UNIVERSITÀ
POLITECNICA
DELLE MARCHE

FACULTY OF ENGINEERING

Course of master's degrees in Biomedical Engineering

Design and development of a measurement system in a Prenatal Incubator for the assessment of humidity and temperature.

Advisor : Prof.Lorenzo Scalise **Candidate**: Joseph Christina Philips

Academic Year:2020/2021

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Abstract

Every year an estimated of 15 million babies are born preterm worldwide, in which Approximately 1 million children die each year, among which 25% of the deaths are occurs due to preterm birth and complications mostly related to heat and water . Preterm is defined as babies born alive before competition of 37 weeks of successive pregnancy period . It is one of the serious medical problem all over the globe which effect the neonatal mortality and long term morbidity. Due to increasing health services and the exposure to neonatal intensive-care unit (NICU, it became easier to control the decline rate of mortality the advancement in medical equipment, in which incubator is is one of the main equipment which helps in maintaining the adequate survival environment for the preterm neonates, thanks to the invention by Dr. Stephane Tarnier who was the first to develop the prototype model of the infant incubator, he names this device as the baby warmer, the preterm or low-birth-weight baby have undeveloped mechanism of Thermoregulation,as the expose in the mothers womb, the intrauterine environment is much different then the external environment, thus they need,thus, they need a stable environment of stable of 37 °C and a humidity of 100% the model developed by the Tarnier provides so far such environment. Till date there are many more advancement in the discovery of the neonatal incubator including monitoring of heart rate, blood pressure, oxygen saturation and humidity control system. In this study we focus on the development of he parameter that mostly affect the preterm which are the humidity and the temperature. We develop a system which measure the overall distributed humidity and the specific temperature inside the incubator there are many model which explain the distribution of the temperature which also include the infant skin temperature and the incubator environmental temperate but the the monitoring of the continuous humidity distribution is the limitation in our study we focused on measurement and evaluation of the continuous humidity distribution, During the first days of life of premature newborn , the daily evaporative loss from can reach up to 20% of body mass,which can be reduced by increasing the air humidity inside the incubator therefore it is the most important parameter which need to be controlled and maintain.

Introduction

The global action report by WHO[1], “Born Too Soon”, has stated that the incidence of Premature or preterm birth (PTB) is a serious medical problem globally, and it is the leading cause of neonatal mortality and neonatal long-term morbidity. Preterm is defined as babies born alive before 37 weeks of pregnancy are completed, Preterm birth is further classified as extremely preterm (<28 weeks), very preterm (28 to <32 weeks), and moderate (32 to <34 weeks) to late preterm (34 to <37 weeks). Every year an estimated of 15 million babies are born preterm every year worldwide, Approximately 1 million children die each year among which 25% of the deaths are cause due to preterm birth and complications(blencowe2012chapter)[2].

Premature infant deaths are caused by several reasons which includes Infections like (sepsis and pneumonia) , asphyxia, hypothermia, poor facility management. In two Millennium Development Goal (MDG) regions (200-2015) , among the 5·9 million deaths of under 5 age child, 2·7 million occurred in the neonatal period. The leading causes were preterm birth complications (1·055 million) , pneumonia (0·921 million) , and intrapartum-related events (0·691 million). The leading cause was pneumonia in sub-Saharan Africa and preterm birth complications in southern Asia[3]. The improving health services leads to overall decline in mortality rates in the last two decades due to reductions in death related to infectious diseases such as pneumonia, diarrhea, malaria, and measles, however COVID-19 pandemic, threatens years of improvement in child survival through the interruption of essential health services. In 2019 More than 5 million children died before reaching age of 5, in which almost half were newborns, the 2020 Report from UNICEF and partners in the UN Inter-Agency Group for Child Mortality Estimation (UN IGME), shows the full scope of child mortality rates across the world[4]. One more major cause of death in premature infant is Reduction of thermal stability major seen in developing countries[5], recent report state the mortality risk increased with 80% for each degree decrease in temperature[6] . Neonatal deaths related to hypothermia are relatively neglected, but considered easily preventable with attention to warmth, feeding and infection management.

I. Thermoregulation

The human fetus floats in amniotic fluid, and the mother maintains a stable temperature of 37 °C and a humidity of 100%[7]. The intrauterine environmental condition of the fetus is thermally stable. Heat is transferred to the fetus through the placenta and umbilical circulation, generally the intrauterine temperature is higher (0.3℃ to 0.5℃) than the mother, temperature gradient between the fetus and the mother was measured in pregnant baboons it was found that Temperatures in the fetal esophagus, scalp, and shoulder were 0.47, 0.28, and 0.19°C. respectively, higher than those in the maternal colon (morishima1977temperature)[8], after the birth there is a sudden change in the environment condition of the new born the temperature of the external environment is much lesser than the intrauterine temperature, for the survival the newborn have to perform independent Thermoregulation, which is the process that allow all homeothermic species to maintain homoeostasis[9]. The preterm or low birth weight (LBW) infants are not capable of performing Thermoregulation during there initial weeks of life and easily become hypothermic or hyperthermic thus they accelerate heat production via non-shivering thermogenesis（NST)[10].

II. Ways of Heat loss

Evaporation : Evaporation: During the birth the newborn is damped with the amniotic fluids, which makes the baby wet this starts the evaporation of the liquids covering the new born, the environmental temperature which is 37^{0C} in the maternal womb drops to the usually less warm air temperature There is considerable amount energy loss at a rate of 0.58 kcal ml^{-1} fluid immediately through evaporation at delivery[11].

Conduction : Human neonates are functionally poikilothermic they adapt the changing temperature, A baby placed naked on a cold surface loses heat through conduction. the study shows The mean rectal temperature was significantly higher in infants who were wrapped compared with infants who received standard (unwrapped)care[12].

Convection/Radiation : A newborn exposed to cool surrounding air or draughts will lose heat through convection. Radiation from cool objects next to the baby (for example, a cold wall) can also lower its body temperature.The study states that These changes body posture is important in regulating heat loss from a baby. A baby loses more heat by radiation than by convection[13].

New-born are less adaptive to the exposure of drastic changing weather, they have immature immune system which leads the life into risk, there is urge need of proper care and to provide suitable environment to cope with external physical condition like temperature, humidity, light etc. The incubators are such instrument which provide a favourable environmental to the new-born.

III. Literature review

The thermal protection is a very ancient technique which is evidently seen in The Bible where its written in Luke 2: 7, 'And she brought forth her firstborn son, and wrapped him in swaddling clothes, and laid him in a manger'[14], also the oldest technique skin to skin holding of a newborn or Kangaroo care of premature neonates is one of interventional technique used from many years[15].

In the 1881, Dr. Stephane Tarnier was the first to introduced prototypes of infant incubators. He designed a box like devices which was made of wood and inside which it has glass lids and compartments that contained hot-water bottles. He called his "baby-warming device" a "couveuse"[16][fig.1].

Figure 1 . Tarnier's Incubators (Jefferey, 2000) [17]

In 1890s a physician Alexandra Lion, who is a son of an inventor, developed a incubator which was much more sophisticated than that of Tarnier (Jefferey, 2000). It is a large metal apparatus equipped with a thermostat and an independent forced ventilation system[17].

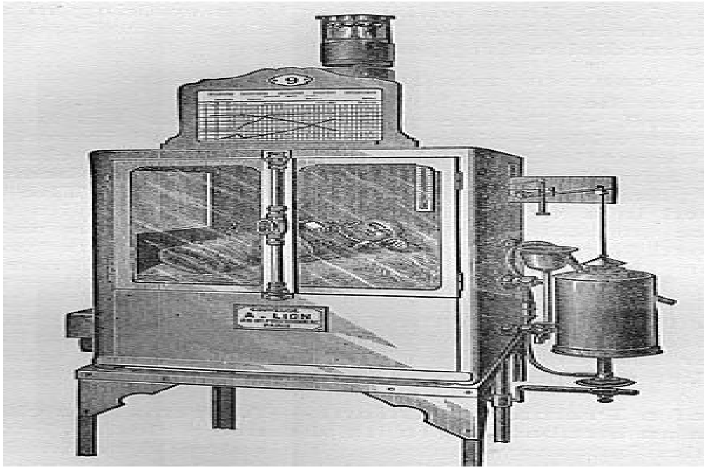

Figure 2 . Image of incubator by Dr. Myer Solid-Cohen, (1906)[18].

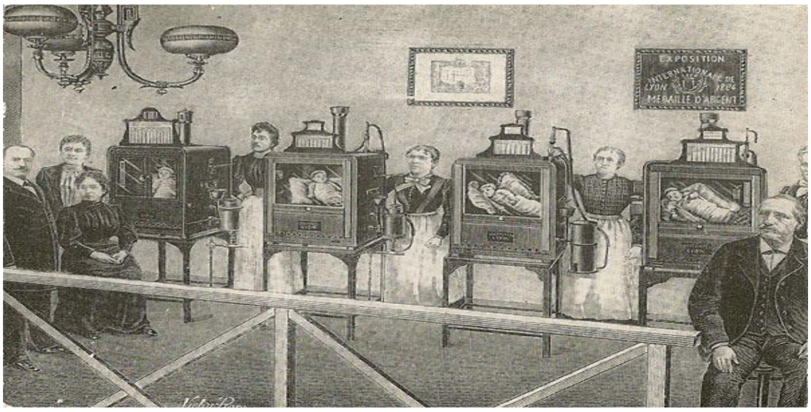

Figure 3. Five of the Lion Incubators for care of premature babies, 1896, in Lion's storefront for the in Paris, France. Dr. Lion is standing by the end incubator[18]

Julius Hess in 1914 developed new own version of incubator, it was an electrical heated bed reminiscent of crede's design that surrounded the infant in a metal jacket containing hot water. He expanded the function of the incubator itself into an oxygen chamber, and developed an automobile-based transport system to address the problem of treating out born infants[19.]

The first official neonatal intensive-care unit (NICU) for neonates was established in 1961 by Professor Mildred Stahlmanat at Vanderbilt University. This lead the special attention towards the development of the neonatal care, In the early twentieth century, , Joseph B.DeLee recognized that the incubator was not self-contained but required a supportive system analogous to that developed within the incubator show[19]. he was able to cannulate and puff-up the lungs of premature infants, and created his own thermostats for his incubator. He set up a transport service through which a portable incubator could be administered with a doctor and nurse to pick up premature. But increasingly technological such as monitoring as monitoring of heart pulse and humidity[20], recent developed in newborn incubator that can check the environment conditions of the incubator by using a humidity control system(Costa et al)[20].

IV. Incubator

The incubator is an isolated area or environment which is free of dust, bacteria, and has the ability to control temperature,humidity, and oxygen to maintain them in acceptable levels. Incubator is designed to keep baby warm and to monitor the vital body functions including heart rate, blood pressure, oxygen saturation and it also helps in breathing if necessary[21].

VI. Parameters affecting incubators

Temperature : Due to limitation in the capacity of low thermal regulation in premature neonates temperature is one of the important parameter need to be maintained, If heat loss is not stop and is continuously carried on, the baby will face hypothermia and will increased health elated problems and death. If the baby is wet it can lose one degree of body temperature per minute t, even in a room which is not naturally cold.

Humidity : The water loss from the skin of the newborn decreases with the increase in the relative humidity within the incubators with 30 weeks of gestation and provide a maintained of corporal temperature[22] . During the first days of life of premature newborn , the daily evaporative loss from can reach up to 20% of body mass. which can be reduced by increasing the air humidity inside the incubator. The skin evaporative exchanges between environment and the neonate are directly proportional to the difference in the partial pressure of water vapour between newborn's skin and the air[23] .

This study, present a system which includes system structure, hardware circuits we used temperature sensor (TM117 and T-type POD thermocouple) and DHT11 as a humidity sensor to obtain adequate humidity and temperature measurement. The goal of this study is develop the continuous monitoring and overall distributed measurement of the parameter and to resolve the existing problem.

Materials and Methods

"System Improvement for Neonatal Care"(SINC) is a project made in alliance with four companies in which two are from departments of research of the “Università Politecnica delle Marche” and the "Women’s and Children’s Hospital G. Salesi" of Ancona as the supervisor of all the regional Neonatal Intensive Care Units[26], The objective of the project is to study, develop and test on real cases an innovative system for neonatal care**.**

The analyzed equipment(“OGB Polycare 3”) is a microprocessed newborn incubator that have a humidity control system of the passive type seen in Fig. 4.

Figure 4. OGB Polycare 3 Incubator

This newborn incubator was used, for the realization of the measurements, it already have a temperature and the humidity sensor which display the measurement on the display board,it have water reservoir, Distilled water was filled in the humidity reservoir. The structure figure of the basement and the incubator is shown in Fig.5,6 .

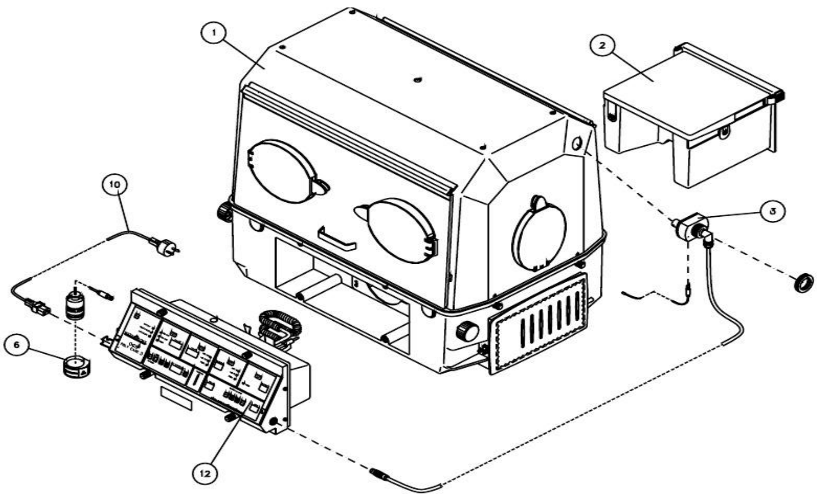

Figure 5 1) incubator body, 2) water reservoir, 3)Temperature and Humidity probe,10) power cable, 12)display

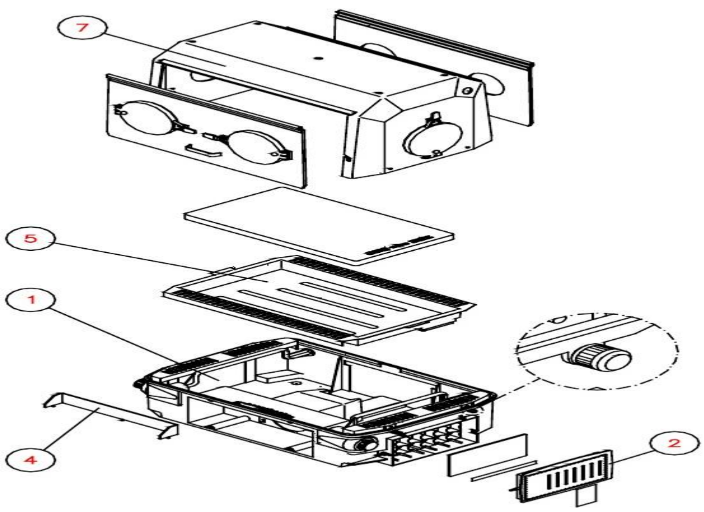

Figure 6 1) Basement for water resservoir 5) Patient tray , 2) Air filter,7) Top cover

I. Design component

Temperature sensor :

Two temperature sensors were used for the temperature measurement as below:

TM117 temperature sensor: 8 Custom made Temperature Sensor for measurement of temperature inside the incubator was used in the range of 28 ºC-38ºC (Fig.7) data was collected using Bluetooth communication . The TMP117 is a high-precision digital temperature sensor. It is invented to meet requirements of (ASTM E1112 and ISO 80601) for electronic patient thermometers. The TMP117 gives a 16-bit temperature output and a resolution of 0.0078 °C with accuracy of up to ±0.1 °C across the temperature range of (–20 °C to 50 °C).

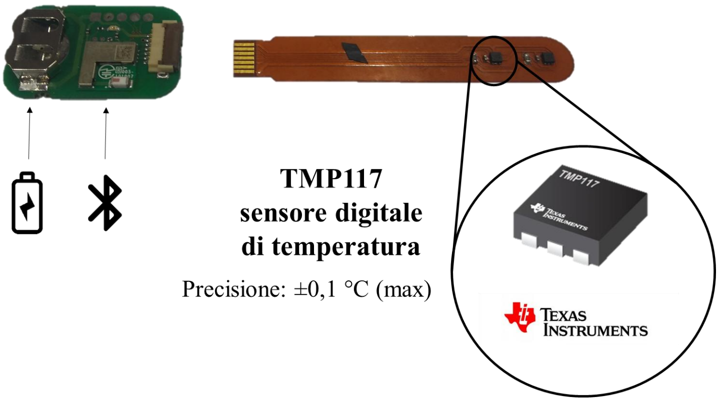

Figure 7 TMPLL7 Temperature sensor

T-type POD thermocouple temperature sensor: Thermocouple temperature sensor(Fig. 8) was used for the calibration of the TM117 temperature sensor, both were connected to the heating bed for collecting the temperature measurement for the calibration, thermocouple voltage signal produce 10 mV/°C @ 25°C (T-type) and 50 mV/°C within the temperature range 5°C to 50°C . It Filtering to reduce noise bandwidth, allowing fast temperature transients to be monitored. (T-type Pod filters by a 2 pole 10 Hz Butter-worth filter). T-type Pod directly measures input connector temperature because it has an Ice Point Reference compensation

Figure 8 . T-type POD thermocouple temperature sensor

Humidity sensor : Humidity sensor have to gives relative humidity (%RH) of range 0-100%RH in the incubator. We used DHT11 humidity sensor for the work.

DHT11 is a complex sensor which measure digital temperature and humidity, it has contains a digital signal output of the temperature and humidity which is calibrated shown in (Fig. 9). it has the ability of digital modules collecting technology along with temperature and humidity sensing technology, which make it high irreproachable and have long-term stability. It sense the wet components and resist such components and , an NTC temperature measurement devices and connected along a high-performance 8-bit microcontroller[24]. it uses a simple single-bus(one data line) communication, the system of data exchange, control by a single bus to complete.

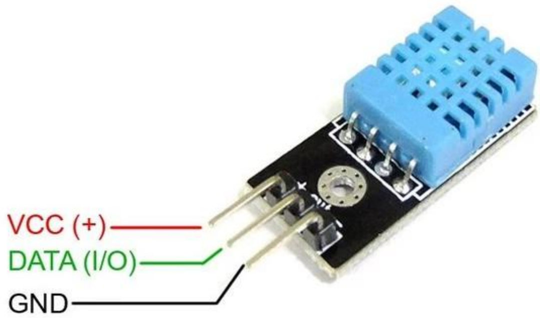

Figure 9. Humidity sensor DHT11

Microcontroller: The Arduino Mega 2560 is a microcontroller board (Fig. 10). It has total 54 digital input/output pins, 14 PWM outputs pins , 16 analog inputs, 4 UARTs which are hardware serial ports , 16 MHz crystal oscillator, , a power jack, an ICSP header,a USB connection and a reset button[25]. It contains everything needed to support the microcontroller, it can be given power with an AC-to-DC adapter or battery to get started and also can connect to a computer with a USB cable. The Mega is well suited with most shields designed for the Arduino Duemilanove or Diecimila[25]

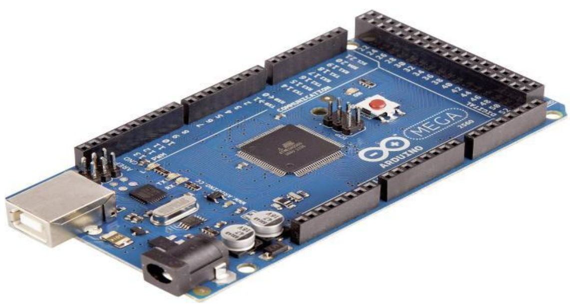

Figure 10 Arduino Mega 2560

II. **Temperature calibration :** Two temperature sensor T-type POD thermocouple temperature sensor and TM117 temperature sensor were used for the calibrator there were placed upon the heating bed which is controlled by the microcontroller with the help of relay circuit to set a threshold temperature value, this is done to understand the better performance of the temperature sensor TM117. the data was collected and was calibrated by using software programming. The block diagram is shown below(Fig.11):

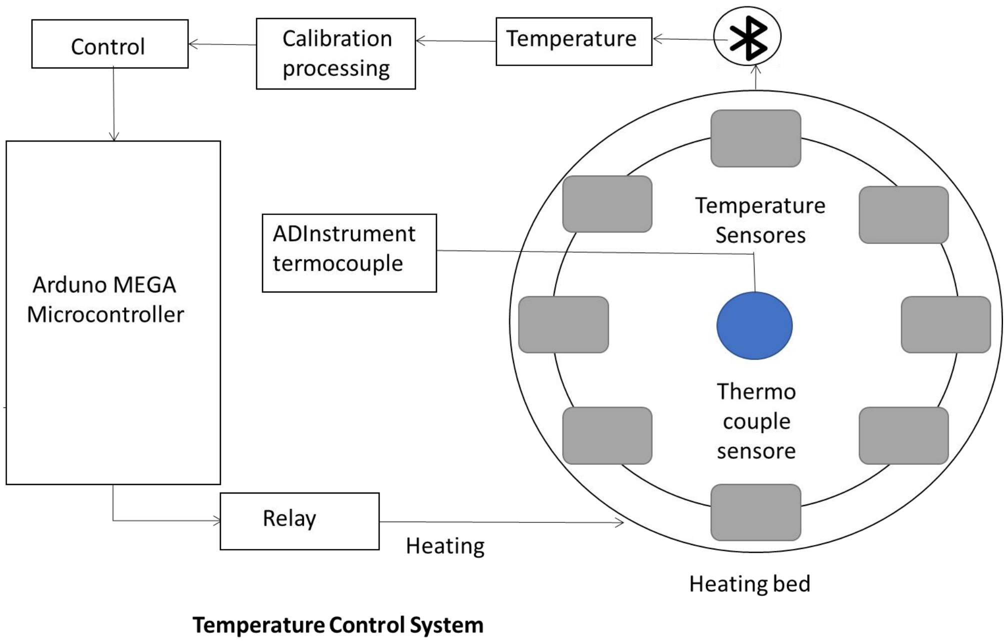

Figure 11 : Temperature calibration system

III. **Data acquisition system:** The baby is placed over the mattress which is completely enclosed by a clear plastic canopy. The parameters need to be controlled is temperature and humidity .The temperature in the incubator is increased by a heater element below the mattress. There is a fan which control by the motor driver near the heater draws in fresh air through a filter and blows it past the heater, warming the air. The air moves up from the gaps in the crib towards \ the area above the mattress and circulated around(Fig 9).The temperature threshold value of (32^0C) was set if the value exceed the the fan will be on and it remains on till the temperature decreased to the threshold value.

Three test were carried out Positioning the sensor at 5 x 3 matrix grid with a difference of 5 cm each located on the mattress . along with this the grids were positioned at three height levels at 10 cm distance. The air temperature and the humidity was collected at different position and monitored using the temperature and humidity sensors , each position was change after 1 minute of time. A program was developed on python which collect the data from the arduino MEGA Microcontroller to segregate the data. The block diagram of the system is explained as below in figure .12.

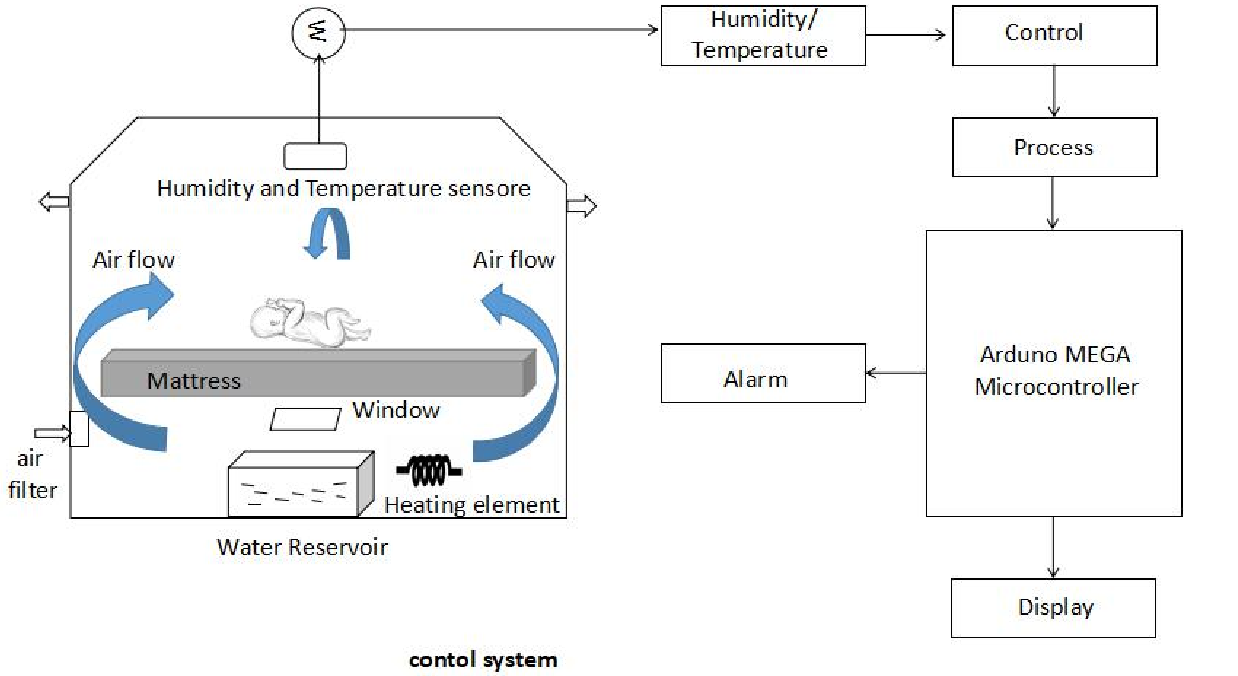

Figure 12 Data acquisition system

Results :

Temperature calibration : By this we found that the performance of both the T-type POD and TM117 perform with the minimal accuracy, both of them reaches the maximum threshold concluding this we used TM117 for our further test

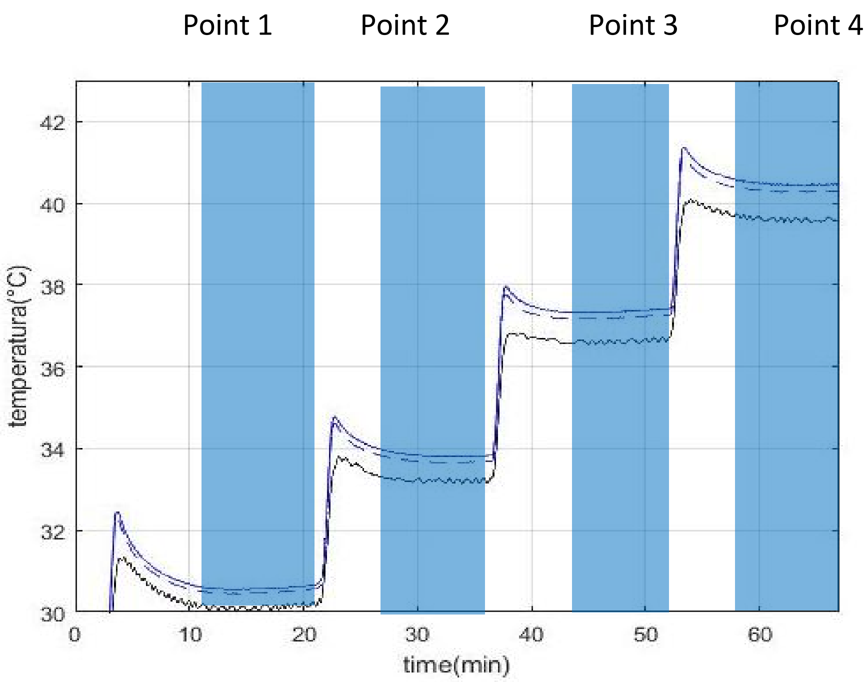

Figure 13 Temperature at different threshold value

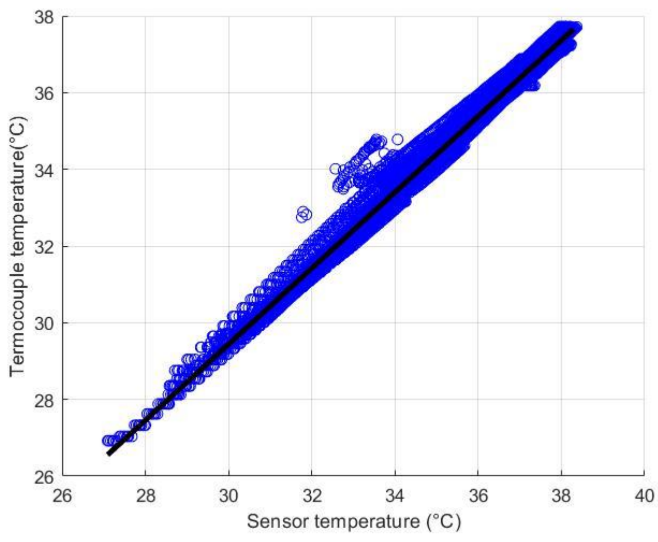

Figure 14 Temperature of thermocouple (T-type POD) verses TM117

Variation of Incubator's humidity with at different level : Using DHT11 we measured the different level of humidity basically we measure at 2 levels with 5x3 matrix grid as shown in Fig. 15

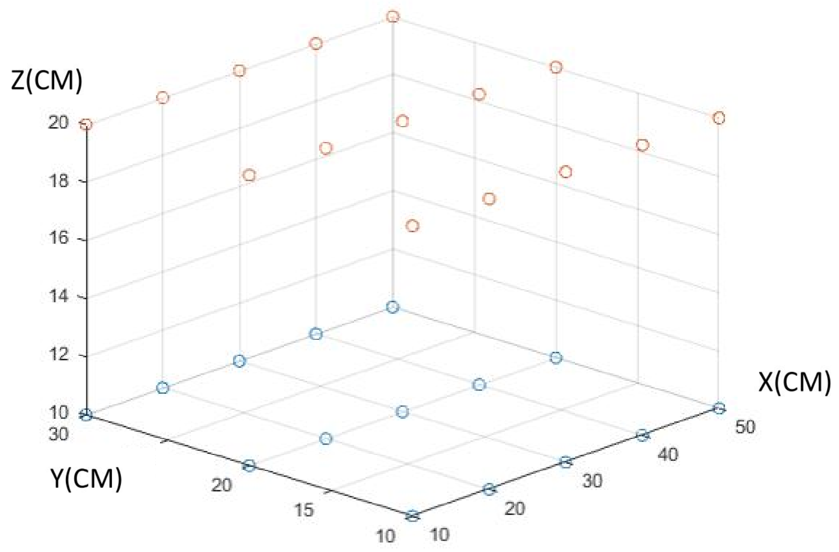

Figure 15 Grid point for humidity sensors

We found that there variation in the humidity values which is more at the top layer and less at the bottom layer as shown in Fig 16

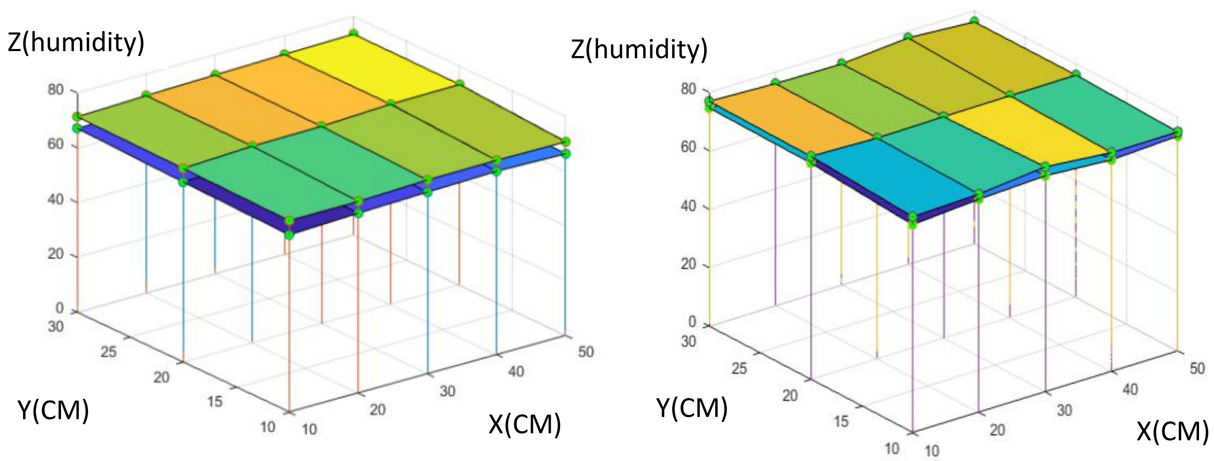

Figure 16 Humidity at different layer

Conclusions:

The humidity values is more at top region but there is a decrease in the bottom this is because of the structural flow of the water vaporous in the enclosed(Fig .17)

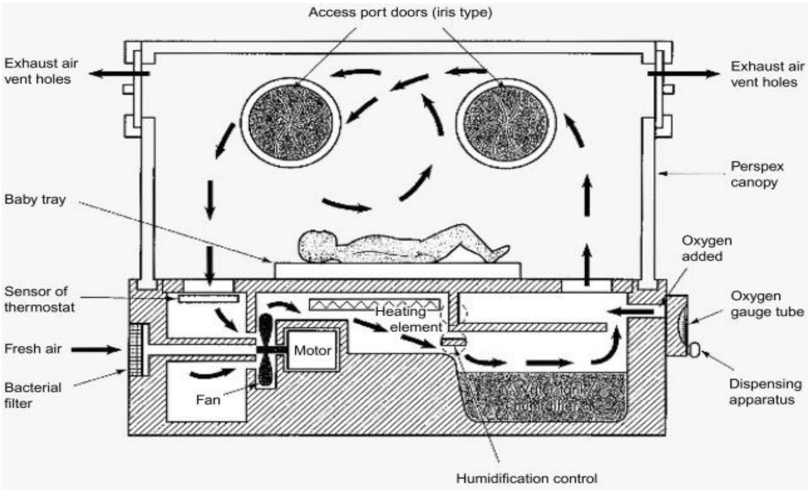

Figure 17 Flow of Air in the incubator

The different in the distribution from the above graph is due to the opening of the crib is only at three side and one of the opening is blocked and this is the reason for the differential distribution of the humidity(Fig. 18)

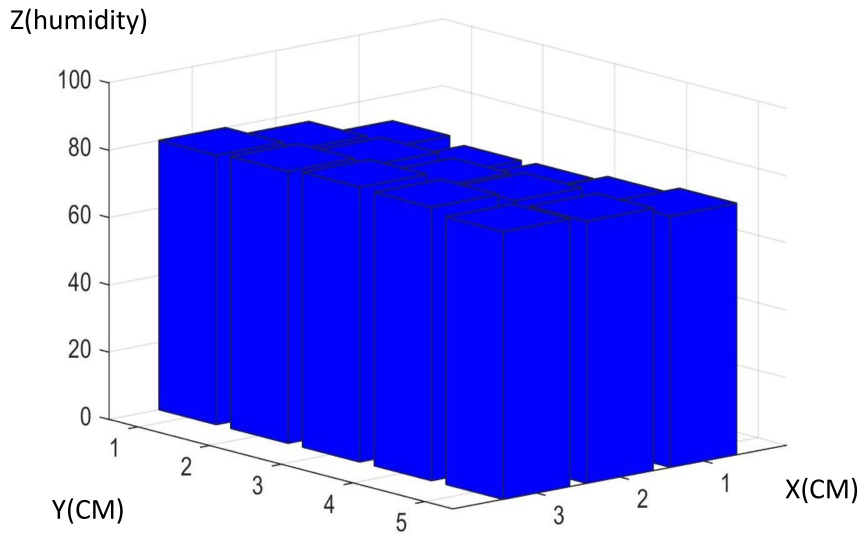

Figure 18 Difference in distribution

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