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Portable Baby Incubator for Monitoring Sleep Apnea

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***Abstract*—A baby incubator is a biomedical equipment that can provide warmth, humidity, and adjust the amount of oxygen input into a chamber for premature newborn babies for ideal conditions similar to those of the mother. Newly born babies or preterm babies are very sensitive to rough environments. Newborn mortality has been a global issue worldwide. Sleep Apnea disorder is a major concern in newborn neonates. Adding to this, newborns may have immature, underdeveloped lungs that necessitate care and additional oxygen. Existing models available in the market are expensive and at the same time very difficult to be used in remote locations like rural maternity centers, makeshift primary health centers or war-affected areas. Due to these issues, a Portable baby incubator is necessary that can provide the same environmental conditions as a mother's womb does and monitors the baby's vital conditions such as heartbeat, blood oxygenation level, skin temperature etc. The COVID-19 epidemic has made healthcare a top priority. Being physically present with the patients has become a huge problem for doctors. In such cases, implementing an application with hospital equipment such as a Smart Baby Incubator is necessary. Our goal is to make a smart baby incubator that can detect a baby's vital parameters and indicate its deviation, from its normal state. The model is integrated with the mobile app so that doctors can track the baby's condition remotely. In the presented model baby's temperature, heart rate and SpO_2 are monitored continuously. The efficiency of the model is tested on neonates and different age groups. The results obtained are found within the standard medical condition limits.**

***Index Terms*— Baby Monitor, Neonate, Portable Incubator, Sleep Apnea, Vital Signs.**

I. INTRODUCTION

An incubator is an enclosed, insulated device that offers the ideal levels of humidity, temperature, and other environmental variables needed for the growth of neonates. A baby can reside in a safe, regulated environment in an incubator as its vital organs grow. An incubator, as opposed to a straightforward bassinet, offers a setting that can be altered to deliver the optimum temperature as well as the ideal level of oxygen, humidity, and light. Incubators are frequently found in a newborn intensive care unit (NICU). The finest setting and ongoing supervision are provided for babies who require additional support by employing them in conjunction with other tools and techniques. For a variety of reasons, babies may be kept in incubators. Some of them are Premature birth, Breathing issues, Infection, the Effect of gestational diabetes, low birth weight etc.

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Premature babies can't alter their physiological or behavioral processes to produce more heat, which limits their ability to generate heat, and they have a limited supply of brown fat and glycogen. Heat loss on the skin's surface is caused by humidity evaporating. Heat transfer occurs when a baby's skin comes into contact with cooler surfaces. The Neonatal Mortality Rate (NMR), which accounts for more than 46% of all child fatalities before the age of five, measures the number of newborn deaths per thousand live births which were 2.5 Million in 2018. which translates to 7000 fatalities daily.

Infant sleep apnea is a respiratory condition that affects sleep. It involves respiratory changes and pauses that take place while a baby is sleeping. In the NICU, apnea monitors are a component of the patient monitoring systems. Infant sleep apnea is particularly common in small, premature infants. Sometimes it affects larger full-term or preterm infants. Infants younger than six months old are less likely to experience it. In the first month after delivery, 84% of newborns weighing less than 2.2 pounds experience it. When a baby is under 5.5 pounds in weight, the risk drops to 25%. In fully developed babies, it is uncommon. Infant sleep apnea typically manifests between the second and seventh day of life in preterm infants. On the first day of life, it is uncommon. When it is present at birth, it typically indicates another ailment. Infant sleep apnea can be caused by a number of medical issues. Lung illness, anaemia, infections, metabolic diseases, neurological issues, seizures, and small upper airways are some of these issues. Figure. 1 shows the Premature Babies in Incubator (Neonatal Intensive Care Unit).

There have been numerous low-cost incubator concepts put forth in the past. In this study, the prospect of designing a design that enables developing countries to build, assemble, and maintain incubators in an efficient and affordable manner using local and accessible resources.

Figure. 1: Premature Babies in Incubator (Neonatal Intensive Care Unit)

II. Literature Survey

This article offered innovative techniques for developing a dependable baby incubator using a UNO microcontroller [1]. The idea of creating an infant incubator based on Android that a medical practitioner could access and control via an Android application is presented in this article [2]. In this work, an Arduino-based infant incubator with serial port control is demonstrated [3].

This study introduces a wearable, precise, and energy-efficient technology for long-term monitoring of obstructive sleep apnea [4]. This study describes a portable, lightweight incubator that uses a solar panel for power. The idea resulted in a portable, easily powered, affordable incubator that can be used in third-world countries. In the third trimester of pregnancy, premature newborns are the main topic of this article. Wi-Fi and infrared technologies, which measure the critical variables that must be regulated for preemies, form the foundation of the design. These variables include temperature, blood oxygen saturation, and heart rate [5]. For the clinic in the remote area, a prototype of a baby incubator that can perform the essential duties of the incubator and is also inexpensive, transportable, and energy-efficient was developed. An infant-friendly, lidded container that is portable is presented [6]. In this study, a brand-new method for video processing-based sleep apnea detection is presented. Non-contact, and light enough to function on a single board computer is proposed [7].

The usefulness of pulse oximetry as a minimally invasive method of automated diagnosis of sleep apnea in newborns is examined in this paper. Detection of Sleep Apnea-Hypopnea Syndrome is addressed [8]. Presents technology, where the temperature variations for certain uses, such as a baby incubator, will be under control.

The use of infant incubators around the world helps babies survive by giving them a warm atmosphere and minimizing heat loss from the baby body is addressed [9]. For the clinic in the remote area, a prototype of a baby incubator that can perform the essential duties of the incubator and is also inexpensive, transportable, and energy-efficient was developed. An infant-friendly, lidded container that is portable is developed [10].
According to medical standards, newborns need a core temperature of about 37 °C and a typical skin temperature between 35.5 °C and 37.2 °C (Asakura, 2004). Lipolysis and gluconeogenesis are therefore involved in the very diversified process of maintaining this temperature zone. This is related to the consumption of glucose, oxygen, and energy. Less energy is available for other processes like growth, brain development, or lung maturation the more energy is required to maintain a stable body temperature. Basically, hypothermia results in acidosis, decreased tissue oxygen supply, and vasoconstriction by increasing oxygen consumption and causing the oxygen dissociation curve to move to the left (Bissinger & Annibale, 2010).

III. Problem Identification and Objectives

A. Problem Identification

Infant incubators are crucial because they assist your baby to maintain a healthy body temperature and so prevent hypothermia. Baby incubator temperature controls can be set manually or automatically based on your infant's temperature. We need an "artificial womb," which is nothing more than an incubator, to care for babies who are born at fewer than 32 weeks of gestation so that they grow as predicted. Most incubators run on electricity, therefore when there is an acute shortage of Electricity, this existing expensive baby incubator is of no use. Based on the field survey, we saw a need for Government maternity homes and Affordable Incubators at rural hospitals. Furthermore, rural hospitals and government maternity homes must have a sleep apnea monitoring facility. Asphyxia, mental stress, and congenital reasons are all brought on by premature infants' lack of sleep monitoring, which is required. To address the issues a portable incubator is required.

B. Objectives

Based on the Survey, we planned to achieve the following design objectives. The first objective was to design a portable Incubator for Premature infants. The model shall maintain the environmental conditions suitable for a neonate. The second objective was to develop a sleep apnea monitoring system. In this design, we monitor the patterns of the vital signs, while the infant is asleep. The objectives achievement is explained in the further section.

IV. Design and Development

The Design and fabrication should offer intricate, sturdy compartmental entities that are designed to occupy space as little as possible and are therefore compactly made. The materials were sourced and acquired in such a way that they were rated according to fundamental engineering principles, among other things, the installation environment, safety, actuation, finishing luster, and durability.

A. System Design

Heart rate, SpO_2, and temperature, the three vital signs depicted in Figure. 2 are continuously and wirelessly monitored for a more thorough diagnosis and a temporary remedy in case of emergency. Sensors are used to monitor the vital signs of the baby. These signals are evaluated by a microcontroller, reported, and displayed on a mobile LCD application and an application.

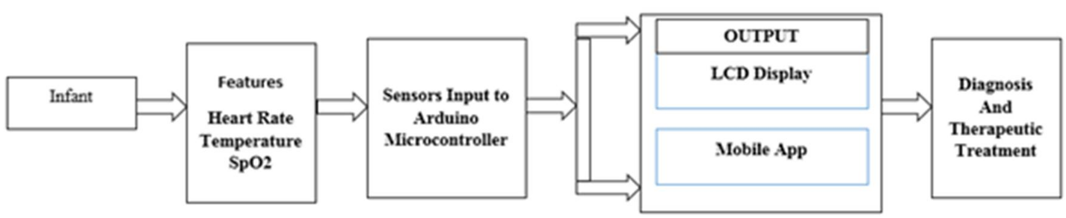

Figure 2: Baby Incubator Block Diagram

B. Extracted Features

In this model development, we extracted a wide range of features, such as temperature, oxygen saturation percentage, and heart rate. The next subsections introduce these features.

1) Heart Rate (HR) and SpO_2: This gauges how many times per minute the heart beats. Electrocardiographs are frequently used to monitor electrical cardiac signals (ECG). By measuring the frequency, time domain, waveform, and amplitude of the heart signal, ECG can analyze it. ECG, on the other hand, necessitates the continual affixing of numerous electrodes with a particular gel, which causes discomfort, agony, and skin damage to the delicate, premature infant. In addition, it is challenging for the mother to handle. To get around this, we decided to use infrared technology to extract the heartbeats. SpO_2 is the percentage of oxygen in the blood. There is a fine line between receiving too much and not receiving enough supplemental oxygen doses in research on preterm babies. SpO_2 must be checked and maintained between 90 and 93 percent to prevent llnesses since both excessive and inadequate usage of supplementary oxygen can harm preemies. As a continuous, noninvasive method of oxygenation monitoring, pulse oximetry has many advantages. In fact, it can be challenging to frequently take enough arterial blood from small premature neonates to assess the partial pressure of oxygen in their blood. Here, we have used MAX30100 SENSOR, an electronic chip from Analog Devices that combines a pulse oximeter and a heart rate sensor. It uses two LEDs, a photodetector, improved optics, low-noise analogue signal processing, and two LEDs to detect heart rate (HR) and SpO_2 readings.

2) Temperature: Infants who do not have their body temperatures controlled are at a high risk of developing hypothermia. It has been shown that neonatal hypothermia increases the risk of preterm delivery problems, coagulation abnormalities, infection, etc. We made care to continually monitor the preemie's temperature as a result. We have used DHT22 digital temperature and humidity sensor It measures the humidity and temperature of the air around it using a thermistor and a capacitive humidity sensor, and it outputs a digital signal on the data pin. It measures temperatures between -40 and +125 degrees Celsius with an accuracy of +-0.5 degrees.

C. Controller and Output

A low-cost, adaptable, and simple-to-use programmable microcontroller Arduino UNO is used for the controlling of commands through the relay to the output. A baby is placed in an open incubator on a level surface with a radiant heat source above. The temperature of the baby's skin automatically regulates the heat output. Although there may be numerous monitors visible, the incubator is open above the infant. Here a 40W bulb is used as heat source to provide the required heat warmth in the incubator. The temperature of the baby's skin automatically regulates the heat output.

D. Heat Exchange Mechanism

Open incubators do not offer the same level of humidity control as closed incubators because of this open-air area. They can still warm a newborn and keep track of their vital signs, though. With a newborn in an open incubator, it is simpler to achieve skin-to-skin contact since you can reach up and touch the child immediately. The infant model is shown in Figure.3. One or four lumps can be used to represent the head, trunk, upper limbs, and lower limbs of an infant in models. The latter model has the advantage of showing that the newborn parts are at different temperatures. Models that have been developed take into account the infant's core and skin layers. The body of a baby has a core and skin, which exchange heat in one- and four-lumps models, respectively.

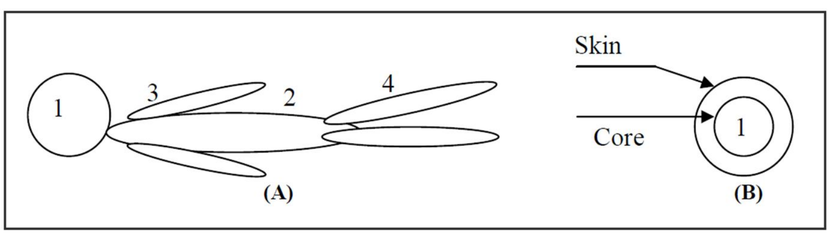

Figure 3: Infant Model (A)/Segments-Layers (B)

The respiratory system and the infant's skin serve as the primary means of heat exchange between the two. The rate of heat energy loss from evaporation has been measured thanks to the development of novel tools for measuring evaporation from the skin and the respiratory tract. It is also feasible to figure out how much heat is lost through conduction, convection, and other types of heat exchange. Additionally, the proportions of surface area involved in the various mechanisms of heat exchange must be taken into account in order to calculate the overall heat loss per unit surface area from the entire body surface area of the neonate. Basically, the heat exchange through radiation (Hrad) can be determined if the mean temperature of the skin (T1, in °K (Kelvin)) and the mean temperature of the surrounding walls (T2, in K) are known:

$$Hrad = S_0.\ e_1.\ e_2.\ (T^4_1 - T^4_2)\ [W/m_2]\text{---Eq.1}$$

where S_0 is the Stefan-Boltzmann constant (5.7 × 10-8 W/m 2K4), e1 is the emissivity of the skin, and e2 is the emissivity of the surrounding walls (0.97).

Heat exchange through convection (Hconv) can be calculated if the mean temperature of the skin (T1, in K) and the mean temperature of the ambient air (T3, in K) are known:

$$H\ conv = k2\ (T1-T3)\ [W/m_2]\text{---Eq.2}$$

where k2 is the convection coefficient (2.713 W/m^2 K).

Heat exchange through conduction (Hcond) can be determined if the temperature of the skin (Tskin; K) and the temperature of the bed (Tbed °C) are known:

$$Hconv = k0\ (Tskin-Tmatress)\ [W/m^2]\text{---------------------------------------Eq.3}$$

E. Simulation and Working

In the section, an open-source 3D modeling tool Tinkercad was used to understand the output of the planned design of the first objective as shown in Fig 4. Arduino UNO, DHT22 sensor with 40W bulb formed the major components for its achievement. For the second objective another open-source CAD software Fritzing was used. The major components included Node MCU, MAX 30100 sensor and an OLED. The program designed gave satisfactory output.

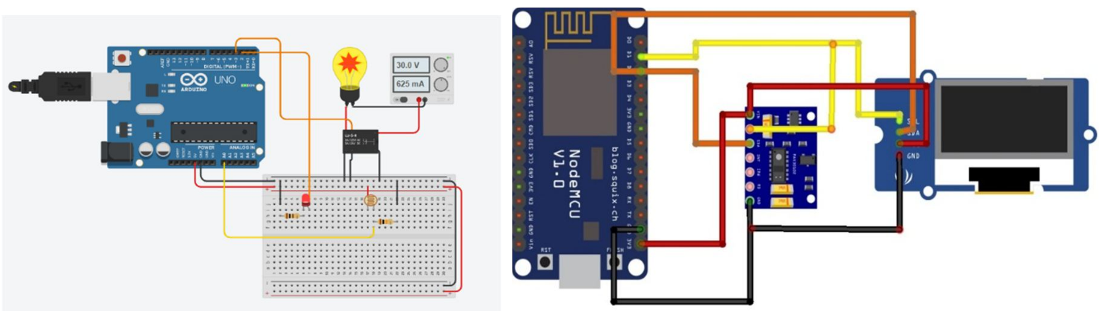

Figure. 4: Simulation through Tinker CAD and Fritzing

The proposed flowchart for the first objective is shown in Fig.5 on the Left Hand Side (LHS). When the Temperature and Humidity are measuring 35^o of 60%, the Heat source i.e bulb remains in the off state. When the Temperature drop below the set value, the bulb is turned on to provide the required warmth and maintain the temperature. The proposed flowchart for the second objective is shown in Fig.5 on the Right Hand Side (RHS). If the vital parameters deviate from 90% for SpO_2 and 145bpm for Heartrate, then a buzzer is provided as an alarm indication.

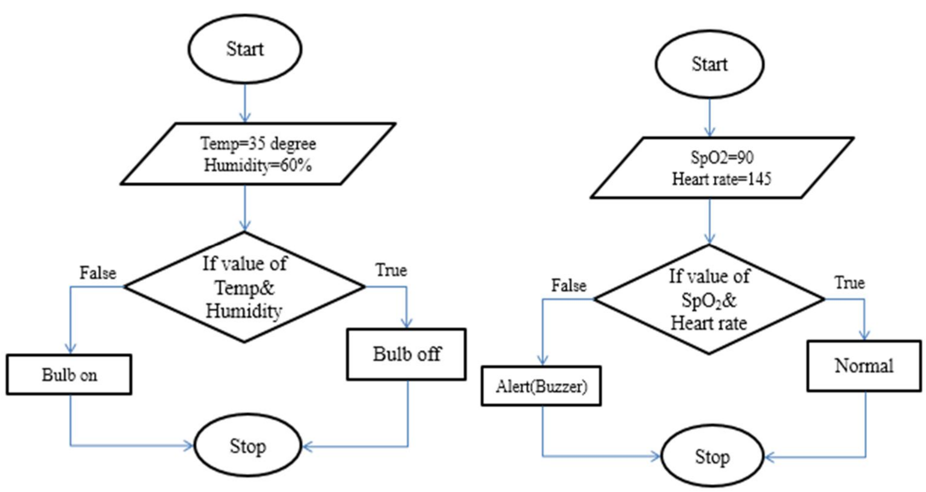

Figure. 5: Flowchart for Temperature and Humidity Monitoring in incubator on the LHS and Flowchart for SpO_2 and Heart Rate Monitoring in incubator on the RHS

V. RESULTS AND DISCUSSION

The design went through various changes and improvements. Fig.6 shows the 3D model of the incubator respectively. The Final model designed is shown in Fig.7. The analysis was carried out on different Test subjects of different age groups. The normal range for a newborn baby's temperature is typically between 96.8 and 100.3 degrees Fahrenheit, with 98.6 degrees Fahrenheit serving as the average. The temperature of a baby can be taken in a number of ways. Despite the differences, each value is significant in its own right. Several methods exist for taking a temperature, including rectal, temporal artery, axillary/underarm, oral, and tympanic. Whereas heart rate varies from 70 to 190 beats per minute in newborns i.e 0 to 1 month of age. 80 to 160 beats per minute for infants aged 1 to 11 months. 80 to 130 beats per minute for kids aged 1 to 2. 80 to 120 beats per minute for children ages 3 to 4.

Figure. 6: 3D model Design of the proposed incubator

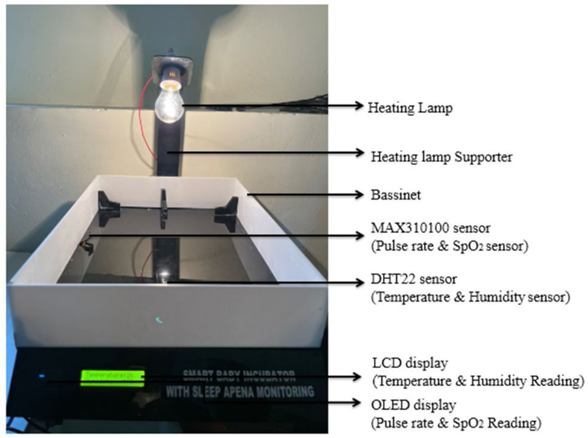

Figure. 7: Final Design of the proposed incubator

The baby shall be placed in the bassinet which is planned after observing the real-time model. It is also observed in warmers, black cloth is tied around the eyes of premature infants to avoid direct rays falling into the eyes which may damage the retinal features. MAX310100 sensor (Pulse rate & SpO_2 sensor) and DHT22 sensor (Temperature & Humidity sensor) are positioned at such a place after iterations to capture the best results. LCD display provides Temperature and Humidity readings, while the OLED display provides Pulse rate & SpO_2 Reading. The bassinet has a width of 13inches and a height of 18 inches. The lamp source is placed at a height of 13 inches from the bassinet where the newborn will be rested. The dimension of the incubator is shown in Figure 8. Here a 60W, lamp load is used as a heating source.

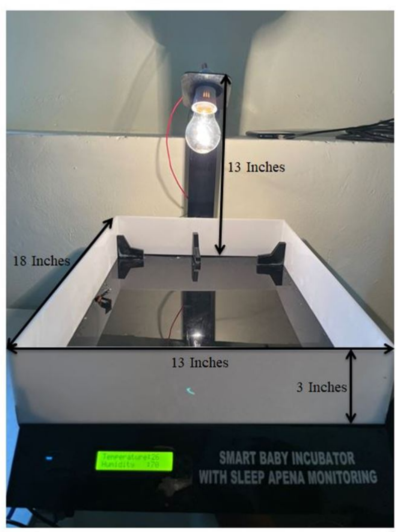

Figure. 8: Final Model Design with dimensions after heat source is on

TABLE I. INCUBATOR HEART RATE RESULTS

SL.No.	RESULTS TABULATED		
	Age Group	Normal Heart Rate in bpm	Obtained Value in bpm
1	<2 Years	135-145	140
2	4-6 Years	120	118
3	8-12 Years	110	110
4	12-15 Years	108	106
5	15-18 Years	104	102

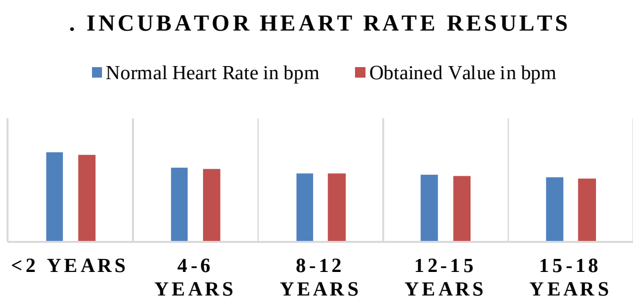

Figure. 9: Normal Heart Rate and Obtained Results

The 95 percent of infants maintain SpO_2 at or above 93-97 percent, depending on age, throughout regular breathing. The Table I, the obtained results are close to the standard values indicating their accuracy. The analysis is plotted in Figure 9. The perfect room temperature is from 72 to 75 degrees Fahrenheit. Premature infants refer to the higher end of this temperature range since they must expend more energy to stay warm in lower temperatures.

TABLE II. INCUBATOR SPO_2 TEST RESULTS

Individual Type	RESULTS TABULATED		
	Normal Level	Obtained Value Test Subject-1	Obtained Value Test Subject-2
New Born	93-97	90	96
Adult	95-100	96	97

Likewise, in Table II, results obtained are close to the standard values. The analysis is plotted in Figure 10. The captured data is continuously logged in the Bluetooth electronics app as shown in Fig. 11. To an HC-06 or HC-05 Bluetooth module, this software uses Bluetooth to interact. The app provides the status of the heat source i.e on/ off condition and captures the temperature, humidity etc parameters. A sample Test subject of age group <2 Years was used for the testing & its results are shown in Fig 12.

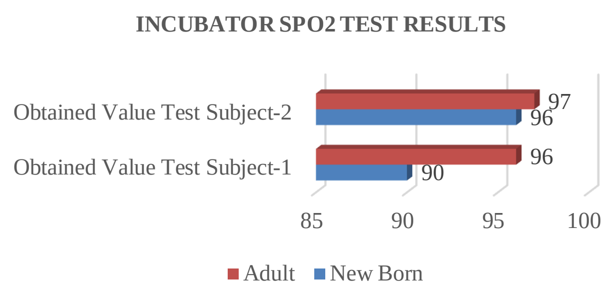

Figure. 10: Normal Heart Rate and Obtained Results

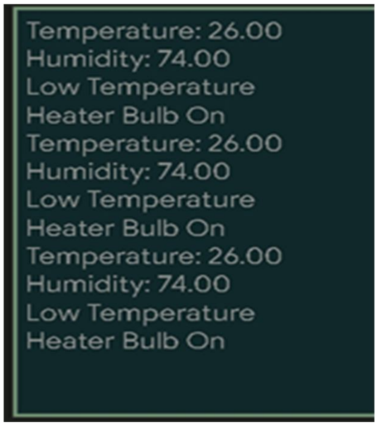

Figure. 11: Application capturing the dynamic vital signs data of the baby

Figure. 12: Baby during the Test process and the results in the OLED

VI. Applications and Advantages

The customized design Monitoring the Sleep Apnea shall help the NICU unit in monitoring the neonates in primary healthcare centers, rural maternity hospitals, makeshift health centers, Pandemic/Flood affected countries with health rehabilitation centers etc. The low-cost ergonomic model can be utilized to cater to the needs of the societal newborn healthcare issue.

VII. Conclusion and Future Scope of Development

Based on the design and fabrication of an effective incubator the proposed objectives were achieved. The developed incubator promotes the infant incubators existing in the market. In addition to the incubator's warming function, it also offers other features like monitoring vital signs to get the baby the medical attention he or she needs to survive. Further, the designed model space required and ease of carrying makes it effective.
As a future development, the team suggests incorporating digital weight measurement in the unit which is an essential parameter to monitor. Also, temperature sensors embedded in a customized bed where the infant rests and its performance can be analyzed.

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