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Research Article

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Design and Construction of an Automatic Temperature Control System

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Abstract This paper presents the design and construction of a temperature controller system that is capable of maintaining an enclosed area temperature to a desired value. A microcontroller and a temperature sensor are used to control and monitor temperature. LM35 temperature sensor is used to sense temperature and it works linearly with increase in temperature. The microcontroller compares the increase or decrease in temperature with the room or set temperature and passes the information to either the cooling fan or the heater to activate or deactivate accordingly. The set temperature in this design is between 25^0C and 26^0C. When the surrounding temperature goes below 25^0Cthe temperature sensor sends signal to the microcontroller (Atmega 328p) which analyses it by comparing it with the set temperature and then latch the transistor to switch ON the heater. But if the surrounding temperature goes beyond 26^0C, the temperature sensor detects the temperature change and sends an information to the microcontroller to signal the relay through the transistor to switch ON the fan and automatically puts OFF the heater. The designed system incorporated a buzzer such that it comes ON to alert nearby people in case the temperature goes beyond 37℃ and the fan fails to cool the environment. The results obtained from laboratory setup agree with that of simulation using proteus software.

Keywords Temperature Sensor (LM35), Arduino Nano Microcontroller (ATMEGA 328P), Relay, Voltage Regulator

1. Introduction

A temperature controller is a device used to hold a desired temperature at a specified value. The most common temperature controller is the thermostat found in homes used to control the temperature of water and maintain it at a certain desired value. Temperature controller can also be defined as a system that monitors and controls the temperature of a room, body or any place under consideration [1].

Temperature controllers are needed in every situation requiring a given set points of temperature to be monitored and kept constant. For instance, a situation where an object is to be heated, cooled or both and to remain at the set temperature. This may also be a living room where temperature sensitive equipment is kept and monitored such that a little change in the ambient temperature might lead to catastrophic failure of the device such as electronic devices or automobile systems that works on very high temperature. Furthermore, [2] states that temperature is one of the main parameters to be controlled in most of the manufacturing industries like chemical, food processing, pharmaceutical etc. The temperature in these industries need to be controlled within an approved limit to ensure potency and safety of the processed and finished products.

Temperature measurement has become a very paramount part of any control system operating in a temperature sensitive environment. There are two fundamental types of temperature control via; close loop and open loop temperature control. However, we are interested in the closed loop system because of its feedback hence it is an intelligent system. In this research paper, a microcontroller has been conditioned to repeatedly analyze its environmental temperature via the feedback from a temperature sensor which gives the controller the sense of judgment whether to switch ON or OFF a fan or switch ON or OFF a heater as the case may be. A liquid crystal display unit is also included to communicate the operational state of the system to the user.

2. Review of Related Empirical Studies

Temperature control is a process to uphold the given temperature at a certain level. This process is commonly explored in almost all applications. It has become an important element in recent times owing to its vast daily life applications in our homes.[3]proposed home temperature control system using PIC microcontroller 16F877A which makes decisions to turn ON or OFF the heater or cooling fan in the home based on information adjusted by comparing the temperature sensor values and the required set-points within a temperature range of 20°C and 28°C. A cheap and simple to operate temperature control system based on AT89C51 single-chip microcomputer (SCM, MCU) which is capable of monitoring computer room temperature and at the same time regulates the cooling system accordingly was proposed by [4].

[2] worked on a microcontroller-based temperature control system which controls the temperature of any device according to its requirement for any industrial application using PIC16F887A microcontroller. The sensed environmental temperature by the thermocouple sensor is displayed on a seven-segment display in the range of 0˚C to 750˚C. This temperature is compared with the value stored by the user, and if the temperature goes beyond the preset temperature then heater is switched OFF but if temperature goes below the preset value, then heater is switched ON. The switching state of the system is interfaced with the microcontroller with the help of a relay and an NPN transistor. [1] also presented a paper based on PIC16F877A microcontroller interface with LM35DZ temperature sensor, LCD, switching transistors and relays. The LM35DZ temperature sensor senses the temperature of a given room and transmits it to the PIC16F877A microcontroller which decodes and compares it with the predetermined temperature value stored in it. The microcontroller in turn automatically switches ON/OFF the heater or the fan based on the comparison result and the measured room temperature is displayed on the LCD accordingly. The design considered a predetermine temperature value of 26^0C as minimum and 29^0C as the maximum. The system has been tested and the results show that switching occurs within a temperature range of 25^0C and 30^0C.

A notable work was also done by [5] where a temperature-controlled system for an air-filled chamber is developed. The system was designed to accommodate the desired chamber temperature in a prescribed range and to exhibit overshoot and steady-state temperature error of less than 1^0K in the actual chamber temperature step response. The details of the design developed by this group of students was based on a Motorola MC68HC05 family microcontroller. The solution requires broad knowledge drawn from several engineering disciplines including electrical, mechanical, and control systems engineering. [6] presented a research paper which focuses on the design and construction of a Dual Sensor heat-monitoring system. The circuit works by monitoring temperature from an external input and comparing the temperature level with that of a preset temperature value. The power output of the circuit is cut OFF or switched OFF or an alarm is triggered ON if the temperature of the external input is equal to or greater than the preset temperature value. The results of the tests show that the power output of the circuit is switched OFF or an alarm is triggered ON when the device temperature exceeded a preset value.

3. Materials and Methods

The major materials used in carrying out this research include LM35 Temperature sensor which operates at ± 0.25°C accuracy at room temperature senses the surrounding temperature and communicates the microcontroller for necessary actions. LM7812 and LM7805 were used as voltage regulators to limit the amount of power that enters the circuit board. ATMEGA 328P (Arduino Nano) Microcontroller is a programmable chip that coordinates the operation of the system. A DC motor has been used to drive the cooling fan while a Liquid Crystal Display (LCD) module visualizes system's operation to the user. Relays were connected to the NPN transistors to initiate appropriate switching process. A DC fan and a heater receives signals from the microcontroller through the relay driver for appropriate ON and OFF state actions. The buzzer comes ON when the surrounding temperature is outside the operating range as signaled by the microcontroller. The entire design was implemented on printed circuit board (PCB) while proteus software was used for simulation.

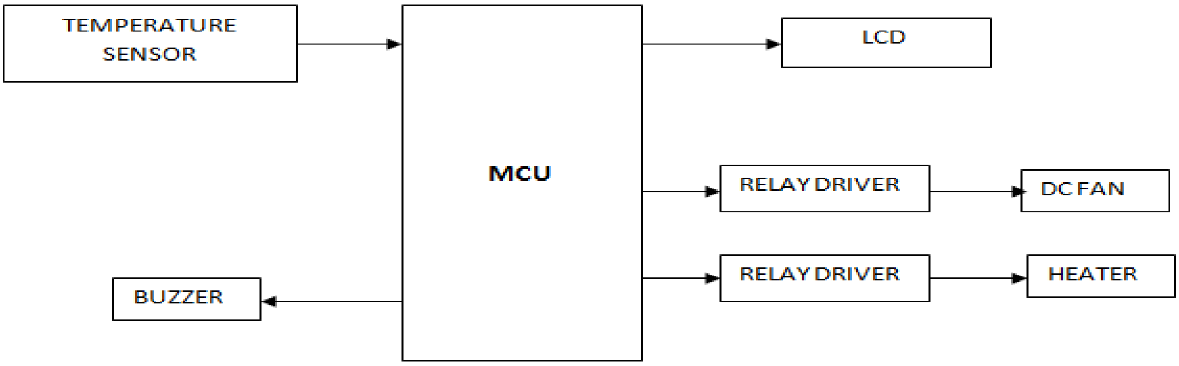

Figure 1: Block Diagram of the Temperature Controller

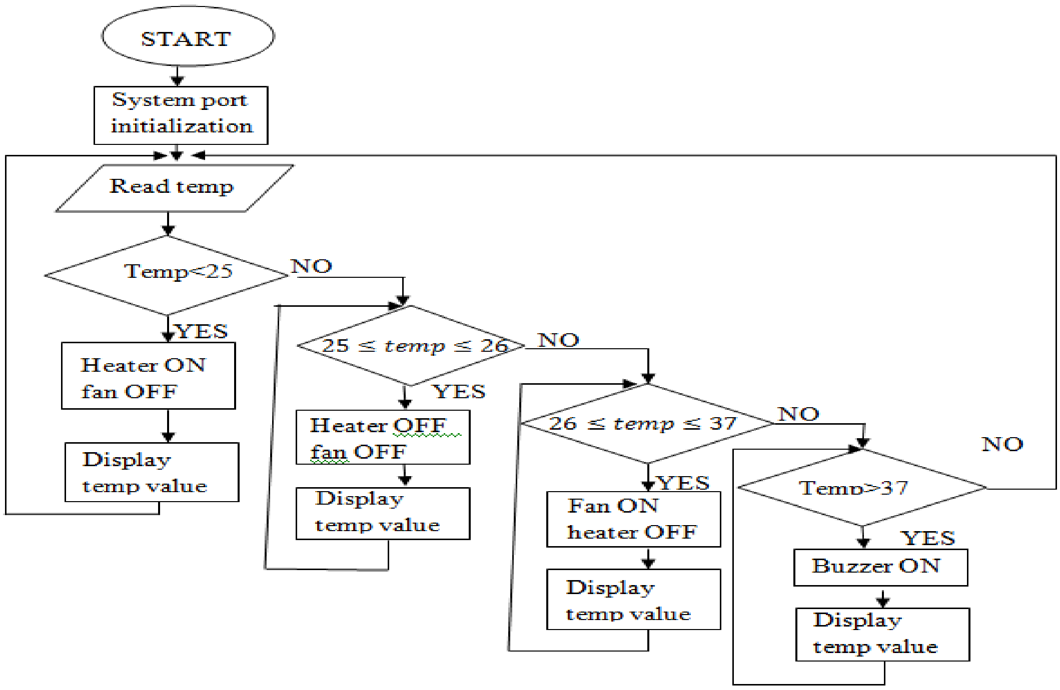

Figure 2: System Flow Chart

(a) Design and analysis of power supply circuit

The power source is made up of an AC transformer, a full wave bridge rectifier circuit and a filter capacitor. The transformer is a 240/15V step down transformer which transforms the high input AC voltage to a low voltage AC output of 15V.

Since the components in the circuit such as transistors need a DC biasing voltage and not an AC voltage, a conversion from AC to DC is required. This conversion is carried out by the full-wave rectification circuit. Rectifier is an electrical device which periodically reverses an AC signal to DC signal that flows only in one direction. There is full-wave and half-wave rectification in general. However, in this paper, we are interested in full-wave rectifier because of its numerous advantages over the half-wave rectifier such as high efficiency, higher output voltage and power, and absence of DC saturation problems.

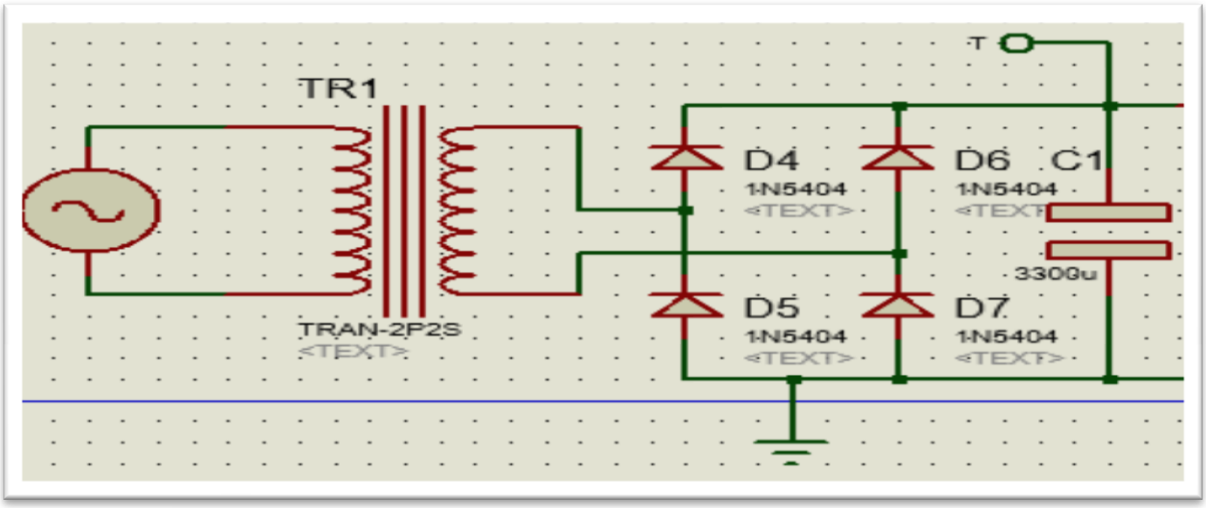

Figure 3: Power supply circuit

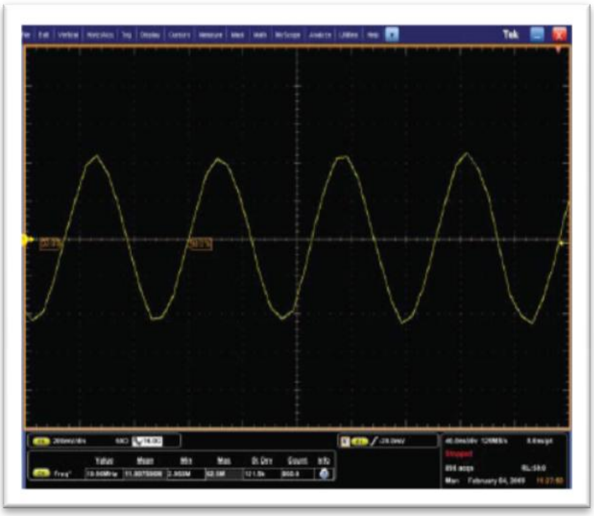

Figure 4: AC scope diagram of the power supply

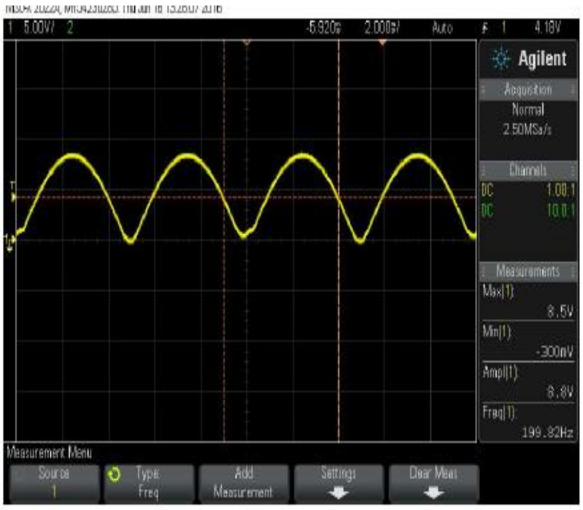

Figure 5: DC scope diagram of the power supply

Table 1: Truth table of the rectifier circuit

Diode	Positive half cycle	Negative half cycle	Output (Adder)
D4	1	0	1
D5	0	1	1
D6	0	1	1
D7	1	0	1

(b) Filter capacitor selection

The choice of the filter capacitor is made based on equation (1)

$$C = \frac{I_{DC}}{4\sqrt{3}\gamma f V} \quad (1)$$

where γ is the percentage allowable ripple, I_{DC} is the current, V_{IN} is the voltage and f is the operating frequency

Peak Inverse Voltage (PIV) = $\sqrt{2} \times 15\ V = 21V$

Given that: $\gamma = 3\%$, $f = 50$ Hz, V_{DC} =15 V and I_{DC} = 500mA = 0.5A

$$C = \frac{0.5}{4\sqrt{3} \times 0.03 \times 50 \times 15} = \frac{0.5}{218.24} = 2.291 \times 10^{-3}\ F = 2291\mu F$$

Therefore, 3300µF was selected for better performance.

The output from the supply is found to be 15.6V which is quite much for a 12V and 5V devices like the microcontroller, relay and the DC fan. 7812 and 7805 discrete voltage regulators were used to ensure output of 12V and 5V respectively. Figure 6 and figure 7 depict the circuit configurations. Also, 10μF and 47μF capacitors were used as decoupling capacitors and for further reduction in ripple voltage.

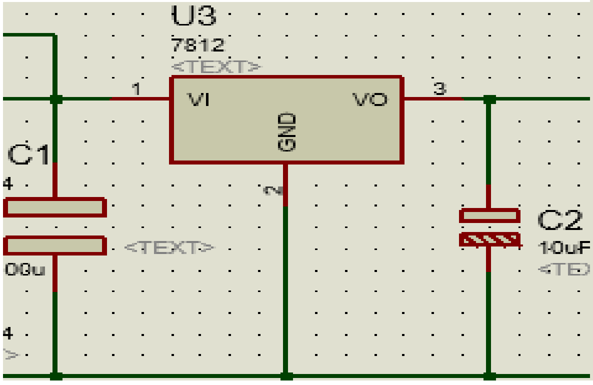

Figure 6: 12V Regulator Circuit

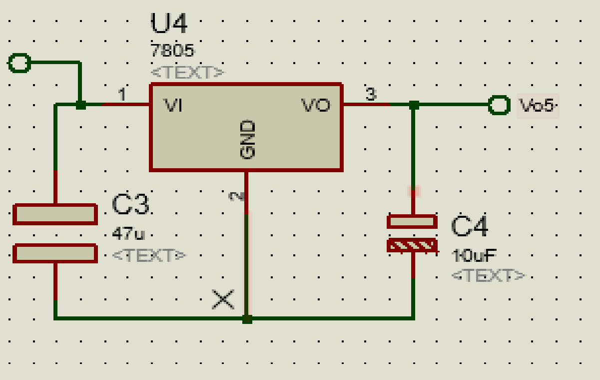

Figure 7: 5V Regulator Circuit

(c) Analysis of the LED power indicator circuit

Figure 8: Circuit diagram of the LED

From the data sheet for Green LED, the voltage drop across the diode is 2.2V and the full drive current of 20mA is chosen.

Taking KVL equation from the 5V to ground, we have:

$$20R_8 + 2.2 = 12 \qquad (2)$$

$$R_8 = 9.80/20 = 0.49K\Omega$$

Therefore, $R_8 = 490\Omega$, but $1K\Omega$ is chosen for better performance.

(d) Analysis of the relay driver circuit

The DC fan and the AC heater are been relayed to supply when the microcontroller gives the actuating voltage. This is achieved by configuring transistors to operate in two of its three modes of operation. The transistor is biased to go into saturation when it is latched by the microcontroller, and go into cut-OFF mode when d-latched. For this to happen, the current through the collector must be far less than beta multiplies by the base current. The relay driver circuit is presented as figure 9.

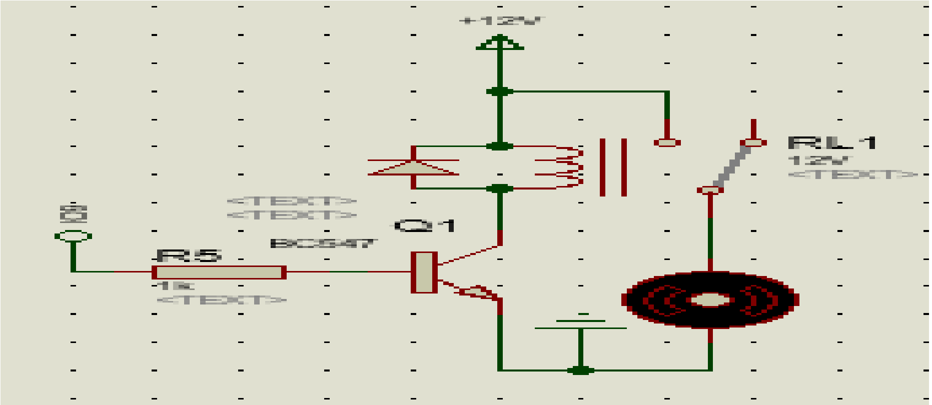

Figure 9: Motor connected to relay driving circuit

The collector current can be expressed as:

$\mathrm{I_C} \ll \beta \mathrm{I_B}$ This implies that

$\mathrm{I_B} \gg \frac{\mathrm{I_C}}{\beta}$ were, $\beta = \mathrm{hFE}$, known as current gain amplification factor

Relay data: 12V, 25mA.

Transistor Saturation Mode data: $V_{BE(SAT)}$= 0.80 V, $V_{CE(SAT)}$= 0.2 V and h_{FE}= 100, $R_5 = R_B$.

Taking Kirchhoff's voltage law (KVL) of C-E loop of figure 9 and making I_C the subject of the relation:

$$\mathrm{I_C} = \frac{12 - \mathrm{V_{CE}}}{\mathrm{R}}$$

Where R is relay resistance.

$$\mathrm{R} = \frac{\text{Relay voltage}}{\text{maximum relay current}}$$

$$= \frac{12\ \mathrm{V}}{25\ \mathrm{mA}} = 480\ \Omega.$$

$$\mathrm{I_C} = \frac{12-0.2}{480} = 24.5\ \mathrm{mA}.$$

Similarly, taking KVL of B – E loop of figure 9 yields:

$$\mathrm{I_B} = \frac{\mathrm{V_{BB}} - \mathrm{V_{BE}}}{R_B} = \frac{5.0 - 0.80}{\mathrm{R_B}}$$

$$\mathrm{I_B} = \frac{4.2}{\mathrm{R_B}}$$

Condition for saturation

$$\mathrm{I_C} < \mathrm{h_{FE}} \times \frac{4.2}{\mathrm{R_B}}$$

Substituting $\mathrm{I_C}$ and $\mathrm{I_B}$ into the above equations and making $\mathrm{R_B}$ subject:

$\mathrm{R_B} < 1\mathrm{k}\Omega$.

To ensure that the transistor is operated in saturation mode, a value of 470Ω is suitable for the base resistance (R_B *or* R_5).

(e) Analysis of the buzzer driver circuit

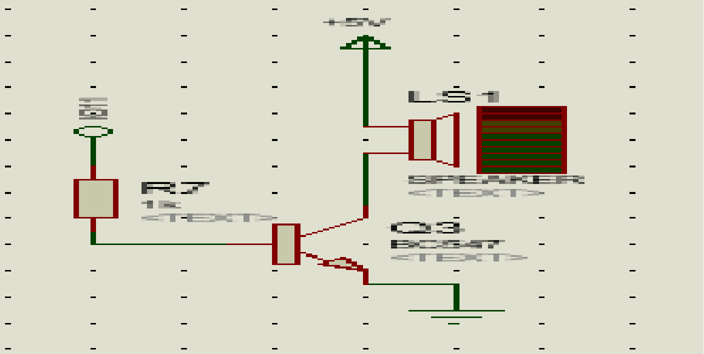

Figure 10: Buzzer connected to transistor driving circuit

Buzzer data: 5V, 25mA.

Transistor Saturation Mode data: $V_{BE\,(SAT)}$= 0.80 V, $V_{CE\,(SAT)}$= 0.2 V and h_{FE}= 100,$R_7 = R_B$

Taking Kirchhoff's voltage law (KVL) of C–E loop of figure 10 and making I_C the subject of the relation:

$$I_C = \frac{5 - V_{CE}}{R_B}$$

Where R is buzzer resistance.

$$R = \frac{\text{buzzer voltage}}{\text{maximum buzzer current}}$$

$$= \frac{5\text{ V}}{25\text{ mA}} = 200\Omega.$$

So, substituting into $V_{CE\,(SAT)}$= 0.2V and R= 200Ω yields:

$$I_C = \frac{5-0.2}{200} = 24\text{mA}.$$

Similarly, taking KVL of B–E loop yields:

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5 - 0.80}{R_B}$$

$$I_B = \frac{4.2}{R_B}$$

Condition for saturation

$$I_C < h_{FE} \times I_B$$

Substituting I_C and I_B into the above equation and making R_B subject:

$$I_C < h_{FE} \times \frac{4.2}{R_B} = R_B < \frac{420}{24} = R_B < 17.5\Omega$$

$R_B < 1\text{k}\Omega$.

To ensure operation of the transistor in saturation mode, a value of 470Ω is appropriate for the base resistance (R_B or R_7).

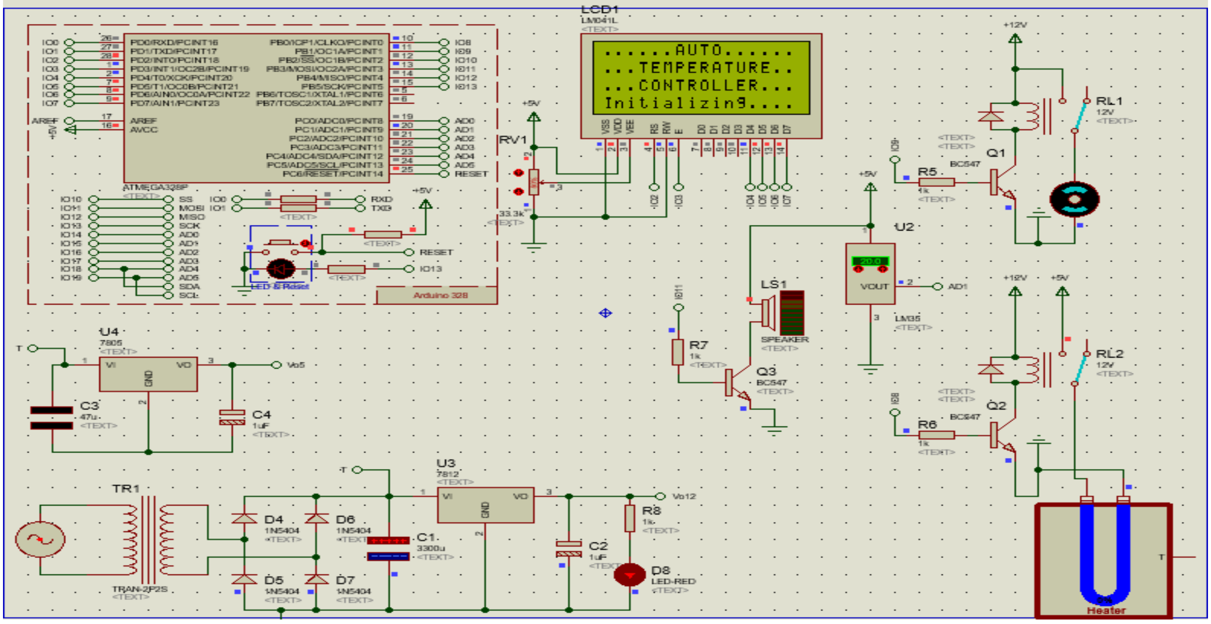

Figure 11: Simulation of complete circuit initialization

4. Results and Discussion

The designed system produced satisfactory results as the system turns ON fan to cool the environment when temperature is above the set limit and in the same manner turns heater ON and automatically turns OFF the fan when the temperature is below set threshold.

Figure 4 and 5 depict the scope diagram of the AC power supply and the DC Scope diagram of the rectifier circuit respectively. Figure 11 represent system initialization of the complete circuit in the proteus software environment. Meanwhile, the complete laboratory setup is shown in figure 12.

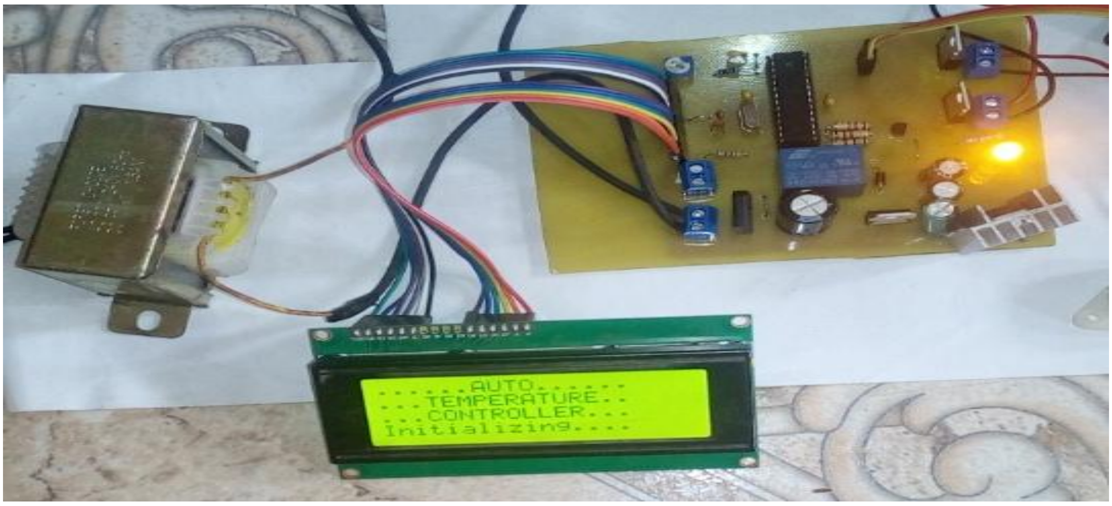

Figure 12: LCD Initialization process of the system setup

5. Conclusion and Recommendation

Automatic temperature monitoring system remains the great solution in reducing food spoilage and preservation of pharmaceutical products. A controlled room temperature is key for optimum human performance and operation of electronic and mechanical devices. The aim of this research work has fully been achieved. However, future work should make use of more accurate temperature sensors and the use of switch mode power supply in order to reduce the direct heating effects on voltage regulators for increased efficiency, accuracy and reliability.

References

[1]. Abubakar, M. A., Adepoju, T. M., Rabiu, M. L. & Muslim, U. A (2017). Microcontroller Based Automatic Temperature Controller. *International Conference of Science, Engineering & Environmental Technology (ICONSEET),* 2(16): 127-131.

[2]. May, Z. T. (2018) Microcontroller Based Automatic Temperature Control System. *International journal of Science and Research Methodology (IJSRM),* 11(2): 52-63

[3]. Lwin M. A. (2019) Implementation of Home Temperature Sensing Control System Using Microcontroller. *International Journal of Trend in Research and Development (IJTRD),* 6(2): ISSN: 2394-9333.

[4]. Xu, K. L. (2015) Design of Temperature Control System for Computer Rooms Based on AT89C51 Single-chip. *Chemical Engineering Transactions,* 46: 271-276.

[5]. McDonald, J(1997) Temperature Control Using a Microcontroller. An Interdisciplinary Undergraduate Engineering Design Project. *IEEE Frontiers of Education Conference:* pp. 1620 – 1624.

[6]. Zungeru, A. M. and Ahmed, M. S. (2012) Development of a Dual Sensor Heat Control System, *International Journal of Instrumentation and Control Systems (IJICS),* 2(4): 11-26.