European Journal of Engineering and Technology
Vol. 3 No. 6, 2015
ISSN 2056-5860

AN IMPROVED TEMPERATURE CONTROL SYSTEM FOR NEONATAL INCUBATOR

Okpagu P. E[1], Mbachu C. B[1], Nwosu A. W[2]
Department of Electrical and Electronic Engineering
Chukwuemeka Odumegwu Ojukwu University, Uli
Anambra State, **NIGERIA**

ABSTRACT

This work is aimed at modeling an improved system to regulate the temperature inside a neonatal incubator. A neonatal incubator is a device consisting of a rigid box-like enclosure in which an infant may be kept in a controlled environment for medical care. An infant incubator provides stable levels of temperature, relative humidity and oxygen concentration. Temperature control is the most important part of a baby incubator which has to be maintained around 37^0C. In this work, we regulated the temperature at the incubator by adopting an automation technique in which PID temperature control parameters were implemented in microcontroller. Mathematical models of the incubator subsystem, actuator and PID controller were developed and controller design based on the models was also developed using Simulink. The models were validated through simulation, adopting Zeigler-Nichol tuning method as the tuning technique for varying the temperature control parameters of the PID controller in order to achieve a desirable transient response of the system when subjected to a unit step input. After several assumptions and simulations, a set of optimal parameters were obtained at the result of the 3rd test that exhibited a commendable improvement in the overshoot and peak time, thus improving the robustness and stability of the system.

Keywords: Neonatal incubator, Temperature control, automation technique, PID controller, Microcontroller.

INTRODUCTION

One of the most important elements in a newborn's survival is the infant's temperature regulation. Mammals have the advantage of being homeothermic, meaning that they are able to produce heat, enabling constant body temperature to be maintained [1]. However a preterm newborn infant needs special care because some vital organs and/or biochemical/enzyme systems may not have developed sufficiently, or because the growth of the fetus may have been disturbed, with the result that the infant is unlikely to survive undamaged without special protection. An infant is called preterm if it is born following a gestation period of less than 37 weeks [1]. The preterm infant has several disadvantages in terms of thermal regulation. An infant has a relatively large surface area, poor thermal insulation, and a small amount of mass to act as a heat sink. The infant has little ability to conserve heat by changing posture and no ability to adjust clothing requirements in a response to thermal stress. Responses may also be hindered by illness or adverse conditions such as hypoxia (below normal levels of oxygen). Heat exchange between the environment and the infant is like any physical object and its environment [2].

The temperature inside the mother's womb is 38^0C (100.4^0F). Leaving the warmth of the womb at birth, the wet new born finds itself in a much colder environment and immediately starts losing heat. In the first 10-20 minutes, the new born who is not thermally protected may lose enough heat for the body temperature to fall by $2\text{-}4^0$C ($3.6\text{-}7.2^0$F), with even greater falls in the following hours if proper care is not given [3, 4]. If heat loss is not prevented and is allowed to continue, the baby will develop hypothermia and is at increased risk of developing health problems and of death. Therefore an infant incubator is necessary which attempts to create the necessary environment for the baby's survival [5].

A neonatal incubator is, usually, a small (approximately: 0.5 x 0.5 x 1 m3) cabinet with transparent walls so that the infant can be easily observed. An artificial climate is maintained inside the incubator, and which usually differs from the local environment with respect to temperature, humidity and/or oxygen concentration. The device may include an AC-powered heater, a fan to circulate the warmed air, a container for water to add humidity, a control valve through which oxygen may be added, and access ports for nursing care. With the technology available currently, incubators use microprocessor-based control systems to create and maintain the ideal microclimate for the preterm neonate [6, 7].

1. The system design

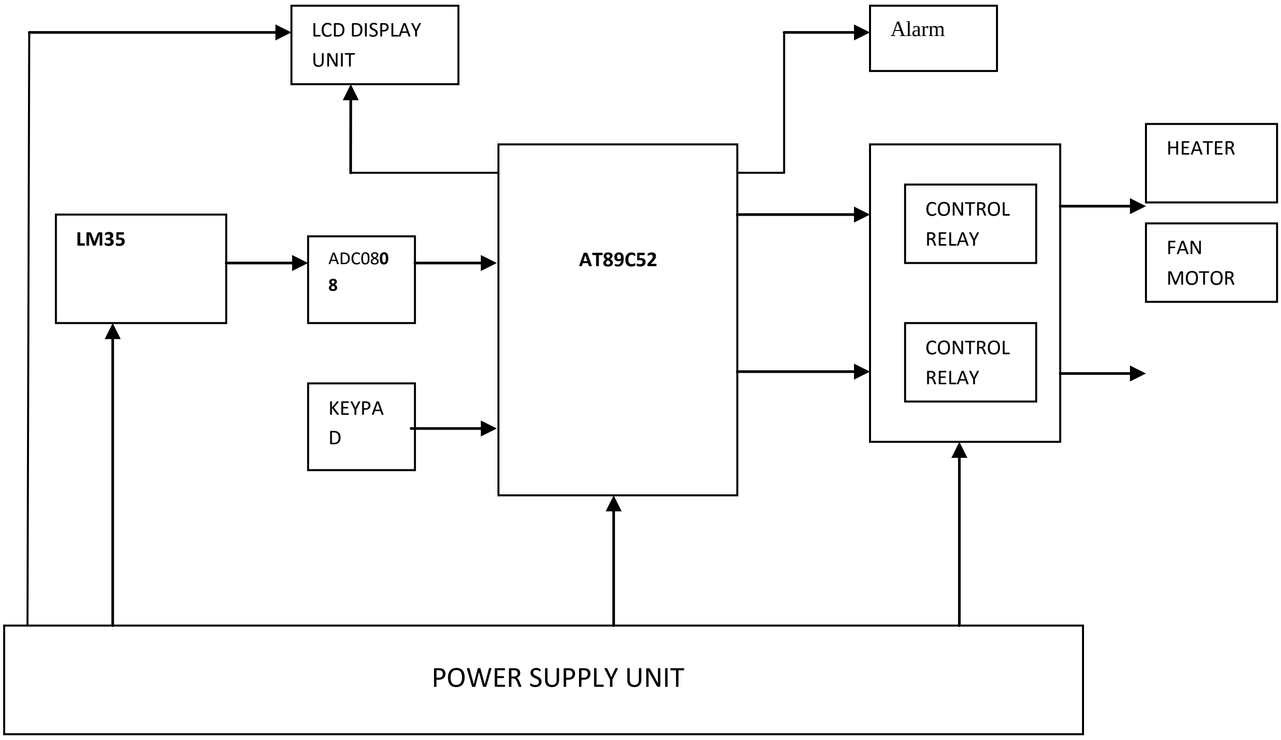

Figure 2.1: Proposed Neonatal Incubation System

The system operation

The proposed neonatal incubator system is shown in figure 2.1. Temperature sensor used is LM35 because of its linear relationship between the measured temperature and its output voltage. Its output is 10mV for a degree rise in temperature. The sensor senses the temperature of the incubator and the sensed signal goes to the signal conditioning circuit where the signal is amplified. The amplified analog signal goes to the ADC for conversion to its digital equivalent. The converted digital output goes to the controller. Here, the controller compares the incubator temperature with the set point temperature of 37^0C which was keyed into the controller using the keypad. The error signal which was generated by the controller goes to the actuator which in this case is relay. The actuator turns ON or OFF the heater / fan motor as the case may be.

According to [8], the acceptable temperature range in neonatal incubator is 26^0C – 37^0C, anything outside this range is unacceptable. Steady- state temperature was maintained at 37^0C using PID algorithm implemented in microcontroller. This system also incorporates high temperature (38^0C) and low temperature (25^0C) alarm for medical attention in the case of accidental failure of the temperature regulating system.

Mathematical model of the incubator subsystem

- Assume the temperature of the incubator before heat is transferred to be θ_1
- The temperature of the incubator after heat is transferred to be θ_2
- Heat transferred to the incubator to be q
- The weight of the baby placed at the incubator be W
- The time it takes for the temperature at the incubator to get to its maximum be t

LM35 is used as the sensing device to take the temperature reading of the system. From the law of heat transfer, temperature rise is proportional to heat added [9].

$$dq = cd\theta_1$$
(2.1)

c = heat capacity

By dividing both sides by dt

$$\frac{dq}{dt} = \emptyset = \frac{cd\theta_1}{dt}$$
(2.2)

The rate of heat transfer into the incubator is $\emptyset = \frac{cd\theta_1}{dt}$ and the rate is governed by the thermal resistance between the air and the incubator. This obeys a law similar to ohms law so:

$$\emptyset = \frac{(\theta_2 - \theta_1)}{R}$$
(2.3)

Where R is the thermal resistance in Kelvin per watt. Equating for $\emptyset$ we have

$$\frac{cd\theta_1}{dt} = \frac{(\theta_2 - \theta_1)}{R}$$
(2.4)

$$\frac{d\theta_1}{dt} = \frac{(\theta_2 - \theta_1)}{RC}$$
(2.5)

$$\frac{d\theta_1}{dt} + \frac{\theta_1}{RC} = \frac{\theta_2}{RC}$$
(2.6)

In all system, the product of the resistance and capacitance is the time constant τ so we have:

$$\frac{d\theta_1}{dt} + \frac{\theta_1}{\tau} = \frac{\theta_2}{\tau}$$
(2.7)

Changing from a function of time into a function of "s" we have

$$s\theta_1 + \frac{\theta_1}{\tau} = \frac{\theta_2}{\tau}$$
(2.8)

$$\theta_1(\tau s + 1) = \theta_2$$
(2.9)

$$\frac{\theta_1}{\theta_2}(s) = \frac{1}{(\tau s + 1)}$$
(2.10)

Where τ = 120 seconds, assumed time it takes to reach maximum temperature
Therefore

$$\frac{\theta_1}{\theta_2}(s) = \frac{1}{(120\,s + 1)}$$
(2.11)

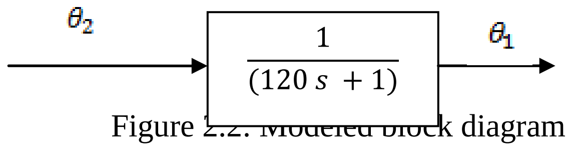

Figure 2.2: Modeled block diagram of the incubation subsystem

Model of the Controller

The Ziegler-Nichols tuning rule was applied in the design of the parallel Proportional-Integral-Derivative controller. The PID controller was selected since it is probably the most extensively used method in industrial process control applications. The block diagram of the continuous PID controller is shown in figure 2.3, where, K_p is the proportional gain, T_i is the integral time constant, and T_d is the derivative time constant [9]. The transfer function of the standard PID algorithm is [9]

$$U_{(t)} = K_p e_{(t)} + \frac{Kp}{Ti}\int_0^t e(t)dt + K_p T_d \frac{de(t)}{dt}$$
(2.12)

$U_{(t)}$ = Signal output from the controller
In the s-domain, the PID controller can be written as:

$$U_{(S)} = K_p [1 + \frac{1}{Ti.s} + T_d.s]\, E_{(s)}$$
(2.13)

The discrete form of the PID controller can be achieved by finding the Z –transform of equation above.

$$U_{(z)} = E_{(z)} K_p [1 + \frac{T}{Ti(1 - z^{-1})} + T_d \frac{(1 - z^{-1})}{T}]$$
(2.14)

Equation 2.14 can also be written as:

$$\frac{U(z)}{E(z)} = a + \frac{b}{1 - z^{-1}} + c\,(1 - z^{-1})$$
(2.15)

Where

$$a = K_p\, , b = \frac{K_p\, T}{T_i},\ c = \frac{K_p\, T_d}{T}$$

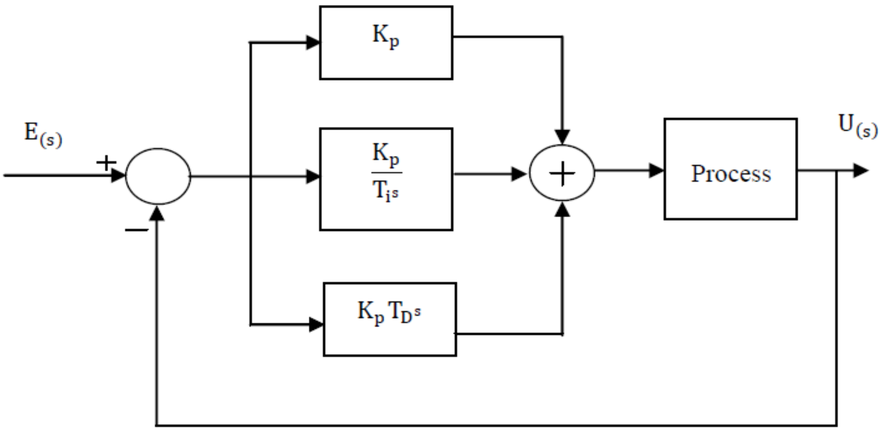

Figure 2.3: Block Diagram of a Continuous Parallel PID Controller [9]

A proportional controller (K_p) will have the effect of reducing the rise time but never eliminate the steady-state error. An integral control (K_i) will have the effect of eliminating the steady-state error, but it may make the transient response worse. A derivative control (K_d) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response.

Model of the Actuator

The relationship between the applied voltage and the energy generated by an electrical heater is non-linear. In this work, this relationship is linearised by driving the heater and motors from a pulse width modulated (PWM) signal. A pulse width modulated signal is generated from the controller as shown in Figure 3.5, where M and S are the mark and the space of the waveform and *T* is the period, i.e.

$$T = M + S$$

(2.16)

This waveform is used to drive a PNP transistor which links the system loads and the controller.

The r.m.s value of the current through each of the loads can be calculated as [9]

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T i^2(t)dt}$$

(2.17)

$$= \sqrt{\frac{1}{T}\int_0^M I_0{}^2}$$

(2.18)

$$= \sqrt{\frac{MI_0{}^2}{T}}$$

(2.19)

Or

$$I_{rms} = {}^{I_0}\sqrt{\frac{M}{T}}$$

(2.20)

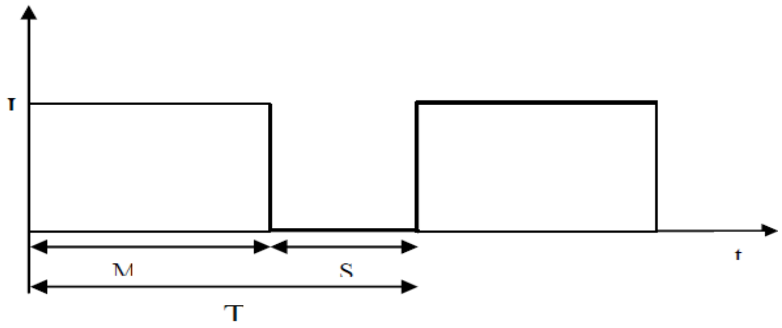

Figure 2.4: PWM Output Waveform

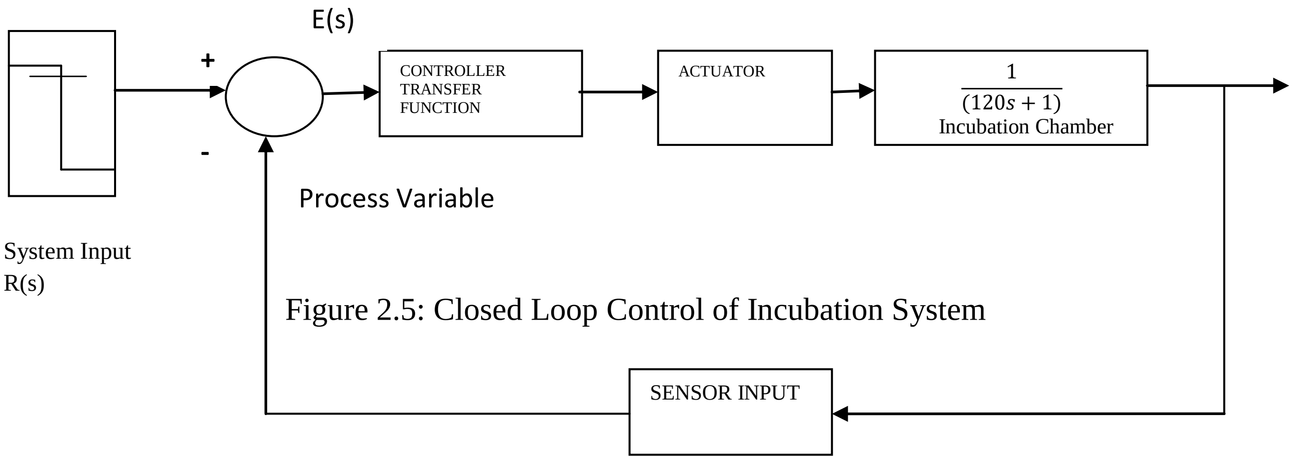

Figure 2.5: Closed Loop Control of Incubation System

SIMULATION AND RESULTS

The system was modeled and simulated using Matlab/Simulink. The simulated results of the system control with PID tuning were analyzed. Figure 3.1 shows the simulink block diagram of the incubation system

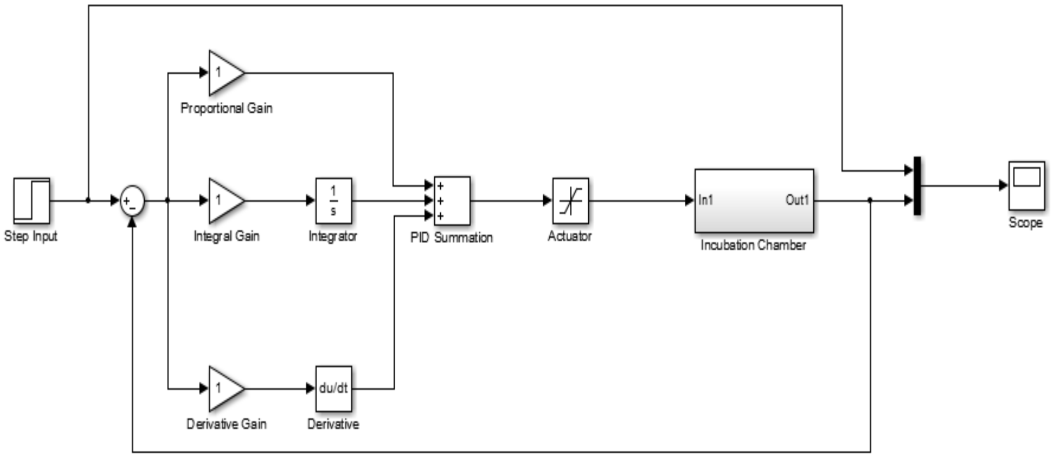

Figure 3.1: Simulink Block Diagram of the incubation temperature control system

TEST 1:

Consider the following assumed values of the parameters of the PID controller and the response of the system to these values

TABLE 3.1
The first assumed values of the PID temperature control parameters

Parameter	K_p	T_i	T_d
Values (sec)	0.2850	0.1170	0.3626

PLOT:

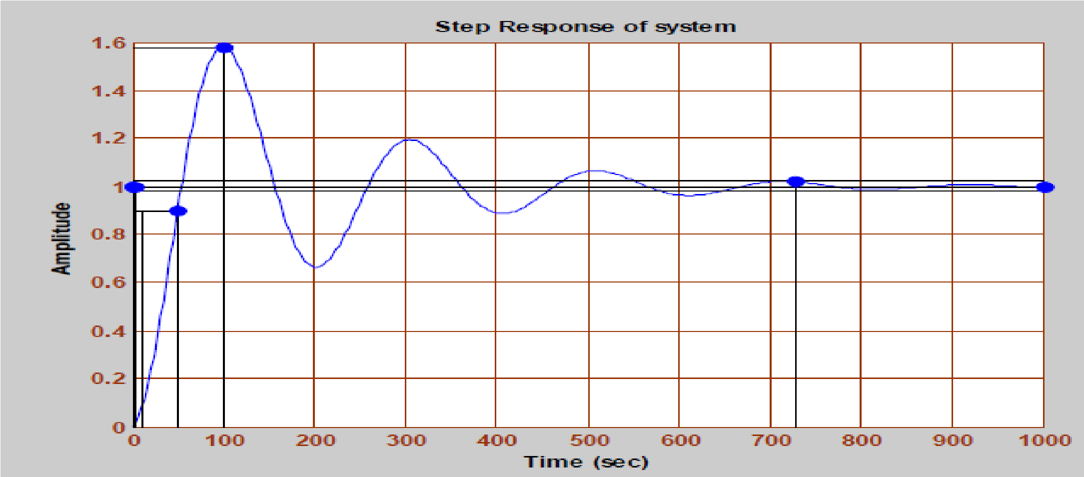

Figure 3.2: Scope of the unit step response of the system for test 1

TABLE 3.2: Result of test 1

parameter	T_r (sec)	T_p (sec)	T_s (sec)	Mp (%)
Values	37.8	100	728	58

TEST 2:

TABLE 3.3
The second assumed values of the PID temperature control parameters

Parameter	K_p	T_i	T_d
Value	1.9689	0.0504	0.6300

PLOT:

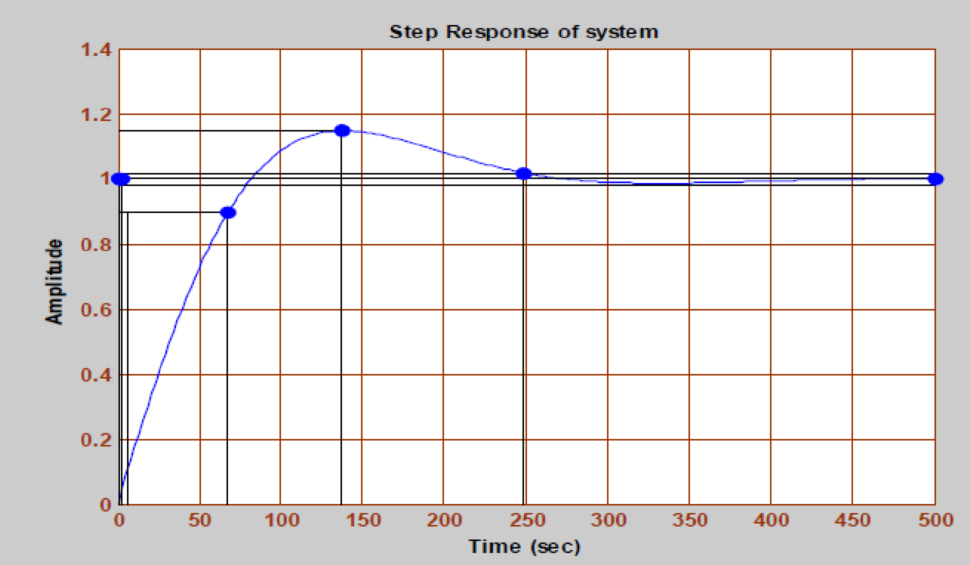

Figure 3.3: Scope of the unit step response of the system for test 2

RESULT:

TABLE 3.4: Result of test 2

Parameter	T_r (sec)	T_p (sec)	T_s (sec)	M_p (%)
Values	62.0	138	249	15.0

TEST 3:

TABLE 3.5

The third assumed values of the PID temperature control parameters

Parameter	K_p	T_i	T_d
Values (sec)	16.374	0.1325	3.3288

PLOT:

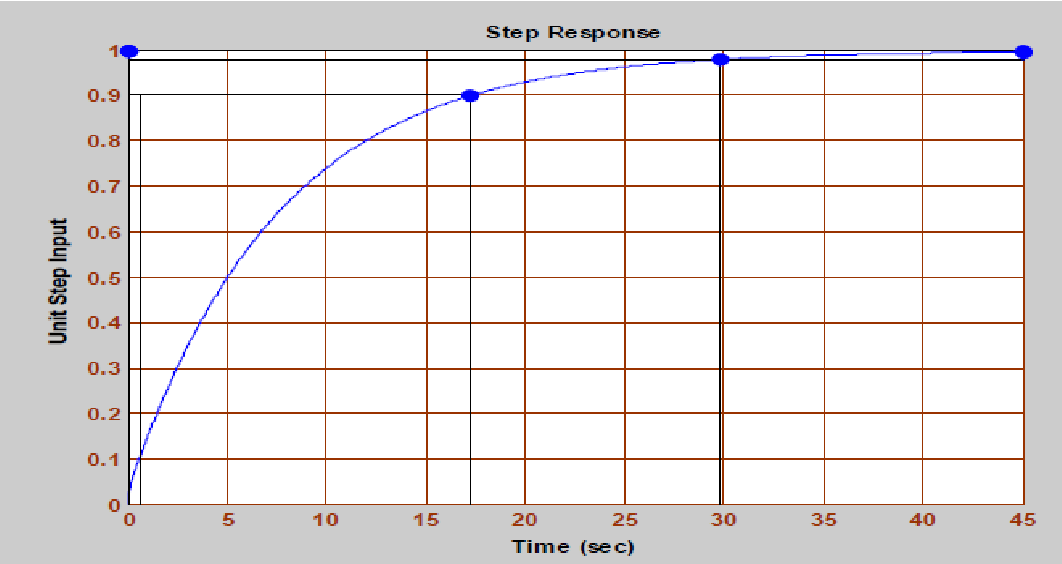

Figure 3.4: Scope of the unit step response of the system for test 3

RESULT:
TABLE 3.6: Result of test 3

Parameter	T_r (sec)	T_p (sec)	T_s (sec)	M_p (%)
Values	16.8	----	30.0	----

RESULT ANALYSIS

Using Matlab/Simulink toolbox, various parameters were tested and the best parameters were used for PID implementation on the microcontroller. The results showed the system responses to a step input with varying PID temperature control parameters based on Zeigler-Nichols tuning method. It can be inferred from the results that the optimal set of parameters that gave a more desirable transient response in terms of short rise time, low overshoot, short settling time, low steady state error were gotten from the results of test 3 where:
Proportional gain, $K_p = 16.374$,
Integral time, $T_i = 0.1325$,
Derivative time, $T_d = 3.3288$.
Hence, a PID algorithm implemented on a microcontroller using the set of parameters obtained from test 3 will exhibit a better control performance to changing temperature conditions in the neonatal incubation system

CONCLUSION

This paper is aimed at regulating the temperature of the neonatal incubator to a desired temperature in the shortest possible time with minimum or no overshoot, short rise time, small peak time and short settling time. The closed loop system is a combination of sensor and actuators that operates synchronously to provide a stable thermal environment inside the incubator. The device would include an AC powered heater, a fan to circulate the warmed air, a container for water to add humidity, a control valve through which oxygen may be added and access port for nursing care.

REFERENCE

[1] Carlos paternain soler (2009). Prototyping a closed loop control system for a neonatal incubator. Helmholtz- institute for biomedical engineering
[2] Eng MIIE MIHEEM. Baby Incubation, Volume 2. HEEM, 1st Edition, 2008.
[3] Emergency care research institute (ECRI). “Healthcare product comparison system – infant incubator”. 2003, www.ecri.org
[4] World health organization, material or newborn health / safe motherhood unit, division of reproductive health (technical support) “thermal protection of newborn: a practical guide”. Geneva, (WHO / RHT/MSM/1997, 2nd edition).
[5] Guler and M. burunkaya, “humidity control of an incubator using microcontroller – based active humidifier system employing an ultrasonic nebulizer”, journal of medical Engineering and technology, vol.26, no.2,2002, pp 82-88.
[6] P.Boyd, H and Lenhart. Temperature control: servo versus non servo – which is best? Neonatal netw. 15(2): 75-76, 1996.
[7] Runjing zhang, Lina and zhou. Design of an incubator for premature infant based on Labview. Conf proc IEEE Eng Med Biol Soc, 4:4079-4082, 2005.
[8] Tamanna Afrin Tisa, Zinat Ara Nisha, Md. Adnan Kiber, “Design of an Enhanced Temperature Control System for Neonatal Incubator”, Bangladesh Journal of Medical Physics, vol.5, no.1, pp. 51-53, 2012.

[9] Okpagu P.E and Mbachu C.B. An improved Electro-mechanical Technique for groundnut oil extraction using embedded process automation. "European Journal of Engineering and Technology". Volume 3. No 1, 2015.