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Microcontroller-Based Generic Remote Process Monitoring System Using Fully Expanded State Transition Table

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Abstract

This work proposes the development of a generic microcontroller–based monitoring system which can be applied to any process control system. It was successfully accomplished using cost reduction techniques. Microcontroller was used to control the example processes by using the technique of ROM based fully expanded table. The process of emulating AT commands using microcontroller was also demonstrated. This approach can be applied to many other monitoring systems. It is adaptable for use in a wide range of applications and yet it is simple and does not need a complicated process of customization. A new application can use the software simply by replacing the state transition table (STT) with that of the new application through a Graphical User Interface (GUI) module. As a result, the developed system can be plugged into many applications that require remote mobile access. It serves as an effective front-end communication interface that provides wireless access to data in real time from anywhere.

1. Introduction

The industrial revolution calls for industrial control systems to be made as user friendly as possible. Industrial process control managers would like to see an integration of user-friendliness and intelligence. These would enable them monitor process progress, material usage, and down-time from any location. The process control industry is therefore moving towards the use of user centric intelligent systems that put managers in firm control of their processes [1]. With real-time monitoring one can determine what is happing in the system with respect to performance issues or problem reports. Real-time monitoring includes statistics that represent the current activity on the system that can help determine usage patterns and resource allocation and identify problem areas [2]. Real-time monitoring is not the same as simulation in the sense that simulation is the imitation of the operation of a real-world process or system over time. The act of simulating something first requires that a model be developed; this model represents the key characteristic or behaviors. The model represents the system itself. Whereas the simulation represents the operation of the system over time [3]. There is urgent need for industrial managers of real-time systems to monitor the state of the process under control without being there especially in this age of mobility. Industries would like to see a real – time or the exact happening in the process control systems without necessarily being on the site. This requires a Graphic User Interface (GUI) that would adequately represent the process under control at the remote site where the real – time event is displayed. This is different from a simulation which mimics the operation of a process while the process may not actually be in progress or in existence [4].

Industries want to see the real- time or ongoing process status graphically at a remote site, in such a manner that the process manager has every information for managerial control without physically being at the work site. This demand by industries has become more urgent in order to match the progress made in other areas by technology [5]. Any nation seeking top ranking industrialization position must have her own indigenous Industrial Process Control experts. Any nation that depends on expatriates for their industries would not be in firm control of their industrialization process. It is therefore not surprising that what Nigeria is seeking for is indigenous process control and automation personal to actualize her industrialization ambition [6].

Furthermore, a process control system can be intelligent or unintelligent. Unintelligent Control System may signal a fault without indicating how the fault might be rectified. Intelligent automation on the other hand, not only indicates a fault condition but also gives detailed rectification steps. This reduces down-time and removes much of the dependence on expatriates. This research is aimed at intelligent real-time monitoring of industrial process control systems using indigenous manpower and readily available devices [7].

Going one step ahead, all the time critical operations are now monitored remotely unlike the old method of placing a person at the site to monitor regularly the condition of the system. So, remote monitoring is nothing but the ability to monitor a process from a remote location and also to control the process along with monitoring from a remote location [8]. A central database at the remote location can be used to log the process details and to store the appropriate commands for controlling the process based on the condition received. This can be achieved by human machine interface or man machine interface, which is a series of interactive commands, bundled up into a GUI package which can be understood by the machine [9].

The communication between the local unit and the remote location unit can be achieved through different communication mechanisms like cable, modem and wireless based on the location and the cost factor involved. Remote device control is one technology that has evolved over the years and has brought about more convenient ways of controlling equipment, machines, and devices. It could be applied to electronic, electrical, or mechanical devices. Remote device control involves making changes or setting a device in place to make the subject equipment behave in a desired manner without having to be at the local station where the device resides.

2.0 Methodology

In this work, algorithmic state machine (ASM) method was used. An ASM chart is a method of describing the sequential operations of a digital system [10]. This method was chosen for this research due to its numerous advantages over others. Such advantages include its simplicity, and the fact that a simple control software can be developed which can be used without any modification in any control system, no matter how complex or how simple, and even when the numbers of input qualifier, state code, size and number of output lines differ from one control system to the another, provided one input port is sufficient for address inputs and one output port for the control pattern output.

2.1 Design approach

The research work, microcontroller-based generic remote process monitoring system is a suprasystem which is further broken down into component systems as illustrated in Figure 1.

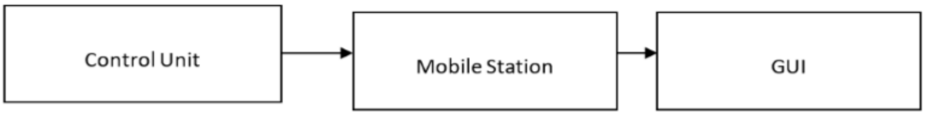


Figure 1: Supra- System Component

2.1.1 Control Unit: This is made up of microcontroller-based control module that receives its instruction from the different input unit, examines the signals and processes the information after which it sends an SMS from a cellular phone that is attached to it, to another remote phone that passes the short message to the GUI for physical display.

2.1.2 Mobile Station: The first mobile station is based on a specific area where our control system is located. The phone receives SMS message which it stores in the SIM memory of the phone. The microcontroller extracts it and processes accordingly to carry out specific operation. While the second mobile station is used to receive SMS messages for the GUI unit.

2.1.3 GUI Unit: This section displays the information received by the cellular phone graphically for clear understanding to the user.

The block diagram of the proposed system is shown in Figure 2. The data acquisition system monitors the plant under control and sends the output pattern as an input to the microcontroller. The microcontroller analyses the data and send the information in form of SMS to the modem attached to it which then forward the same message to another modem that display the information to the GUI remotely. The microcontroller can as well actuate the output port that will affect the control of the plant under control. The analysis and electronic control of the system can be achieved using the intelligent agent embedded into the control software in the microcontroller.

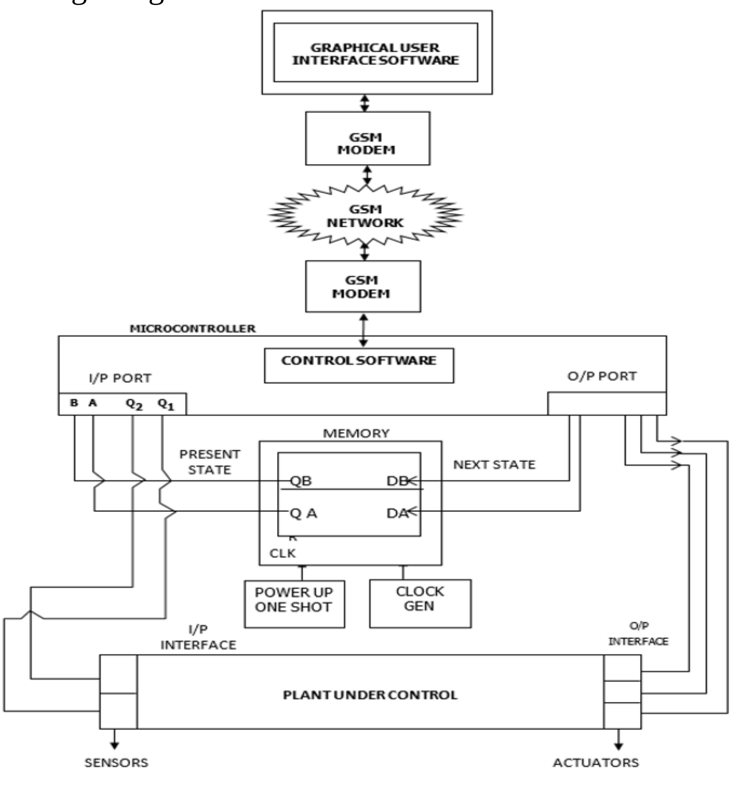


Figure 2: Block Diagram of the Developed System

3.0. System Design

3.1. Process Control

A process control approach is used for the design and implementation of the proposed system for temperature control process. The process control is Microcontroller Based and has its own set of input and output interfaces. Microcontroller was used to control the process by using the technique of fully expanded state transition tables which were made to be ROM based.

3.2 The System Algorithm

In this work, a given environment is being monitored to see that temperature is within a certain range. For example, if the temperature is low a heater is turned ON to heat up the environment to a desired level, but if the temperature is high a cooler is then turned ON to cool the environment. In a situation where it happens that the temperature is outside the range an error signal in form of alarm will occur and a reset button will now be reset to bring it to the normal range.

3.3 The ASM Chart

Figure 3, shows the ASM chart of the temperature process control system. The ASM chart comprises of two symbols the rectangular boxes or state and the decision boxes or qualifiers. The labels or names inside the rectangular boxes are the state outputs, while the labels inside the decision boxes are regarded as the input qualifiers. For this example, the ASM chart has two outputs HHEATER (when the temperature is high) and HERROR. The logic level of the output signal is high or active when the control system is in that state. The bit pattern at the top right end of the state box is its state code. The letter B, A of the ASM chart signify the two flip flops B and A that are used to represent the various states of the machine. The state code is the logical levels at the Q outputs of these two flip flops respectively. Each rectangular box in the ASM charts is a state box. The word ST0 enclosed in a circle at the bottom left-hand corner of a state box is the state name. Here ST0 stands for state 0, and similar interpretations apply to the other states. Hence ST1 means state 1 and so on. Each decision box has one entry path and two exit paths. The exact value of an input qualifier determines which exit path is followed out of a decision box. In the ASM chart of Figure 3, Lth, Uth and RST are the input qualifiers. With the help of a K-map of Table 1 in which the state names are inserted serially in an adjacent cell and which is called a state map, the state codes are chosen such that only one-bit changes level as one moves from one state of the control system to another. This is clearly brought out in the state assignment table of Table 2.

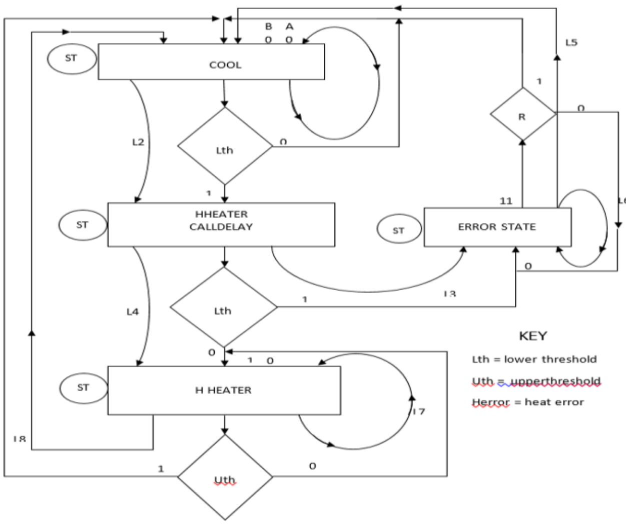
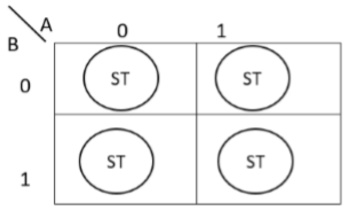


Figure 3: ASM Chart for Temperature Control System

Table 1: State Assignment

State Name	State Code
ST0	00
ST1	01
ST2	11
ST3	10

Table 2: State Map



3.4 State Transition Table (STT) For Temperature Control

System the ASM chart of the temperature control system has an equivalent tabular representation known as a state transition table (STT) shown in Table 3. An ASM chart can be fully described in terms of the link paths comprising it. A state machine transits from the present state to the next when a clock pulse occurs. A link path is a path that follows from the present state to itself or to another state when the clock pulse arrives. When there is an input qualifier between the present state and another, the logic level of the qualifier determines the next state the machine goes to at the clock pulse. If there is no qualifier between the present state and the next, the machine must conditionally transit from its present state to the adjacent state in forward direction when a clock pulse arrives. The ASM chart of Figure 4 has eight link paths labeled L1 to L8. L1 is the link path from state 0 back to itself when the input qualifier is 0. Also, L2 is the link path from state 0 to state 1 when the input qualifier is 1. Similarly, L3 represents the transition from state one (ST1) to state two when the qualifier Lth is 0. L4 is the transition from state two back to itself when the input qualifier Uth is 0 and L5 is the transition from state one to state three which is the error state where the system stays until a button is pressed to return it to state 0 through link path L7. In the STT of Table 3 a number of dashes appear under the column heading input qualifiers (Lth, Uth, and RST). The dash (-) implies that the input qualifiers are not relevant to the transition that is being made by the link path. An Input qualifier that is relevant to the link path will either be 0 or1, rather than dash. A dash in the STT also means that the input qualifiers that appear in column heading may be at logic 0 without affecting the control process.

Table 3: State Transition Table of Temperature Process Control System

Link path	Input qualifiers Lth uth rst	Present state name	Resent state code	Next state name	Next state code	Output Hhtr herror
L1	0 - -	ST0	0 0	ST0	0 0	0 0
L2	1 - -	ST0	0 0	ST1	0 1	0 0
L3	1 - -	ST1	0 1	ST2	1 1	1 0
L4	0 - -	ST1	0 1	ST3	1 0	1 0
L5	- - 1	ST2	1 1	ST0	0 0	0 1
L6	- - 0	ST2	1 1	ST2	1 1	0 1
L7	- 0 -	ST3	1 0	ST3	1 0	1 0
L8	- 1 -	ST3	1 0	ST0	0 0	1 0

3.5 The Fully Expanded Table of the State Transition Table

Table 4, is the fully expanded table of the state transition table of the temperature control system. An STT is said to be fully expanded when all the dashes on each row are given all the possible combination of logic values, leading to new rows in the state transition table, one for each combination of the values for the dashes on that row. In this respect, an STT data row with one dash becomes two rows, one row when that (dashed) qualifier is given the logic value 0 and the other when the qualifier is given logic level 1. Similarly, an STT data row with two dashes expands into four STT rows. Assume the dashed qualifiers are represented by q1, q2. Then the first STT row in the expansion will be q1q2=0, 0, the second value is q1, q2= 0, 1, the third row q1, q2=1, 0, and the fourth row q1 q2 1, 1. As shown in Table 3, two dashes on STT data row would in like manner lead to four rows in fully expanded STT.

Table 4: Fully Expanded STT Table for Temperature Control System

LINK PATH	PRESENT STATE CODE	INPUT QULIFIER LTH UTH RST	NEXT STATE CODE	STATE O/P HHT HER0R	LOCATION ADDRESS (HEX)	LOCATION CONTENT (HEX)
L1	0 0 0 0 0 0 0 0	0 0 0 0 1 0 0 0 1 0 1 1		0 0 0 0 0 0 0	0 0 0 2 0 1 0 3	0 0 0 0 0 0 0 0
L2	0 0 0 0 0 0 0 0	1 0 0 1 1 0 1 0 1 1 1 1	0 1 0 1 0 1 0 1	0 0 0 0 0 0 0 0	0 4 0 6 0 5 0 7	0 4 0 4 0 4 0 4
L3	0 1 0 1 0 1 0 1	1 0 0 1 1 0 1 0 1 1 1 1	1 1 1 1 1 1 1 1	1 0 1 0 1 0 1 0	0 C 0 E 0 D 0 F	0 E 0 E 0 E 0 E
L4	0 1 0 1 0 1 0 1	0 0 0 0 1 0 0 0 1 0 1 1	1 0 1 0 1 0 1 0	1 0 1 0 1 0 1 0	0 8 0 A 0 9 0 B	0 A 0 A 0 A 0 A
L5	1 1 1 1 1 1 1 1	0 0 1 1 0 1 0 1 1 1 1 1	0 0 0 0 0 0 0 0	0 1 0 1 0 1 0 1	1 9 1 D 1 B 1 F	0 1 0 1 0 1 0 1
L6	1 1 1 1 1 1 1 1	0 0 0 1 0 0 0 1 0 1 1 0	1 1 1 1 1 1 1 1	0 1 0 1 0 1 0 1	1 8 1 C 1 A 1 E	0 D 0 D 0 D 0 D
L7	1 0 1 0 1 0 1 0	0 0 0 1 0 0 0 0 1 1 0 1	1 0 1 0 1 0 1 0	1 0 1 0 1 0 1 0	1 0 1 4 1 1 1 5	0 A 0 A 0 A 0 A
L8	1 0 1 0 1 0 1 0	0 1 0 1 1 0 0 1 1 1 1 1	0 0 0 0 0 0 0 0	1 0 1 0 1 0 1 0	1 2 1 6 1 3 1 7	0 2 0 2 0 2 0 2

3.6 The Input Interface Design

The input interface of the temperature control system comprises of the sensor, which senses the temperature of the environment and sends the condition as input to the input port of the microcontroller as shown in Figure 4.

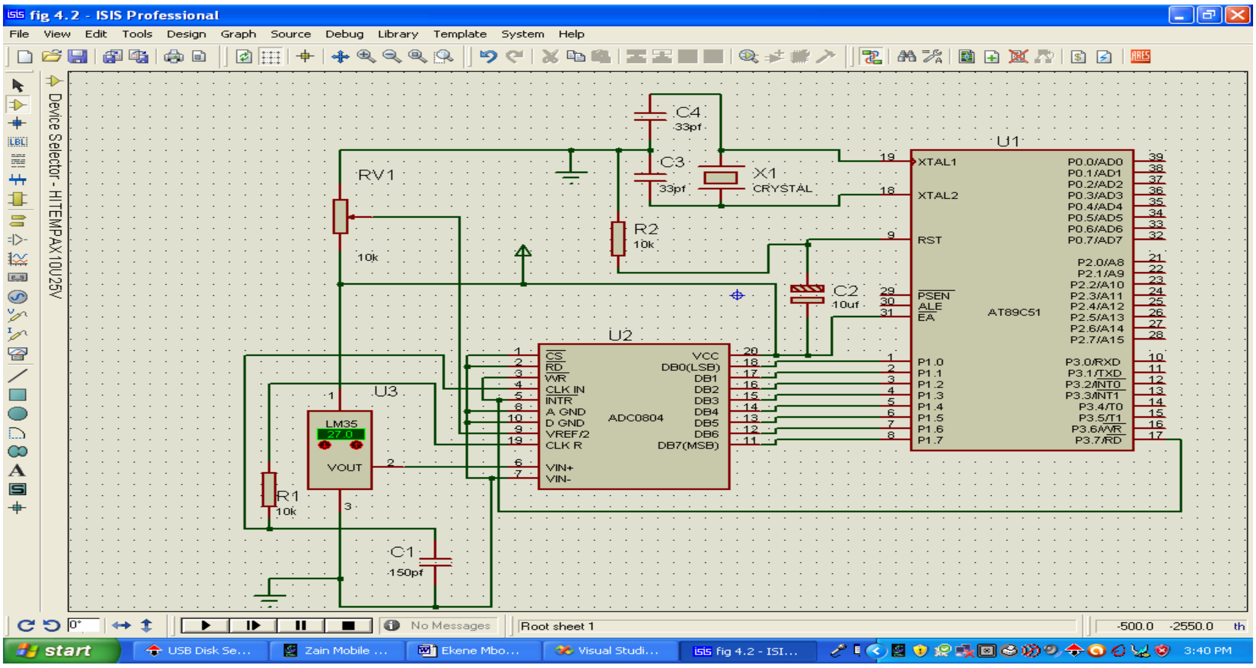


Figure 4: Interfacing the temperature sensor Lm35 to the microcontroller AT89C51

3.7 The Output Interface

In this work the output devices are the transducers such as light emitting diodes (LEDs). This displays the information required for this operation visually. Another one is the liquid crystal display (LCD) that controls the reflection of the available light which can be ambient light such as sunlight or normal room lighting. LCD can display in the form of graphics or alphanumeric characters. One of the advantages of LCD is its low power consumption because it operates from low frequency (25 to 60Hz) ac signal and draws very little current. Alarm is another output device used.

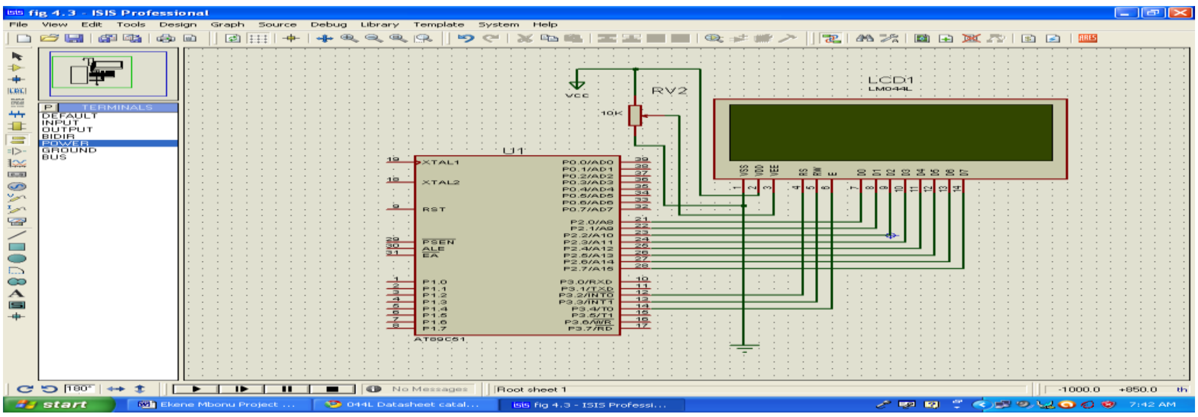


Figure 5: Interface of the Liquid Crystal Display (LCD) to the Controller

AT Command

Since SMS software uses AT command features at microcontroller end (sending end) and at remote end (receiving end), it is important to discuss AT command in some detail. This system uses AT command to establish communication with the modem. Most of the AT commands that were used in this research work are; AT+CGMS- Sending SMS Messages AT+CMGD – to clear the SMS receiving memory location in the GSM modem or message storage. AT+CPMS- preferred message storage AT+CMGS –Tells modem to operate in test mode. To find out whether a GSM/GPRS modem or mobile phone support the sending of SMS message through AT commands, one has to; 1. Use the AT command +CSMS (command name in text: select Message Service) to check whether mobile-originated SMS message are supported. 2. Perform test operations to check whether +CMGS (command name in text: SEND Message Indications to TE), + CMGL (command name in text: list Message) and/ or +CMSS (command name in text: send Message from Storage) are supported. (You may want to check the AT command + CMGW [command name in text: write Message to memory] and +CMGD [command name in text: Delete message] in addition as they are sometimes used together with +CMSS). 3.8 Graphic User Interface (GUI) The SMS message from the microcontroller reaches the remote site via the communication interface. The remote GSM modem attached to the remote PC receives the transmissions of the microcontroller and makes its data available to the GUI software. The data sent by the microcontroller have two parts, namely the address part (made up of the state code and qualifiers) and the output part (made up of the next state code and the state outputs). The GUI software unpacks the received pattern and depending on the display setting set by the user, displays information either for the process manager, or for maintenance personnel or for the engineer. Suppose the user specified that the information should be displayed for the process manager who merely wants to know whether the system is working normally or having any kind of trouble. Colors are used to convey this status information for the process manager. For temperature control system, the display presented to the process manager is shown in Table 5.

Table 5 for temperature control system has the State Name that enable the manager to know which state the system is, the colors and description gives the happening at the system.

Table 5: Data for temperature Control System Manager

State Name	Colors	Description
ST0	Green	The system key
ST1	Amber	The system is doing some testing
ST2	Red	The system is at error state
ST3	Green	Normal state

If on the other hand the display setting recommends that the maintenance personnel should receive feedback information. From Table 6, one will find out that the system is at error state. The result will enable the maintenance man know what actually is the problem and what to do. Table 6, shows the maintenance site for the temperature control system.

Table 6: Data for the Temperature Control System Maintenance

Feedbacks	Fault Rectification
0010001	Error state, Reset the system and press the button

Note that each table tells the maintenance man what is happening and what is expected of him if any, depending on the state of the process being monitored. The project engineer needs more detailed information to facilitate digital logic troubleshooting. The display given to the engineer when the user selects that display setting is shown in table 6. Table 7 for temperature control system will enable the engineer to compare the input, expected output and the actual output to see if they are the same, or if there is any mismatch the engineer will use the result to do what is called logic debugging. This is done for every feedback pattern.

Table 7: Temperature data for Control Engineer

Feedback	B	A	HHEATER	HERROR	
0010001	0	0	0	1	Expected output
	0	0	1	0	Actual output

4.0 Results and Discussion

After the correction of the errors encountered during the sub-system testing, the overall test was carried out and the required result was achieved with the hardware and software parts working together harmoniously. When compared with the works of [9] and [10], the developed system was found to perform optimally providing ease of use, reliable results and consistent output result through the GUI. Figure 10, shows the graphically representation of the monitoring system with the temperature range of 33<=T<35 degree centigrade. Before the control system is switch ON the incubator was at room temperature of 25^{o}C. The control system is now turned ON and the incubator temperature raises steadily as the heater is turned on by control system. When the temperature of the plant gets to 35^{o}C (upper threshold) the incubator heater is turned OF the incubator temperature slightly overshot the upper threshold and then begin to come down. When it falls down to 33^{o}C (lower threshold) the incubator heater is turned ON once again. The temperature of the incubator begins to raise again after a slight undershot. As shown in Figure 7, the control system keeps the temperature of incubator in the range between 33^{o}C and 35^{o}C except for the slight overshot at 35^{o}C and undershot at 33^{o}C. When the control system is turned OFF, the incubator temperature falls steadily down to room temperature of 25^{o}C.

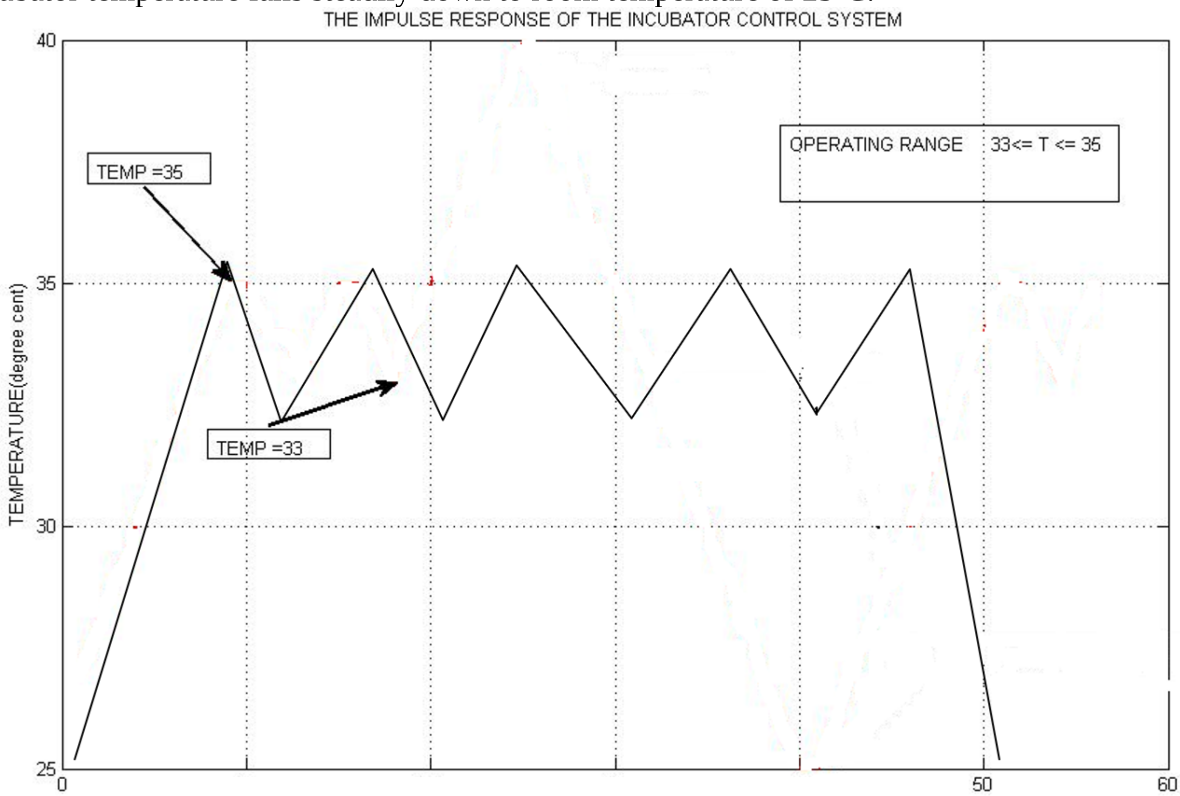


Figure. 6: The Impulse Response of the Incubator Control System

5.0 Conclusion

This paper has presented a microcontroller –based monitoring system that is generic in nature that can be applied to any process control system. It was successfully accomplished using cost reduction techniques. Microcontroller was used to control the example processes by using the technique of fully expanded table which were made to be ROM based. The process of emulating AT commands using microcontroller was also demonstrated. This approach can be applied to many other monitoring systems.

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