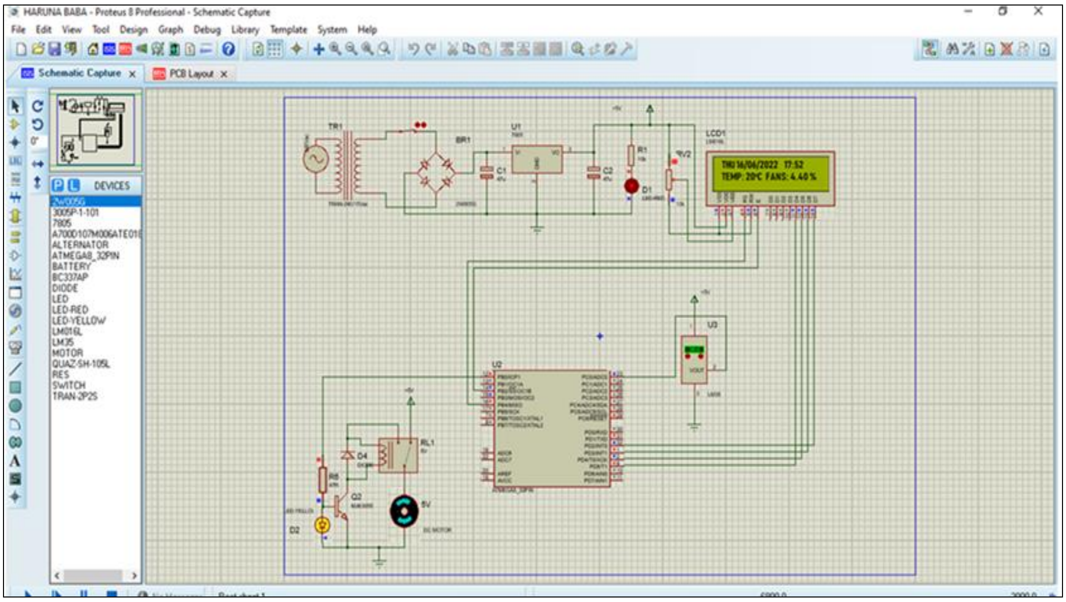


Fig 10: Simulated result indicating date, time, and fan speed at 20°C

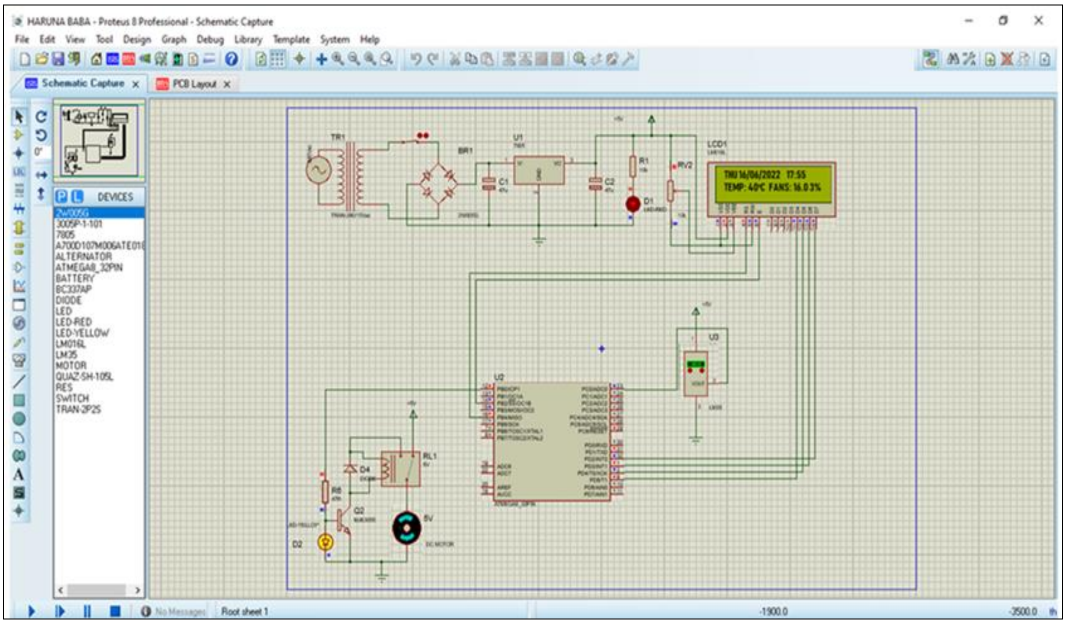


Fig 11: Simulated result indicating date, time, and fan speed at 40°C

Fig 9 shows the simulation result when the system has been powered ON and the initializing sequence has been completed indicating a welcome message. Fig 10 indicates when the device is sensing the temperature of the room or surrounding to adjust the fan speed making the red LED to glow. At this stage the temperature was at 20°C and the fan speed was 4.40%. It also displayed the date (Thursday 16/06/2022) and time (17:52). Usually, it takes a short delay time for the temperature sensor to read the temperature of the surrounding before the fan starts working.

In Fig 11, the temperature of the room was altered by bringing a hot material closed to the sensor and the speed of fan changed. At this time the temperature was at 40°C and the fan speed was about 16.03%, indicating an increase in speed due to increase in temperature. The date (Thursday 16/06/2022) and time (17:55) were also displayed.

3.3 Hardware Construction

3.3.1 Circuit Construction

The construction was carried out first on a bread board to ensure that the circuit is working as required, then transferred to the Vero board for permanent soldering. The microcontroller and the Arduino Uno exists as a component while the temperature sensor, the LCD, the motor unit and every other component in the system were interfaced with the microcontroller and Arduino board. The shunt and limiting resistors were also connected to limit and control the flow of current to the input terminals of each component. The constructed circuit showing the top view of the device is shown in Fig 12.

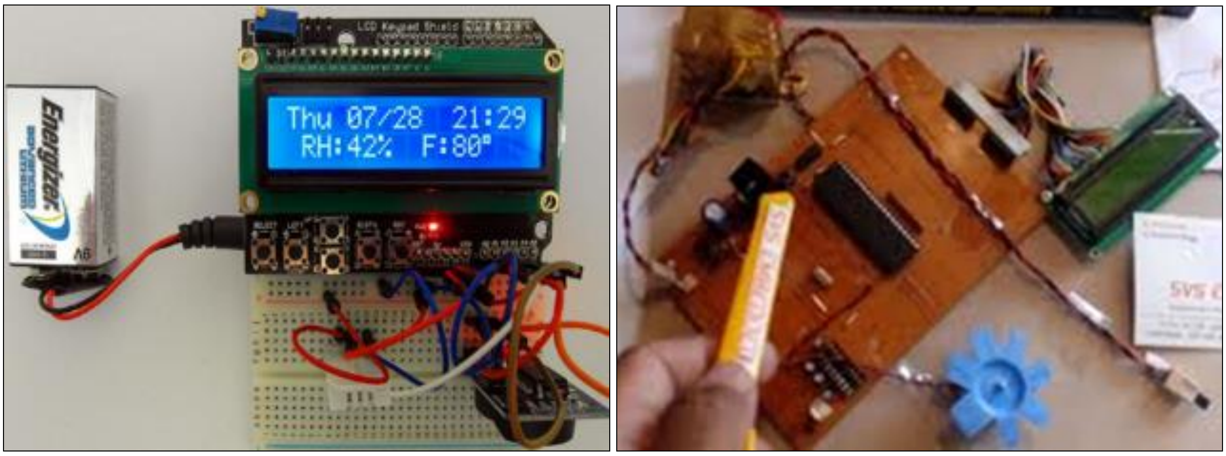
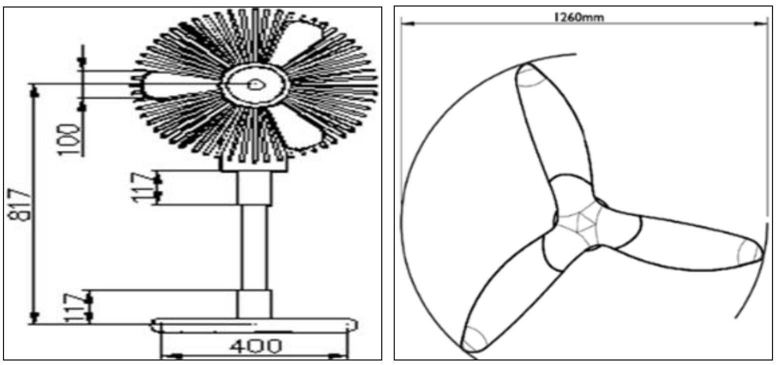


Fig 12: Constructed automatic speed controller using temperature sensor (Constructed circuit on breadboard (left), Constructed circuit on Vero board (right))

3.3.2 Casing and Packaging

A casing made of aluminum sheet measuring 8.17cm height with a 4.0cm diameter base was finally provided to the system for mechanical protection. It is provided with 5.0cm diameter blade case which houses 4.3cm diameter of fan blades. It has 3 blades which are 1.26cm apart with 1.0cm blade tip circumference and 0.5cm diameter holes on the blade centers. Finally, the neck of the fan and above the base has 1.17cm protection to provide more strength to the frame. The complete isometric diagram of the casing showing its dimensions and that of the blades is shown in Fig 13, while the complete packaged device with full casing showing its top and front view is shown in Fig 14.



a) Dimensions of casing, b) Dimensions of fan blade

Fig 13: The isometric diagram of the casing

Fig 14: Complete packaged device with full casing

3.4 Analysis and Testing

3.4.1 Continuity Test

In this study, the multi meter was used to perform this test. The multi meter was set at the continuity mode and the two ends of the probe was placed at the ends of a particular wire that is being checked for continuity, if there is a negligible resistance between the ends of the wire or path or the multi meter buzzer sounds then, the ends or path is continuous.

3.4.2 Power ON Test

In this test, the multi meter was used in voltage mode to check the input and output of each stage of the circuit so as to confirm that the voltage reaching each of the devices are according to the specification of the designed circuit.

3.4.3 Performance Evaluation Test

The test was carried out by powering the system. After initializing, it first displayed ATmega8 microcontroller based automatic fan speed regulator". Then it displayed 27°C (room temperature) with time and date. It also displayed the duty cycle 40 which is the corresponding speed level for room temperature between 25°C - 28°C, and the fan turns at speed 3 corresponding to 7.1rad/s. Heat source (soldering iron) was brought in close contact with the temperature sensor and the temperature increased from 27°C to 38°C and automatically the fan speed changed to speed 5 and was displayed on the LCD. Next, Ice block was brought in close contact with the temperature sensor and the temperature decreased from 32°C to 20°C and automatically the fan speed changed to speed 1 and was displayed on the LCD. By varying the room temperature, the output of the temperature sensor against the duty cycle measured by a tachometer was recorded and the using Eq. (12) and (13), the frequency and angular speed of the fan were calculated. For example, the frequency and angular speed for speed 2 and 3 are given as follows:

For speed 2:

$$F_2 = \frac{25}{35.4} = 0.7Hz$$

$$\omega_2 = 2 \times 3.14 \times 0.7 = 4.4\text{rad/s}$$

For speed 3:

$$F_2 = \frac{40}{35.4} = 1.13Hz$$

$$\omega_2 = 2 \times 3.14 \times 1.13 = 7.1\text{rad/s}$$

Similarly, using the same method, the frequency and angular speed for the remaining states were calculated and the result of the output test was presented as show in Table 1. A graph of the variation of temperature with the duty circle, frequency and angular speed is shown in Fig 15.

Table 1: Change in temperature with duty cycle, angular speed and frequency

S. No	Temperature (°C)	Duty Cycle	Frequency (Hz)	Angular Speed (rad/s)
1	17-20	0	0	0
2	21-24	25	0.70	4.40
3	25-28	40	1.13	7.10
4	29-32	55	1.55	9.70
5	33-37	70	1.98	12.40
6	38-41	82	2.32	14.60
7	42-45	90	2.54	16.00
8	46-50	106	3.00	18.84

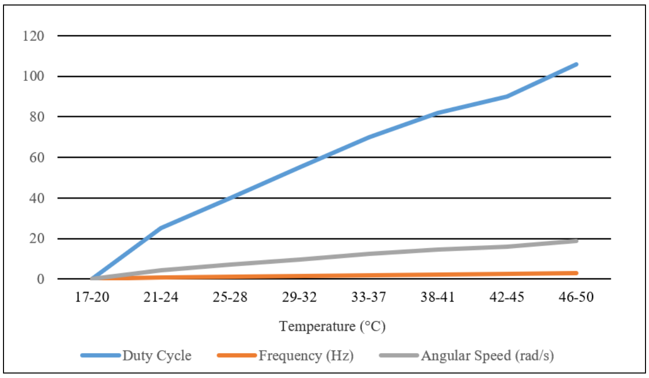


Fig 15: Variation of temperature with duty circle, angular speed and frequency

Table 1 is the analysis result for the test carried out on the constructed device. The output test results revealed some vital information that was useful in the analysis. It is clear that an increase in temperature results in an increase in duty cycle, which results in an increase in frequency and subsequently an increase in angular speed. This is confirmed by the linear relationship observed in Fig 15.

4. Discussion

The constructed automatic speed control was tested to determine the functionality of the circuit. The continuity test showed that the circuit was continuous as there were no short circuit or broken conductors. The voltage at the different stages were according to the specification of the simulated circuit as confirmed by the power 'ON' test. This is similar to that of other researchers such as Parekh [8], Vats and Kumar [4], Adeloye *et al*. [9], Saad *et al*. [3], and Santhosh Kumar and Xavier [10], who designed a home automatic dc fan speed controller and obtained similar results.

Findings from the performance analysis on the device revealed a linear relationship between temperature and the angular speed. Indicating that an increase in temperature of the surrounding results in an increase in the fan speed. The automatic control fan uses a microcontroller to sense the temperature of its environment with the help of the temperature sensor that measures the temperature of the environment. The desired temperature set point had been programmed on the microcontroller with the Arduino program where the temperature sensor reads the temperature every 10secs and compares it with the desired values. If the desired value is higher than the measured value, the fan will not come up. Once the measured value becomes higher than the desired value, the fan comes up with the required speed to cool the room as desired by the user. It can monitor the temperature and displays it on an LCD display in the range of 17°C to 50°C. This confirmed that the constructed circuit conformed to the designed specification with satisfactory results. This design is similar with that of other researchers such as Verma *et al*. [11], Parekh [8], Barman *et al*. [12], Mohite *et al*. [13], Bhatia and Bhatia [14], Bagal *et al*. [15], Prince *et al*. [16], and Singh [17], who designed a home automatic dc fan speed controller and obtained similar result. The designed system is economical, it helps to save energy and easy to operate especially for the old age and disabled. The system is very useful in the tropical areas where temperature is considerably high.

5. Conclusion

The goal of this work was to construct a circuit that will automatically control the speed of a fan according to changes in the temperature of the surrounding. The circuit was simulated, constructed and tested by varying the temperature of the surrounding and the corresponding fan speed was noted and measured with a tachometer and the result showed a linear relationship. The inclusion of time and date monitoring to the circuit made it unique and different form the works of previous researchers. With automated fan control, you no longer need to disrupt your workflow to adjust the speed and direction of your fans. The device can be used in the tropical areas where the temperature is very hot and especially for the old aged and disabled people homes and in the hospitals for the sick who cannot stand up to regulate their fan. The device can also be used to improve comfort in our various homes and offices.

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