Temperature control for a Neonatal Incubator

Group Tubelight: Hritik Chouhan[1], Kshitij Nair[1], Shubham Mehra[1]

Abstract : We as a group have designed the temperature control aspect of an infant incubator. Our work includes designing and simulating. We have worked on Simulink™ to design a system containing different blocks which will work to control temperature. The basic idea is to provide the infant with an enclosure that is of ideal temperature regardless of what the temperature is outside the incubator. A PID controller was used for this purpose which would take the temperature inside the incubator to the desired temperature and keep it there, despite the temperature outside the incubator varying continuously.

1. Introduction:

There are many complications that can occur during and just after childbirth that cause the infant severe problems, some can even be a threat to their survival. Some of these complications/conditions are Premature birth, traumatic birth, Respiratory illnesses, Hypoglycemia, Sepsis. It is important that when these conditions are being treated, the neonatal infant must be kept under ideal conditions, that is temperature and humidity must be controlled. They must be controlled because if an infant isn't able to regulate its body temperature, it could lead to hypothermia, a condition where body heat is lost faster than the rate at which the body can produce heat. They would also be prone to attacks from allergens and germs. To tackle these problems, Neonatal incubators are designed, they are the bassinets enclosed in plastic with climate controlled equipment and hand-access ports with doors that are intended to keep infants warm and limit their exposure to germs.

1.1 Principles of operation

These devices provide a closed, controlled environment that warms an infant by circulating heated air over the skin. The heat is then absorbed into the body by tissue conduction and blood convection. Ideally, both the skin and core temperatures should be maintained with only minor variations.

Incubators depend on the principle of thermo-electricity. The incubator has a thermostat which maintains a constant temperature by creating a thermal gradient. When any conductor is subjected to a thermal gradient, it generates a voltage called thermo-electric effect. Temperatures range around 30 to 37ºc, humidity levels range from 50 to 90%, depending on the baby's size and age. The incubator keeps the baby warm with moistened air in a clean environment, and helps to protect the baby from noise, drafts, infection, and excess handling.

1.1.1 Types of incubators:

There are different types of incubators that can accommodate the changing needs of the preemie. Among the five types commonly found in the NICU:

- Open box incubators, also known as Armstrong incubators, provide radiant heat below the baby but are otherwise open to the air, allowing for easy access.
- Closed box incubators have a fresh air filtration system that minimizes the risk of infection and prevents the loss of moisture from the air
- Double-walled incubators have two walls that can further prevent heat and air moisture loss.
- Servo-control incubator. This incubator can be programmed to adjust the temperature and humidity level based on sensors that are attached to the baby.
- Portable incubators, also known as transport incubators, are used to move the newborn from one part of the hospital to another.

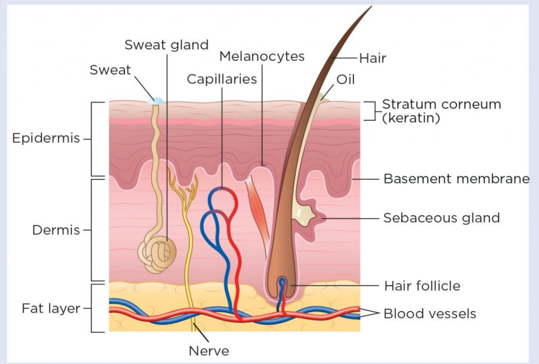
2. Theoretical background

A temperature sensor is taped to the baby's skin, and the incubator heater adjusts to maintain the baby at a constant temperature or, the temperature is controlled by a thermostat in the heated air stream.

Underneath the baby is an air-blown electric heating system and humidification system which circulates heated humid air at a desired temperature and humidity through the incubator chamber. Additional oxygen may also be introduced into the chamber.

2.1 Anatomy of skin

Fig 1. **Cross-section through the skin**



Dermis :

Middle Layer of the Skin.
They contain blood vessels, hair follicles , oil and gland and nerve endings. They transmit the sensation of pain, itch and temperature.

EPIDermis :

Outer Layer of the Skin.
Contains upto 5 layers.

Subcutaneous Tissue :

Made up of fat and connective tissue.
Houses larger blood vessels and nerves.
Regulates body temperature.

The heat loss in the body occurs due to :

- Evaporation : Heat loss due to water evaporation from skin and respiratory tracts.

- Conduction : Heat loss to cool the surrounding air.

- Convection : Heat loss to cool solid objects which are in direct physical contact.

- Radiation : Heat loss to cool solid objects which are not in direct physical contact.

- Radiation : Heat loss to cool solid objects which are not in direct physical contact.

Hypothermia :Low body temperature is called Hypothermia. It occurs when core body temperature drops to 95°F/35°C or lower. It Happens when heat loss exceeds heat gain. For this condition we require an incubator.

Hyperthermia : High body temperature is called Hyperthermia.

Hyperthermia in Neonates can lead to :

- Increased oxygen requirements
- Apnea
- Dehydration
- Metabolic acidosis
- Heat stroke, brain damage, shock and
- even death.

Neonatal Risk :

The newborn baby has immature thermoregulatory controls during the early neonatal period, which resemble a poikilotherm or at best a partial homeotherm. So, when kept in an incubator, their transition from the Poikilothermic to Homeothermic state is delayed.
Reliance on external heat to maintain their core temperature. If the thermostat fails the body temperature could change and cause drastic effects.
Thermal instability can last for several days or even weeks!

Remedies to this risk are below :

- NICU (Neonatal intensive care unit)
- SCN (Special Care Nursery)
- Postnatal care wards

- Transport Incubators can be found in Labour ward to transport the new born to Postnatal wards or NICU.

2.2 Parameters affecting the incubator other than temperature

Humidity :

Low relative humidity of a servo controlled incubator increases the temperature of the incubator itself and the oxygen consumption of premature infants accordingly. This causes an increase in the insensible water losses. In addition, premature infants with small weight or illnesses are susceptible to unfavorable incidents such as apneic spells.

Furthermore, the heat conducting ability of air is considerably better when it is humid, so that heat transfer improves. On top of this: humid air prevents water loss by the child. Therefore, relative humidity of the air should be kept above 60%

Oxygenation :

If a baby is born very prematurely (> 2 months premature),the baby's breathing difficulties can cause serious health problems because other immature organs in the body may not get enough oxygen. Ventilation is necessary to provide the patient with fresh air and sufficient oxygen. Flowing air is also necessary to provide sufficient transfer of heat from the heat source to the shell environment and the patient.

3. Design

This section discusses our design of various components utilised in projects, as well as block-by-block descriptions, gain value selection, passive component values, gain, and sampling concerns.

3.1 Thermometer

A thermometer's temperature sensing component is generally one of the following:

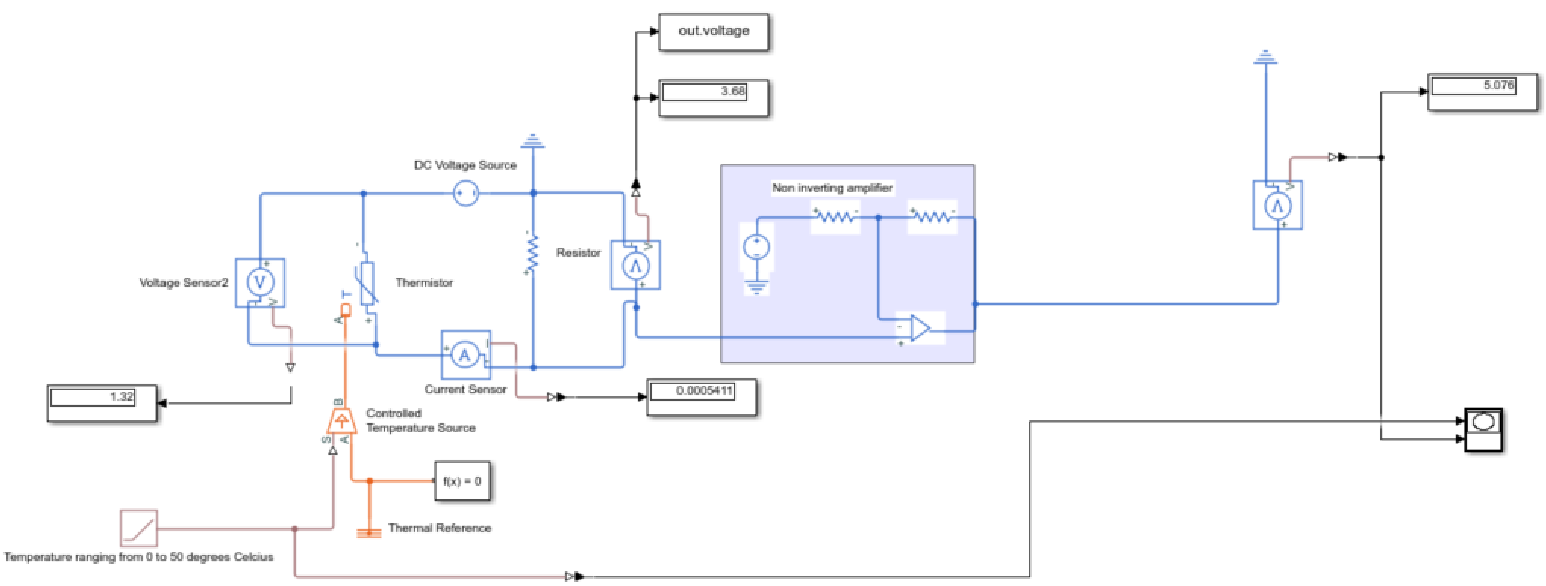
- Thermocouples
- Thermistors
- RTD (Resistance Temperature Detector)
- Semiconductor based integrated circuits

Among these components, thermistors were chosen among others because of the relative ease of simulating it. Thermocouples were also an option but they are more used in industries for very high temperature sensing applications.

Thermistors - A resistor whose resistance varies with temperature. There are 2 main basic types of thermistors, an NTC type and a PTC type.
In NTC (Negative temperature coefficient) type thermistors the resistance decreases as temperature increases. Whereas, in a PTC (positive temperature coefficient) the

resistance increases with increase in temperature.
Since NTC thermistors are mainly used for temperature sensing applications, the same was used for the design.

The simplest way of doing this is to use the thermistor as part of a potential divider circuit as shown. A constant supply voltage is applied across the resistor and thermistor series circuit with the output voltage measured from across any resistance.
The output voltage can be amplified to fit a certain range.
It was implemented like in the figure.



An NTC thermistor follows the following formula:

$$R_t = R_0 \times e^{\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

Where,
R_t is Thermistor Resistance
R_0 is Nominal Resistance = 6800Ω
β is Characteristic temperature constant = 3950K
T_0 is reference Temperature = 298.15K
T is Temperature at which the thermistor is exposed to
.

The thermistor's values are taken from the real world NTC Thermistor 'NCP15XW682p03RC' made by Murata Manufacturing Co. Ltd.

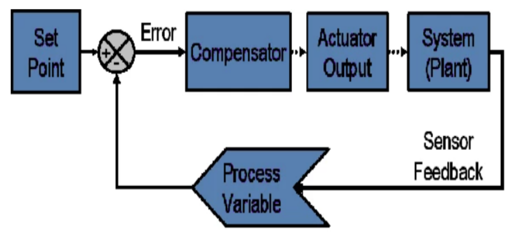
3.2 PID

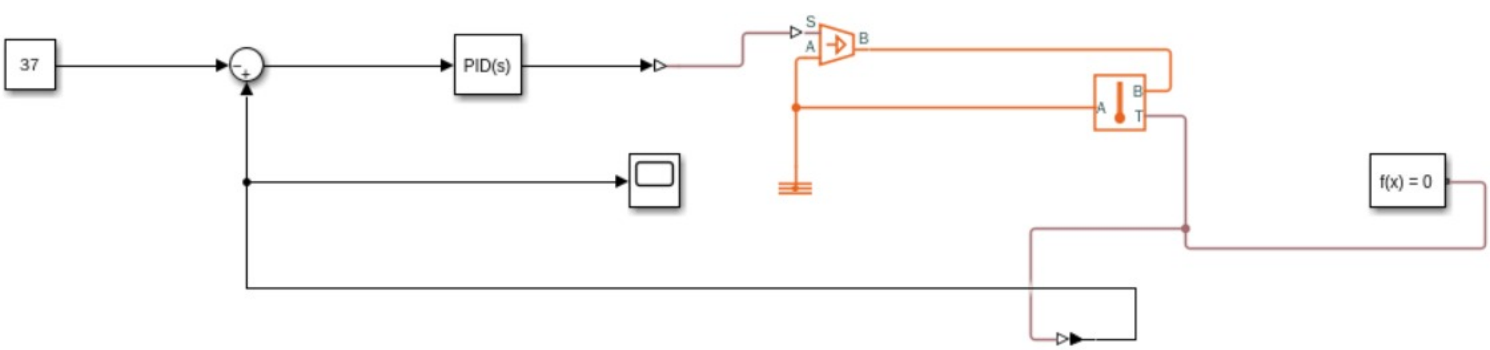
A Proportional–Integral–Derivative controller is a control loop mechanism employing feedback that is widely used in e(t) as the difference between a desired set point (SP) and a measured process variable (PV) and applies a correction based on proportional , integral, and derivative terms (denoted P, I, and D respectively), hence the name.

We utilise PID as a temperature controller in this project, and we apply the basic principle of PID to control the temperature at 37°C. We set the set-point(sp) temperature to 37°C (normal body temperature)
And the PID works to increase or decrease the incubator temperature based on the process variable (pv), where pv is the ambient temperature. The control system

industrial control systems and a variety of other applications requiring continuously modulated control. A PID controller continuously calculates an error value

algorithm (compensator) uses the difference between the process variable and the set point to determine the appropriate actuator output to drive the system at any given time (plant).





3.2.1 Components

The components used in temperature control circuit are :-

PID controller:- It is used to control control temperature , the values of three basic control behaviors that are use :

- Value for P - 1(controller gives an output that is proportional to current error e (t))
  Use p =1 , so that it does not oscillate.
- Value for I - 1(I-controller is needed, which provides necessary action to eliminate the steady-state error.)
- Value for D- 0(I-controller doesn't have the capability to predict the future behavior of error. So it reacts normally once the setpoint is changed.)
  We use d value zero because we cannot change set point , we fixed set point to 37°C (normal body temperature)

Controlled temperature source : The Controlled Temperature Source block represents an ideal source of thermal energy that is powerful enough to maintain specified temperature difference across the source regardless of the heat flow consumed by the system.

Temperature sensor: it determines the temperature difference between set value and passive value. And output of this is used as feedback error and to see results.

In this circuit error continuously is decreased and goes to 0 .
Or we can say that the temperature is moving towards a set-point value.

For example :-
The original error was -17°C(20°C-37°C) if the ambient temperature was 20°C.
The accumulated error is now multiplied by the integral gain (Ki) and added to the controller output using the I controller.

This error was decreased as a result of this.

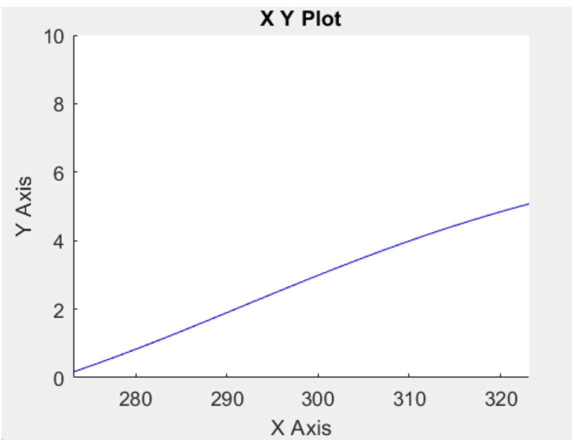
The integral term speeds the process's approach to setpoint and eliminates any residual steady-state error.

It repeats until there is no more error, and the temperature reaches the set-point value.

4. Results

Several results and graphs are discussed in this section.

4.1 Temperature Sensor & its Accuracy



The Y-Axis of this graph represents the voltage output and the X Axis represents the temperature that the thermistor was exposed to.
Now to check for the accuracy of this circuit combination, voltage was exported to MATLAB.

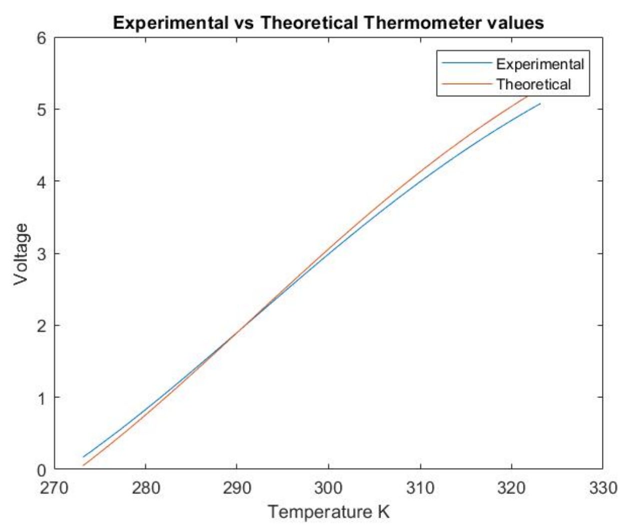
Relation between temperature and voltage was calculated using the formulas for voltage divider circuit and thermistor resistance.

$$R_t = R_0 \times e^{\beta(\frac{1}{T} - \frac{1}{T_0})}$$

$$R_t = R_c({}^{E}/_{V} - 1)$$

$$T = \frac{T_0 \times \beta}{(T_0 \times \ln({}^{r}/_{r_0}({}^{e}/_{v} - 1) + \beta)}$$

With this relation, one can convert voltage outputs to temperature.

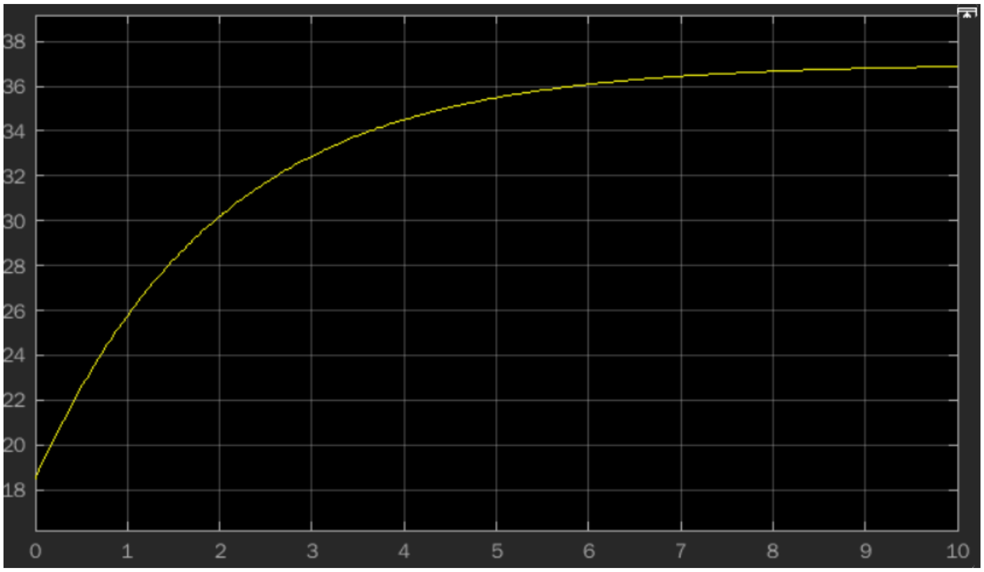


As seen the errors can be considered negligible, although it is seen as the temperature increases so does the error.

4.2 PID Results

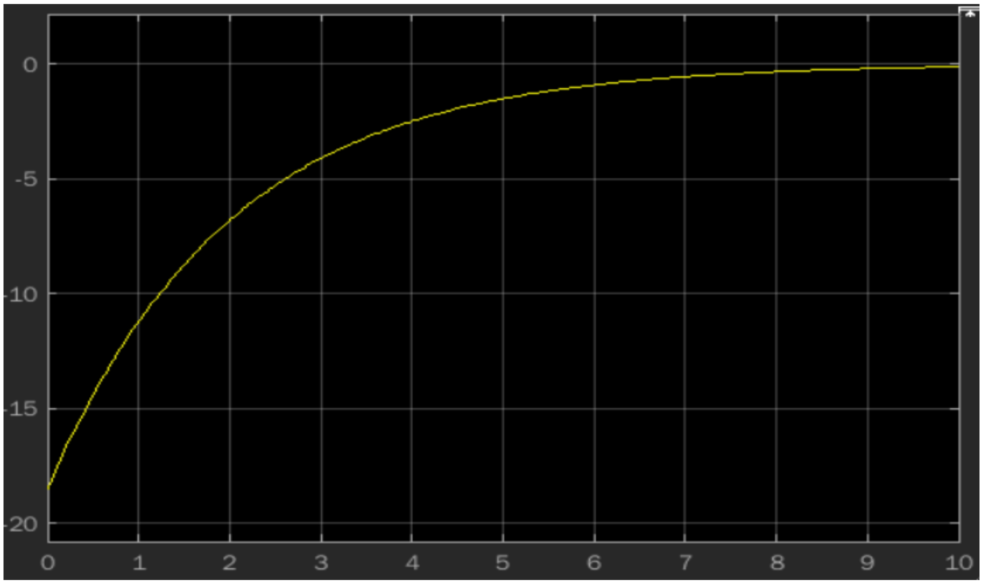
4.2.1 Temperature Vs Time

We can see from the graph that the temperature ultimately reached 37°C. Which is the same as the set-point we chose.
We can observe that our graph is not oscillating because p = 1 and I = 1 in PID, and that it has achieved our set-point.



4.2.2 Error Vs Time

The error vs. time graph shows that error continues to decline until it reaches zero, as is required for the surrounding temperature to reach a set-point value.



4.3 Contributions

Designing the Temperature sensor and its research was done by Kshitij Nair
Designing the PID controller, literature review, research regarding neonatal incubators was the joint effort of Hritik Chouhan and SHUBHAM MEHRA.

5. References

[1]Al-Taweel, Yasser Amer. "A simulation model of infant-incubator-feedback system with humidification and temperature control." (2006).

[2] Matamoros, Manuel et al. "Temperature and Humidity PID Controller for a Bioprinter Atmospheric Enclosure System." *Micromachines* vol. 11,11 999. 12 Nov. 2020, doi:10.3390/mi11110999

[3] Zimmer, Daniel & Inks, Aaron & Clark, Nathan & Sendi, Chokri. (2020). Design, Control, and Simulation of a Neonatal Incubator. 2020. 6018-6023. 10.1109/EMBC44109.2020.9175407.