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Microcontroller-Based Design of an Intelligent Incubator System

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ABSTRACT

This paper describes the design and implementation of an intelligent incubator system. The system was developed using AT89C52 microcontroller. Unlike the conventional incubator system that its temperature regulatory sub-system is integrated in the whole system, this microcontroller-based type is a separate module that can be used as a stand-alone system or latched to other systems that require temperature regulation. An algorithm for the operation was developed, from where the program written in Assembly language that controls the operation of the incubator was derived. The design was tested ok when implemented. However, this research work spans through the review of relevant literatures on temperature regulation as well as detailed information on incubator designs. It also presents the expected performance of the system and recommendations for improving on the research.

KEYWORDS: Microcontroller, incubator, temperature, sensor, regulation, and comparator.

I. INTRODUCTION

1.1 The Background of Study

An incubator system is a temperature controller which regulates a closed environment at a particular (set) temperature. However temperature regulation or control is a process in which change of temperature of a space (and objects collectively there within) is measured or otherwise detected, and the passage of heat energy into or out of the space is adjusted to achieve a desired average temperature [1]. Temperature controllers are used in most manufacturing industries. The industries like textile mill, pharmaceutical industry, oil refinery, etc, all require temperature controller. The temperature controllers are used to maintain constant temperature of process or plant or any material [2]. In such temperature controller system, there is one reference temperature called set point or set temperature that is the desired temperature that must be maintained. This reference temperature is set by external means. Also it can be always adjustable according to requirements. Once this temperature is set the system tries to maintain it by sensing the current temperature of the environment and controlling it using heater, cooler or compressor, relay, comparator, etc.

It senses current temperature, compares it with reference temperature and generates error signal. Then based on this error signal it controls heating element (or cooling element). If set temperature is more, then error signal is negative and vice versa [3]. Instance of this is one such temperature control system that senses current temperature using temperature sensor. It compares it with a reference temperature signal that is set by an external variable resistor. And it gives indication of error signal as positive or negative.

* If error is positive, that means current temperature is more than set temperature that has to be reduced.
* If error is negative that means current temperature is less than set temperature and it is required to increase it.

The major building blocks of an intelligent incubator system are temperature sensor, reference potentiometer, Analog to Digital Converter (ADC) or comparator, microcontroller, and clock generator.

Temperature sensor: It is used to detect the temperature of an environment. It gives corresponding voltage (or current) output as change in temperature occurs. It can be calibrated in degree Celsius.

Reference potentiometer: It sets reference temperature between minimum to maximum value. The system of operation depends upon this set temperature value.

ADC: It is analog to digital converter with built in multiplexer. It takes two analog inputs one from temperature sensor and another from reference potentiometer. It gives 8-bit digital output corresponding to selected analog input. To get the digital output of any one channel, microcontroller will select the required channel and takes digital output.

Clock generator: ADC requires clock signal for its operation. This clock signal is generated by IC555-based clock generator.

Microcontroller: A microcontroller is a single chip computer [4]. It controls the operation of ADC. It takes digital output of both channels and processes them. It takes suitable decision by comparing two temperatures.

There are many egg incubators in the market nowadays. They come with several features that differentiate one product from the other. However, almost the same principle is used in designing each one. For example, Automatic Forced-Air Incubator uses a light bulb to increase the temperature in the incubator; while Mini Eco Eggs Incubator uses heater coil for the same purpose.

The scope of this research is within the use of AT89C52 microcontroller to design and implement a microcontroller-based intelligent incubator system. The programming language used was Assembly language. The research did not handle the technology behind the components used. It is necessary to state that Analogue to Digital Converter (ADC) was not used and therefore not explained, but rather a comparator (LM324) was used. Also, the choice of the temperature sensor (LM 35) was considered because it is calibrated in degree Celsius. The designed methodology should be seen as a prototype which can be developed to any required size.

1.2 Problem with the Existing System

The existing system does not use programmable and this brings about the use of several components to take care of the control program. It is usually bulky and does not allow easy trouble shooting and repair.
However, it usually has a problem of efficiency since discrete components are not reliable. The accuracy of the system is also not certain as components most times get heated and burn. That is why in some cases with these old types of incubator, one experiences eggs hatching more than 21 days. Moreover, because of the use of several components, it is not good to even move it from place to place. It easily damages in transit.

1.3 The Proposed System

The proposed system is a programmable type of incubator. It uses a microcontroller which can be programmed in any embedded system language. Such language may be Assembly language, embedded C++, etc. One clear advantage it has is that the output temperature is usually accurate. Its principle of operation is based on the execution of the stored control program. The proposed system is however simple, reliable and can be trouble-shooted and repaired easily because its components are relatively small.

II. LITERATURE SURVEY

2.1 Review of Past Related Works

There have been many developments in automatic control theory during recent years. It is difficult to provide an impartial analysis of an area while it is still developing. However, looking back at the progress of feedback control theory, it is now possible to distinguish some main trends and point out some key advances with respect to temperature regulation.

The Industrial Revolution in Europe followed the introduction of prime movers (or self-driven machines). It was marked by the invention of advanced grain mills, furnaces, boilers, and steam engine. These devices could not be adequately regulated by hand, and so arose a new requirement for automatic control systems. A variety of control devices was invented, including float regulators, temperature regulators, pressure regulators, and speed control devices [5].

Cornelis Drebbel of Holland spent some time in England and a brief period with the Holy Roman Emperor Rudolf II in Prague, together with his contemporary J. Kepler. Around 1624, he developed a temperature control system for a furnace, motivated by his belief that base metals could be turned to gold by holding them at a precise constant temperature for long period of time. He also used this temperature regulator in an incubator for hatching chickens [6].

Temperature regulators were studied by J.J. Becher in 1680, and used again in an incubator by Prince de Conti and R.-A.F. de Réaumur in 1754. The "sentinel register" was developed in America by W. Henry around 1771, who suggested its use in chemical furnaces, in the manufacture of steel and porcelain, and in the temperature control of equipments in a hospital. It was not until 1777, however, that a temperature regulator suitable for industrial use was developed by Bonnemain, who used it for an incubator. His device was later installed on the furnace of a hot-water heating plant [7].

The invention of computer and microcontroller coupled with advancement in digital electronics has given rise to the development of more functional, sophisticated and reliable systems for the measurement and regulation of temperature [8]. An example of such a system is the temperature-based fan control. This system uses a fan to regulate the temperature of a region by varying the speed of the fan with respect to the region's temperature.

An advanced study of temperature regulation resulted in the development of a thermostat. A home thermostat is an example of a closed-loop temperature controller: It constantly assesses the current room temperature and controls a heater and/or air conditioner to increase or decrease the temperature according to user-defined setting(s). A simple (low-cost, cheap) thermostat merely switches the heater or air conditioner either on or off, and temporary overshoot and undershoot of the desired average temperature must be expected. A more expensive thermostat varies the amount of heat or cooling provided by the heater or cooler, depending on the difference between the required temperature (the "set-point") and the actual temperature. This minimizes over/undershoots. This method is called Proportional control. Further enhancements using the accumulated error signal (Integral) and the rate at which the error is changing (Derivative) are used to form more complex PID Controllers which is the form usually seen in industry [9].

The default method to detect the temperature is through the use of an iButton, but if the correct iButton is not available or there is a problem in communication, the system uses a thermistor through the MAXQ2000's SPI to get the temperature reading. The iButton (DS1920) is a temperature-sensing 1-Wire device. The system uses an RL1005-5744-103-SA thermistor in conjunction with the MAX1407 ADC.

Once the temperature is read, the display is sent to the LCD, and the PWM duty cycle is adjusted based on the temperature reading. There are two thresholds in the system, the minimum temperature and the maximum temperature. If the temperature is below the minimum temperature threshold, the fan turns off; if it is above the maximum temperature threshold, the fan is set to its maximum speed. If the temperature is between the minimum threshold and the maximum threshold, the speed is proportional to the fractional distance between the two temperature thresholds. The two thresholds are configurable through the two buttons. Each time one threshold is changed, the fan speed is recalculated.
Figure 2.1 shows one of the ways the PWM generated from microcontroller is connected to the output circuit. The output circuit can either use one or two MOSFETs as the driver.

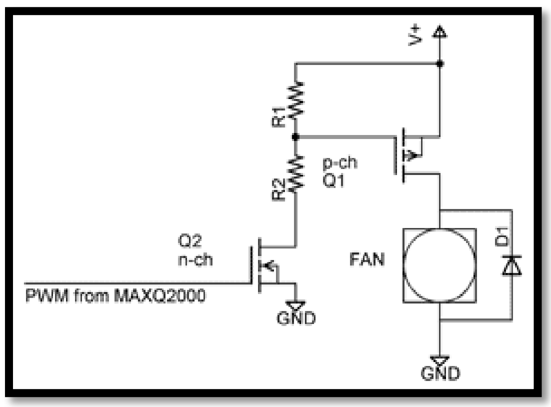

Figure 2.1: Possible hardware set-up for connecting the PWM output to the fan.

An improvement to this system is the inclusion of an IC that provides alert signal that interrupts the microcontroller when the temperature violates specified limits as well as a safety feature in the form of a signal called "overt" (an abbreviated version of "over temperature"). Overt could be used to shut down the system power supplies directly without the microcontroller, and prevents a potentially catastrophic failure [10].

III. METHODOLOGY

3.1 Design Methodology

In the course of the research development, several steps were taken and they are enumerated below:

- Understanding the problem and gathering information.
- Choosing the appropriate method that will be used in solving the problem based on the information gathered. From the information gathered, it was found out that there are three distinct ways of designing the system in view. These include: on/off control, proportional control and proportion with integral and derivative (PID) control. However, based on the nature of the system that is to be designed which involves switching of a heater and a fan, the use of the on/off control for the design was chosen.
- Selection of design tools and sourcing of components.
- Hardware construction and testing.
- Software design and testing.
- Software and hardware integration and final testing.

The chart in figure 3.1 summarizes the design methodology employed.

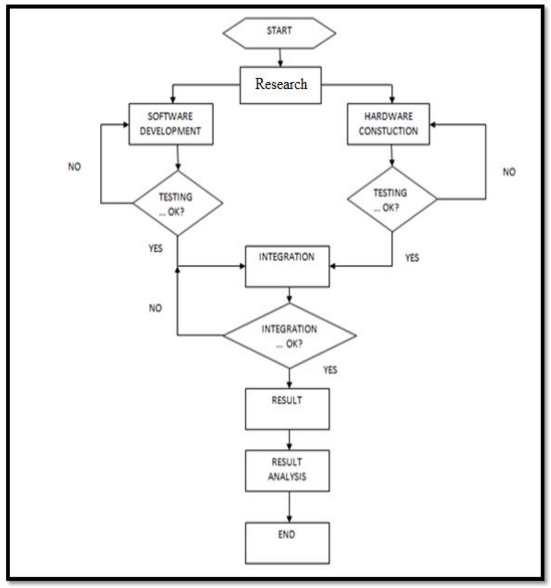

Figure 3.1: Design Methodology Chart

Each design phase of the research should be in the development chart of the work. Thus the purpose of the design phase is to achieve a specific task and certain results.

If the design characteristics are neglected, the incubator will not be a perfect one and as such it may cause damage to the embryo of the egg during the hatching process. Such design characteristics that enhance the performance of an incubator include normal hatching temperature and zero humidity in the incubator. Also the type of the casing material should be considered so that the casing will be the type that will conserve heat and will not melt. It will also be an insulator so that it will not be the type that will electrocute a living organism if an earth-fault exists inside the incubator.

3.2 Block Diagram of the Proposed System

The block diagram of the proposed system consists of the Power supply, Sensing unit, Signal conditioning unit, Signal converting unit, Controller unit, Relay or Actuating unit, and Heating unit. These units are represented in the block diagram, shown in figure 3.2.

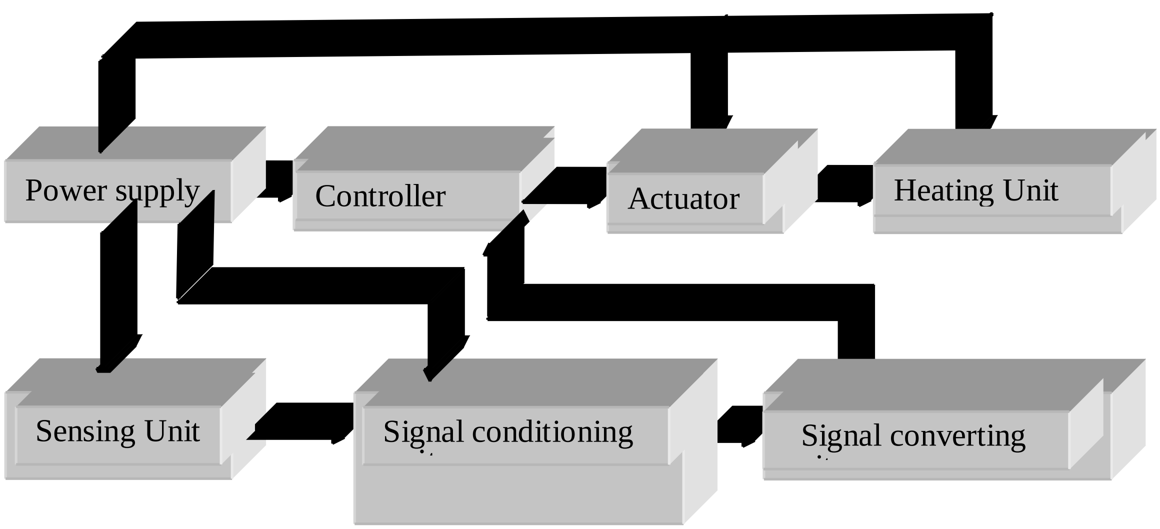

Figure 3.2: Block Diagram of the System

3.2.1 Power supply Unit

This consists of a 220/12V step down transformer in which the primary turns are connected to an ac supply, while the secondary turns are connected to a bridge rectifier whose function is to convert an alternating current (AC) input to a direct current (DC) output. A 1000µF capacitor is connected to the bridge rectifier to filter the D.C. signal that is produced. The positive terminal of the bridge rectifier with that of the capacitor is connected to the V_{in} of both the 7805 regulator which produces 5V and 7812 regulator which produces 12V. The negative terminal of the bridge rectifier is connected together with the ground of the capacitor and the regulators. The 5V signal is supplied to the sensor, microcontroller and the comparator; while the 12V signal is supplied to the relay.

3.2.2 Sensing unit

The sensing unit comprises of the temperature sensor called LM35. Its output is proportional to the temperature (in ^{o}C). The sensor circuitry is sealed and therefore it is not subjected to oxidation and other processes. With this sensor, temperature can be sensed and noted more accurately than with a thermistor. It also possess low self heating and does not cause more than 0.1 ^{o}C temperature rise in still air. The LM35 does not require any external calibration or trimming and maintains an accuracy of +/-0.4 ^{o}C at room temperature and +/- 0.8 ^{o}C over a range of 0 ^{o}C to +100 ^{o}C [11].

3.2.3 Signal conditioning unit

The main device here is a comparator which is an operational amplifier in an integrated circuit form. The type used is LM324. It has 4 (a quad) independent amplifiers in one IC. It has two input pins: the inverting and the non-inverting inputs, one output pin and other useful pins.

3.2.4 Signal Converting Unit

This unit comprises of 7404, which is an inverter or buffer. It is a single-input and single-output device, which produces the state opposite of the input. If the input is high, the output is low and vice versa.

3.2.5 Controller unit

The Controller unit is the main brain of the system because all the process flows are controlled by this hardware according to how it is programmed. It consists of one device called the microcontroller. The work of the microcontroller is to monitor and control the temperature of the incubator by constantly putting it ON and OFF, thereby maintaining a constant temperature. The microcontroller used is Atmel 89C52 which has 8 special pins and 32 programmable input and output pins.

3.2.6 Actuating Unit

This unit houses a 12V relay. The operation of the relay is controlled by the microcontroller. The relay is used for switching the incandescent lamp to 230 V supply. It is triggered using BC337 NPN transistor and the microcontroller. A diode is connected across the relay to avert damages on the transistor due to back EMF.

3.2.7 The Heating Unit

Since temperature regulation is the reason for the system design, cooling and heating sources are needed. The driver for the fan and the heater is a BC337 transistor. The choice for this transistor is stated below:

- The BC337 is a voltage controlled device.
- It is compatible with the microcontroller because microcontroller can directly drive the BC337.
- It is less temperature dependant and harder to false trigger due to the threshold voltage required to turn it on.
- It is better to use in high frequency operations to minimize switching losses.

IV. SYSTEM DESIGN

4.1 System description

The design of the system is based on the developed block diagram. Each block unit is designed in form of module. When all the modules are interconnected, they form the smart incubator system. Modular design is done using required electronic components or devices as the case may be. A system is constructed with certain components and every component has its own function. When integrated, the components form the modules, which in turn form the entire system.

Since the system requires the use of microcontroller, the design consists of two parts: hardware and software. Hardware is constructed and integrated module by module for easy troubleshooting and testing. The software on the other hand is object oriented in nature. It is worthy to note that the system is programmable and smart (intelligent) in nature because of the use of the stored control program for its operation.
Being a programmable hardware, the system must have an input, a controller and an output. In this case, the input is a temperature sensor (LM35), the controller is AT89C52 microcontroller and the output is fan and heater (bulb) driven by a power transistor and isolated from the main circuit by a relay.
The sensor will basically be the input that will trigger the microcontroller to control the fan and heater as determined by the embedded program in the microcontroller.

4.2 System Architecture

The system architecture of an intelligent incubator can be divided into modules which when integrated gives the whole system. The modules are:

i) The power module

ii) Sensory Module

iii) Controller Module
iv) Comparative and Conditioning Module
v) Actuator Module
vi) Heater Module

4.2.1 The power module

The power module supplies power to the whole circuit, it supplies both the 12V which drives the relays and the 5V needed by the sensor, microcontroller and other components. This module is made up of a transformer, a bridge rectifier, an electrolytic capacitor, and two regulators.

1) **Transformer**: The type of transformer used is a simple step-down transformer with primary voltage of 220V/50Hz, a secondary voltage of 12V and a current of 1000mA (which is greater than the current requirement of the circuit).

The primary and the secondary windings are related by the equation:

$$\frac{Vp}{Vs} = \frac{Is}{Ip} = \frac{Np}{Ns} \text{ ……………... 4.1}$$

Where Vp, Ip and Np are the primary voltage, primary current and number of turns of the primary coil; while Vs, Is and Ns are the secondary voltage, secondary current and number of turns in the secondary coil.

Since the maximum required voltage is 12V and the mains voltage supply is 220V, we have:

$$\frac{220}{12} = \frac{Np}{Ns} = \frac{55}{3} \text{ ……………... 4.2}$$

Hence the ratio of the primary to the secondary coil of the transformer used is 55:3.

2) **The bridge rectifier**: A full wave bridge rectifier is used with a step-down transformer to convert the AC voltage coming into the circuit to a DC voltage. There are basically four diodes used. D1 and D2 are forward biased and conduct current when the input cycle is positive. The positive half of the input cycle is made from the voltage across the load resistance, D3 and D4 are reversed biased. Throughout the negative input cycle, D3 and D4 are forward biased and conduct current. A voltage is again made across the load resistance in the same direction as during the positive half-cycle. Thus this analysis is represented in figure 4.1.

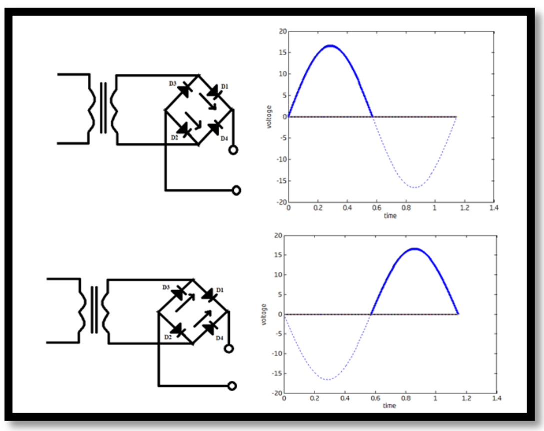

Figure 4.1: Positive and negative cycles of a full-wave bridge rectifier

3) **The filter**: A capacitor is positioned in parallel with the output of the bridge rectifier to minimize the ripples in the rectified voltage, which will create a clean DC voltage. The filter capacitor filters the output voltage as shown in figure 4.2.

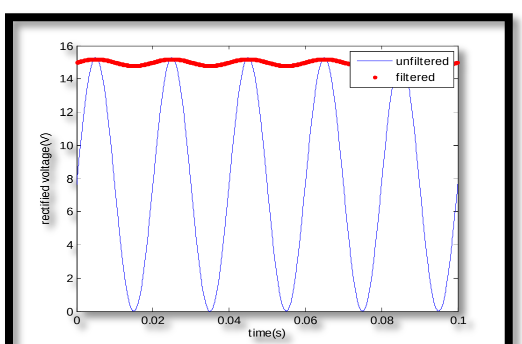

Figure 4.2: Filtered output wave form

The formula below is used to calculate the capacitance value for the filtering capacitor:

$C = \frac{I}{2V_{pp}\ F}$ ………………………….. 4.3

Where:

V_{pp} is the peak-to-peak ripple voltage

I is the current in the circuit

F is the frequency of the ac power

C is the capacitance.

From the transformer used,

$V_{pp} = \sqrt{2} \times 11.5 = 16.26V$;

I = 0.5A; F = 50Hz.

Hence, $C = \frac{0.5}{2 \times 16.26 \times 50} = 307.44\mu F$

The minimum capacitance that the calculations give when using the formula is not used. In practice a larger value is used so that the capacitor can charge more. In this project, 1000µF was used.

4) **Regulators:** The voltage regulator ICs called 7805 and 7812 were used to produce the 5V and 12V DC voltages needed for the microcontroller and the relay circuit respectively. The output from the filter circuit is 12V when tested, and after regulation we have 5V and 12V. The final circuit for the power module is shown in figure 4.3.

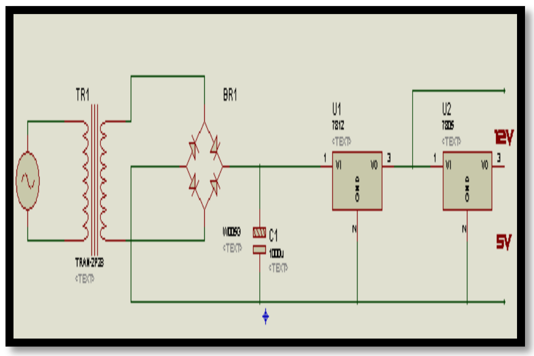

Figure 4.3: The circuit diagram of the power module

4.2.2 The Sensory module

This module serves as input to the microcontroller. It senses temperature from the controlled environment (incubator), and consists mainly of temperature sensor (LM35DZ) with few components.

LM35DZ: This is the sensor that notes the temperature of the incubator. The LM35DZ is a semi-conductor temperature sensor. It comes in a TO92-100 IC package. It has three terminals: Vs connected to a voltage source (4 to 30V), GND connected to ground and Vout which is connected to the comparator. When temperature rises, the voltage at Vout increases with respect to GND by a factor of $10mV/^{0}C$ called the scale factor. Hence the temperature at any given time can be calculated thus

Temp in $^{0}C = Vout \times (100℃/V)$ ….. 4.4

Figure 4.4 (a) shows how the LM35DZ can be connected to read temperature values from 0℃ to 150℃. For the full scale deflection (-55℃ to 150℃), figure 4.4(b) is used.

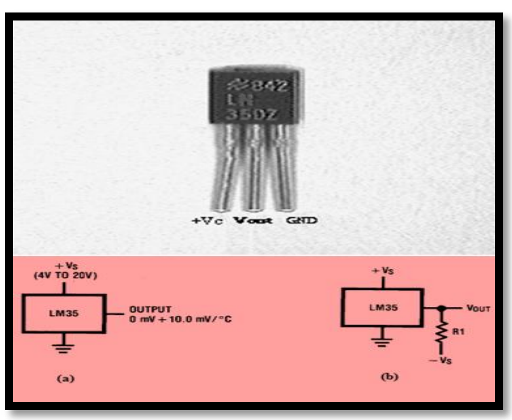

Figure 4.4: Sample of LM35DZ

The value of R1 is calculated as below.

$R1 = \frac{-Vs}{50\mu A}$ …………………….. 4.5

$Vout = +1500mV \text{ at } 150℃$

$Vout = +250mV \text{ at } 25℃$

$Vout = -550mV \text{ at } -55℃$

The choice of LM35DZ temperature sensor is because of the following:

- It is readily available in the market.
- It can measure temperature more accurately than using a thermistor.
- The circuitry is sealed and not subject to oxidation.
- The LM35DZ generates a higher output voltage and thus does not require an amplifier.
- The self heating effect is quite low at about 0.08℃ in still air.

4.2.3 The Comparative and Conditioning Module: This module comprises of comparator and a buffer. The comparator's work is to compare if the voltage at the non-inverting terminal is greater than the voltage at the inverting terminal. If that is so, then the output will be high; and when the voltage on the inverting terminal is greater than the one at the non-inverting terminal, the output will be low. It consists of 14 pins having pin 4 as the Vcc and pin 11 as the ground. Figure 4.5 shows how a comparator is connected.

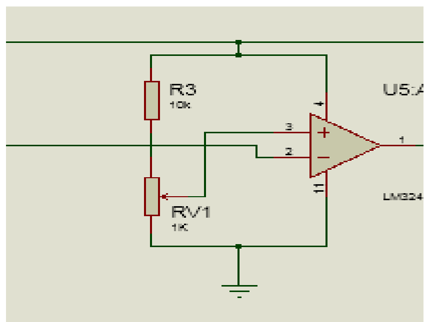

Figure 4.5: Connection of LM 324

Calculations:

To get the value of temperature at which the microcontroller triggers the heater ON or OFF, we use this constant rating for LM35 which states that:

10mV = 1^{o}C rise or fall in temp ……4.6

Since the temperature of a typical incubator system is 32.9^{o}C, then set the circuit so that it switches off the heater at 32.9^{o}C. From equation 4.6, it will be:

32.9 X 10mV = 329mV

So the supply voltage entering into pin3 of the Voltage Comparator (LM324) is varied through the variable resistor (10K) to 329mV.

Then the principle guiding the output of our LM324 is:

If $V_1 < V_2$, then $V_o = 1$ (high)

But if $V_1 > V_2$, then $V_o = 0$ (low)

Where Vo is the Output Voltage from LM324 to the microcontroller.

V_1 is the voltage from LM35 to the inverting input (Pin 2) of LM324.

V_2 is the voltage from the variable resistor to the non-inverting input (Pin 3) of LM324.

With this calculation, one can vary the temperature at which the microcontroller switches the heater ON/OFF.

The signal leaving the op-amp is not perfectly at low or high. The buffer sends a distinct high or low to the microcontroller thereby avoiding error due to analog signals in the LM324 op-amp. The 7404 has 14 pins. Pin 14 is the V_{cc} and pin 7 is the ground while pin 1 and pin 2 are the input and output of the NOT gate respectively. Figure 4.6 shows the diagrammatic symbol of a buffer or an inverter.

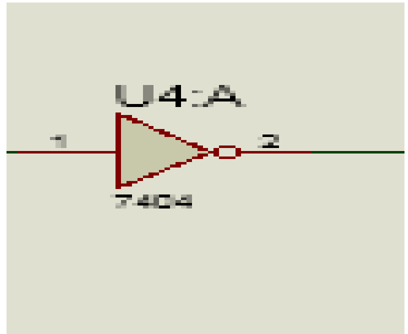

Figure 4.6: Diagrammatic Symbol of a Buffer or an Inverter

4.2.4 Microcontroller module

The AT89C52 microcontroller is chosen as the controller for the project since it offers various functions that are needed for the system to be developed. Also it is the most available microcontroller in the Nigerian market. The AT89C52 microcontroller has a power circuit, reset circuit, and clock circuit.

I. Power circuit: The power circuit provides power for the microcontroller. The AT89C52 uses a voltage of 5V DC and this is supplied by the power module. The power circuit of the microcontroller simply involves connecting pin-40 of the controller to 5V supply and pin-20 to ground.

II. The reset circuit: This circuit resets the device when a high is on the reset pin (pin-9) for two machine cycles.

III. Clock circuit: This provides timing for the microcontroller. The AT89C52 can generate its own internal clock signal. In order to generate clock for the microcontroller, the output of the clock circuit must be connected to XTAL2 (pin-18) and XTAL1 (pin-19). An oscillator and two capacitors are required for the connection. If a crystal oscillator is used, then the capacitors required will be 30pF±10 and if a resonator is used, the capacitors will be 40pF ±10.

Figure 4.7 shows the microcontroller module and some of its basic connections.

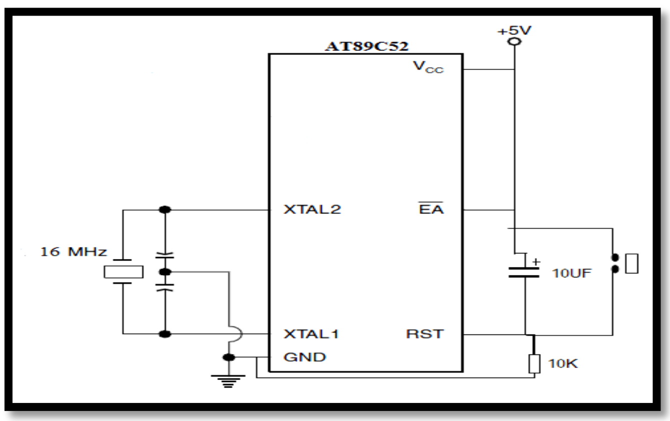

Figure 4.7: The microcontroller module

4.2.5 The Actuator Module

The actuator module comprises of a transistor (BC 337), a relay (12V /400Ω coil), a diode (1N4148) and a resistor. The transistor is controlled by the microcontroller in such a manner that when a high is applied to the base, a voltage drop of 5V develops across R1 which will cause a minimum current of 1mA, which will produce a current of 100mA at the collector circuit; since BC337 has a gain of 100 enough to drive the relay which requires a minimum of $30mA$ (ie. $\frac{12V}{400\Omega}$) to flow through the base when a high is on that pin.

$$R1 = \frac{Vc}{i} = \frac{5}{1mA} = 5000\Omega$$

Current flowing through the relay creates a magnetic field which collapses suddenly when switched off, thus inducing a high voltage across the transistor which may damage its IC. To prevent this, the diode D1 is connected across the coil in such a manner that the high voltage will drive a brief current through the coil and the diode itself so that the magnetic field dies away slowly rather than instantly. And this prevents high voltage from developing across D1 when the relay switches off. Figure 4.8 shows the actuator circuit.

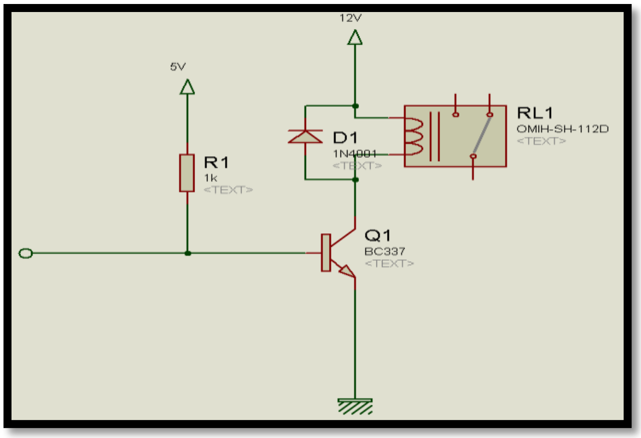

Figure 4.8: The Actuator Circuit

4.2.6 Heater Module

Due to the fact that the paper is a prototype, the heater that was used is an electric bulb of 60Watts. From the test carried out, this bulb delivers the needed 32.9^{o}C, while the microcontroller maintains this temperature value as long as the system is on.

The complete circuit diagram is shown in figure 4.9.

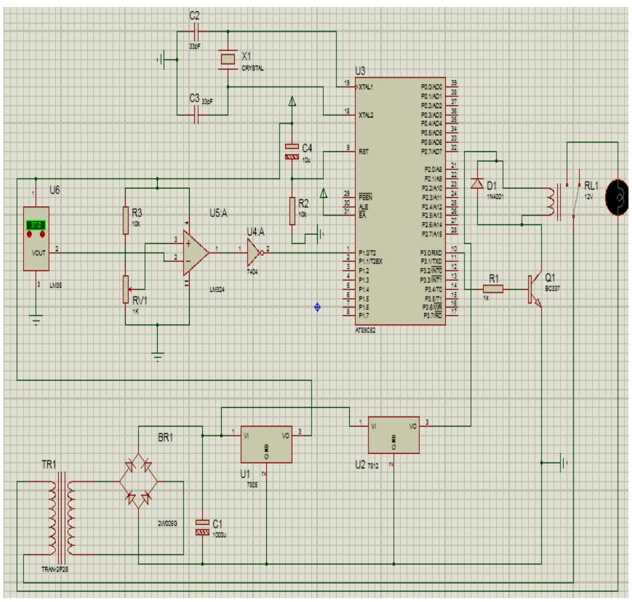

Figure 4.9: Complete Circuit Diagram of the System

4.3 Software Design

Without the control program that is "burnt" into the microcontroller, the hardware design is as good as useless. In the development of a software program for the system, the following steps were necessary:

- Design conception
- Planning
- Selection of tools
- Coding

Proper planning is required, if not, the software program is seldom successful. The first step in the development is to set out some form of blueprint based on the information gathered on the required system that is to be developed. As a guideline, a flow chart is used to represent the system's functionality. The flowchart of the intelligent incubator is as shown in Figure 4.10.

The flowchart makes coding simpler since it elaborates the interaction between the various functional elements of the system as well as the objects.

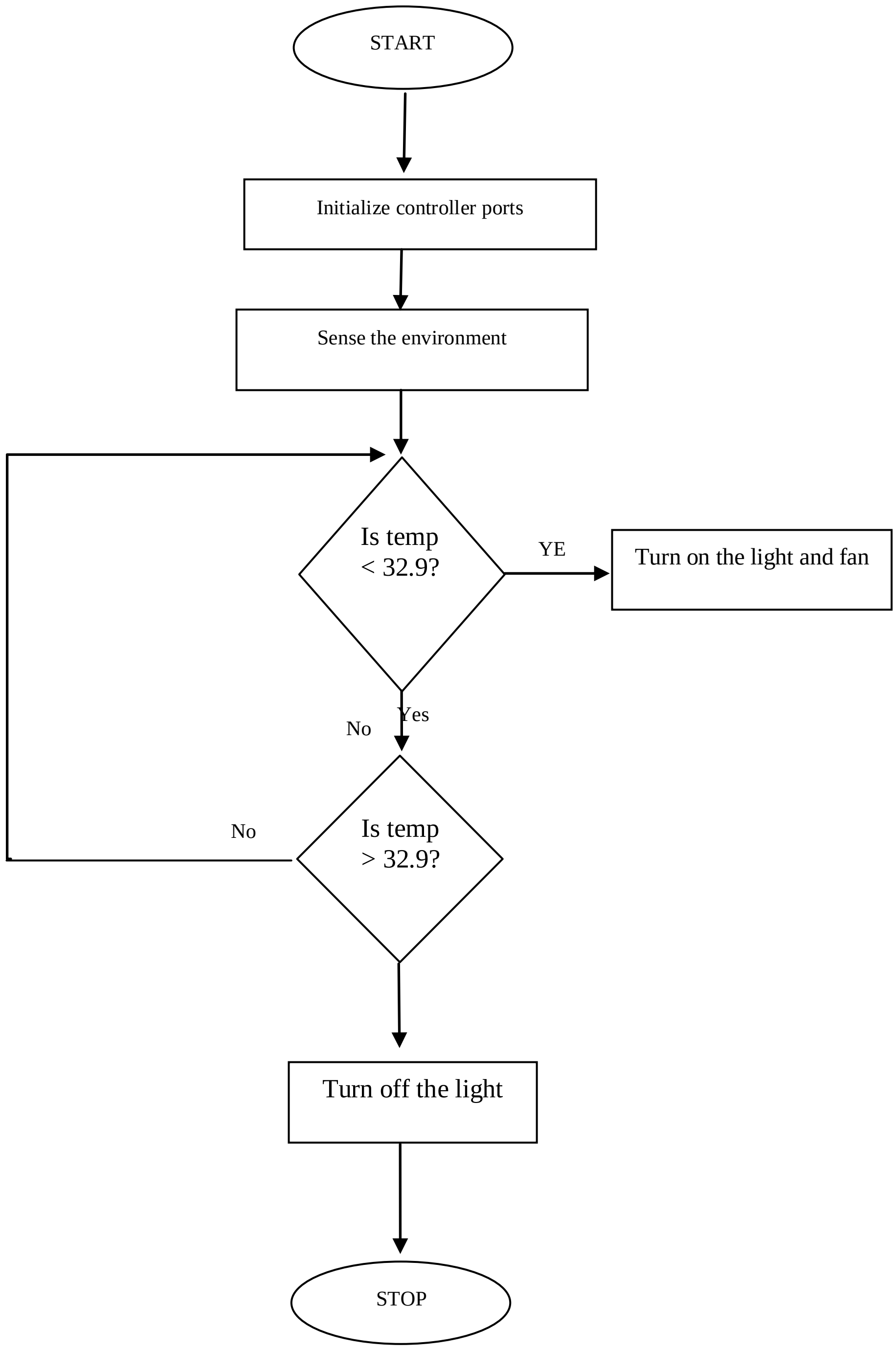

Figure 4.10: The Flowchart of the Intelligent Incubator

The program is as shown:

```
Org 00h
Mov p1, #00000000b
Start: jb p1.0, start
Setb p3.0
Check: jnb p1.0, check
Clr p3.0
Jmp start
End
```

After successful coding, the program is saved with a file name ending with '.asm' extension. Next, it is run by clicking the build command in the MIDE-51 (a software used in writing the program code) toolbar.
If the run program is without errors, the '*.hex*' file generated is used in the real time simulation of the circuit with ISIS schematic capture tool in the Proteus software. It is also this hex file that was burnt into the microcontroller chip using a Wellon universal programmer.

V. ANALYSIS, RESULT AND TESTING

5.1 Operational Analysis

The sensor which is the LM35 keeps sensing the temperature of the incubator and outputs a corresponding voltage signal which is compared by the comparator LM324, having a fixed voltage of the value of the triggering voltage i.e. 3290mV (because 32.9^{o}C is needed). At this point, the system is expected to start heating up and once the output of LM35 reaches 329.1mV, the system is expected to start cooling.
The microcontroller controls the relay which switches on the heating lamp. The fan helps to circulate the heat from the incandescent bulb uniformly. Once the signal going to the microcontroller is low, the output of the controller is set and then the lamp comes on otherwise it is off and the system is cooled. Once the temperature drops below 32.9^{o}C, the system starts heating up again in a continuous loop operation.

So the p1.1 of the microcontroller is connected to the output of the inverter while P3.0 is connected to the base of the transistors controlling the relay. The microcontroller monitors the bit status of p1.1 which is dependent on the temperature condition of the incubator (variation with respect to the reference voltage at the non-inverting input of the comparator). When a low falls on p1.1 (i.e temperature falls below 32.9^{o}C), the microcontroller actuates the relay by setting P3.0 to high. When the temperature exceeds 32.9^{o}C, the reverse occurs, P3.0 is cleared and process continues in a loop.

5.2 Process Result

The work was developed with a view of maintaining a constant temperature at a given area over an extensive period of time. The expected result is that the incubator system will be in one of the three given states at any point in time.

These three states are stated below.
i) Heating state: In this state, the ambient temperature of the controlled region is lower than the preset value of the region. When the microcontroller detects this by comparing the set temperature with the temperature of the controlled environment as captured by the LM35, it sends out a signal that triggers the activation of a heater (on the bulb).
ii) The cooling state: In this state, the ambient temperature of the controlled region is above the preset temperature for the region. When the microcontroller detects this by comparing the set temperature with the temperature of the environment as captured by the LM35, it sends out a signal that triggers the heater (bulb) off.
iii) The dormant state: This is a transition state between the heating state and the cooling state. This state occurs when the microcontroller detects that both the temperature of the controlled region and the preset value are the same. When this event occurs, the microcontroller sends out signals that turn off both the fan and the bulb.

5.3 Testing

Testing is necessary in determining if the circuit meets the desired purpose for which it was designed as well as for optimization. The circuit of this system was tested module by module as it is being integrated. These tests include:

- Each component was checked to see if they are ok before they were used in the circuitry.
- Potentiometer was adjusted to the proper range.
- The power supply was properly checked to see if it falls within the tolerance calculated theoretically so as to avoid damage to the components.
- The components which were not functioning properly were changed as soon as possible to avoid other components being affected by the damaged.
- Testing equipment was in proper range of the output measured at any point of the circuit, or component so as to avoid wrong readings.

5.4 Problems encountered

Apart from the normal circuit faults and components being damaged by wrong connections, the major problem was developing an instruction or code that will implement an " else-if" condition in assembly language; but it was later resolved.

Another problem encountered was how to stabilize the output as it reaches the set temperature. But this problem too was later overcome by adding a delay of a second before an output for the actuators are triggered.

5.5 Precautions Taken

5.5.1 During Soldering of components into Vero board

a) The bit of soldering iron was kept clean with the help of a file from time to time.
b) The solder wires are of smaller thickness.
c) Extra solder was not used because it may cause a short circuit in the conductive path.
d) The components were not overheated during soldering.
e) The leads of the components were cleaned with a sand paper before soldering.
f) The bit of the soldering iron was cleaned properly before soldering.
g) The joint was heated up to the required temperature at which the solder melted before coming around

the joint. The joint was not disturbed before the solder set.

5.5.2 During Using the Power Supply

a) Switches and fuses were used in the circuit.
b) Only insulated wires are used.
c) Power supply is switched off, when it is not required.
d) Any fault in the circuit was repaired before connecting power supply.

VI. CONCLUSION

The work, microcontroller-based design of an intelligent incubator system, was successfully researched, and it shows how the temperature of an enclosure can be controlled using a fan and a heater (bulb). It is a stand-alone device unlike other regulators that are embedded into the system they control.

The temperature sensor which is the LM35 senses the temperature of the incubator and sends out a corresponding voltage signal. This signal is compared by the LM324 comparator which has two inputs: one is inverting input and the other is the non-inverting input. The non-inverting input has a fixed value of voltage set using variable resistor in the circuit. It is 329mV because 32.9^{o}C is needed. The inverting input has the voltage signal corresponding to the temperature of the incubator as sensed by the LM35 temperature sensor.

When the system is switched on, the microcontroller controls the relay which switches on the heating lamp. The fan helps to circulate the heat from the incandescent bulb uniformly until the incubator temperature is 32.9^{o}C. When the incubator temperature is slightly above 32.9^{o}C, the microcontroller sends low to the pin connected to the relay and it is switched off. Once the temperature drops slightly below 32.9^{o}C, the system starts heating up again in a continuous loop operation. By this way, the incubator temperature is maintained at 32.9^{o}C. The temperature of the incubator must be precisely maintained within the limits of 32.9^{o}C for optimum growth of the egg.

Recommendations

After analyzing the results obtained from testing, the following recommendations were noted for future improvement of this work:

i) A good heater and cooler can be used to improve performance in terms of response time and stability of the system.

ii) Employing the power of modern-day network capabilities to remotely control the system will also be considered as an improvement on the work.

iii) The system can also be extended in functionality by adding other related sensors to it so that it can measure as well as regulate other physical properties like pressure and humidity.

iv) Using progressive control instead of on/off control for the fan and the cooler can be used to reduce the settling time of the system.

v) Making the set point to accept temperature ranges instead of a fixed temperature value will make the system more functional and also eliminate unnecessary oscillations when on/off control is used as the temperature reaches the set point.

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