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Affordable Diagnostic Infused Thermal Incubator

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Abstract:
Preterm birth complications are the leading cause of death among infants with most of the deaths occurring in developing nations. 20,000,000 premature Babies are born each year and 4,000,000 babies die within their first day of their life. Neonatal incubators are very limited and unavailable in rural areas. Preterm birth children are more susceptible to critical conditions like Hypoxia and Apnea. Risky methods like use of incandescent bulbs are used in rural Primary healthcare centres. Long term vitals monitoring is really uncomfortable in existing systems. Our solution is a novel diagnostics enabled body warmer which would continuously monitor parameters such as Respiration Rate, SPO2, ECG and temperature of the body. The bodysuit consists of fabric based resistive filaments that safely provide warmth to the neonate as due to preterm birth body fat is miniscule. The heating is carefully controlled and will use PID control for accurate temperature control. The oxygen saturation in blood is measured in the earlobe. Hypoxemia and Apnea can be detected early using Respiration and Blood Oxygenation data to trigger alerts. The device can potentially be the only incubation system in remote village where standard incubators may not present.

Keywords:*Respiration Sensing, Neonatal Care, Assistive technology, Incubator, Wearable sensor, BLE, telehealth.*

I. INTRODUCTION

India has the considerably larger number of preterm and low weight babies by birth. We have an addressable market of 15.1 million babies worldwide and out of which 4.8 million suffer from preterm birth complications. Even in urban areas, preterm birth children need monitoring post discharge we see a plausible opportunity in making a wearable monitoring device for infants using the monitoring elements without the warmer[1]. Most of the preterm birth occurs in Southeast Asia and Africa. India fights to decrease Neonatal mortality rate along with many countries.In 1990,World leaders pledged at the United Nation's Millennium Summit to reduce the deaths of children under 5 years old by two thirds by 2015. Though under mortalityratehas been declining over the last two decades, the decline in neonatal mortality rate (the first 28 days of a baby's life) has been slow. Currently, neonatal mortality constitutes about 37%. Thus the neonatal health care needs an intervention. 20 millionbabies born every year lave low birth weight; Among them 4 million die, and many of those that survive may have low IQ, early diabetes, and heart disease [2]. These problems could be avoided by providing thermal regulation, which is the function of an incubator. Traditional incubators are expensive and available only in urban hospitals. Rural parents could not havean access to incubator. Also, Continuous monitoring of the electrocardiogram, Body temperature, oxygen saturation in blood andrespiration are crucial for early diagnostics and accurate treatment. Early diagnosis can reduce the mortality rate. Diagnosis becomes slow due to lack of proper tools. Providing timely aid decreasesthe deathrateofchildren. Human and monetary resource can be conserved by monitoringremotely. Currentlyoximeters are not portable and they are expensive. The changes in CO_2level in exhaled gascould also be monitoredto know the respiration. Hypoxemiamay occur when theoxygen concentration in the blood goes very low. The

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Temperature of the body helps on diagnosingthe effectiveness of medication. This method needs dedicated manpower. The purpose of wearable sensor in infant's health monitoring is to provide appropriate care during complications. Thus, health monitoring system provides early intervention.

EXISTING INCUBATORS (GE HEALTHCARE – LULLABY WARMER)

Figure1:LullabyBabywarmerbyGEHealthcare

The Lullaby Warmer is very simple and easy to use. System operation is intuitive and requires minimal training. The heat distribution is uniform and stationary in nature. It is more expensive than our solution[3].

Figure 2: Low cost Embrace Babywarmer

The cost of Embrace infant warmer is low. It maintains premature and low-birth-weight babies' body temperature. This infant warmer is safe, reusable, portable. Also it requires only intermittent access to electricity. The baby warmer is priced at $25approximately. It regulates the temperature of vulnerable low-birth-weight and premature infants. It is estimated that the Embrace infant warmers have helped over 50,000 babies in India [4].

II. SPECIFICATIONS

Monitoring vital signs are an important part of maintaining the health of infants and patient status is determined by whether each parameter falls within the range that is set out in clinical guidelines. Pulse oximetry along with the traditional four vital sign parameters of respiratory rate, heart rate, blood pressure, and temperature are recorded because, if abnormal, they indicate that a patient has deranged physiology. These observations need to be repeated at a frequency that will provide useful information on the progression of the disease. Failure to measure vital signs will deny the deteriorating patient the possibility of early detection and therefore missing the opportunity for improved prognosis. It has been suggested that practice of vital sign measurement can sometimes become a nursing ritual than a useful activity, an integrated monitoring system would assist the nurse in detecting deterioration in this situation. Physiological data typically collected in NICU are listed as below.

- Heart rate
- Respiration rate
- Oxygen saturation
- Core and peripheral temperature

Table 1 Normal range of measurements [5]

Heart rate	130-160 bpm
Respiration rate	30-60 bpm
Oxygen saturation (Spo2)	86-100%
Peripheral temperature	36.5-37.5 °C

1) **Respiration Sensor**:

Respiratory Rate (RR) is to be monitored for both healthy and children under critical condition. The Respiration Rate is defined as the number of breaths

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in one minute. A typical RR for a neonatal infant is 30 to 50 breaths per minute. We have come up with a novel method to measure the thoracic expansion due to breathing using a custom piezoresistive fabric belt sensor. Electronic textiles are helping to improve interfacing of electroniccomponents. The emerging technologies are useful for wearable sensors. This monitoring can be achieved by integrating biosensors into portable health monitoring devices. The spirometer is the most accurate instrument in respiration monitoring.

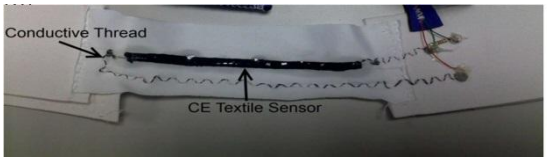

Figure 3: Thoracic Respiration Sensor using piezoresistive fabric.

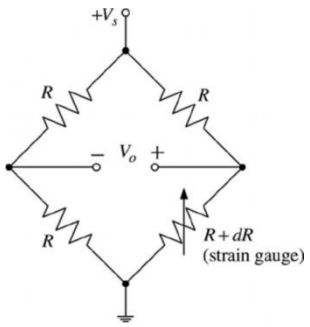

Figure 4: Wheatstone respiration circuit

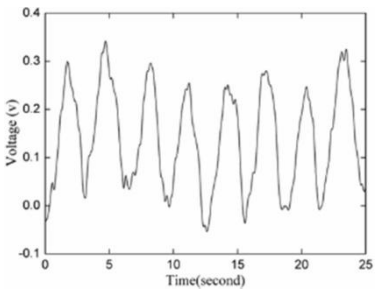

Figure 5: Data plotted from sensor

Breath-by-breath annotation files corresponding to salient points in the breathing cycle, the start of inhalation and exhalation, were created as part of this work. To construct breath-by-breath reference time-stamps for each database, the peaks of the reference airflow respiratory signals are taken to be the start of each respiratory cycle. Using this respiration rate can be found.

2)Electrocardiogram:

ECG is a biosignalthat describes the heart activity. The ECG is used for cardiorespiratory monitoring in neonates. The use of gel electrodes for ECG may cause irritation and allergy and the wiresmay disturb infants and nurse. Hence, the use of traditional gel electrodes may be avoided in the measurement ofinfant's ECG measurement.

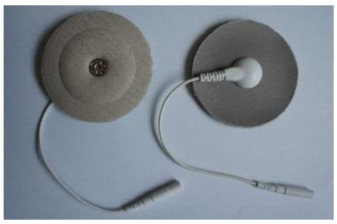

Figure 6: Conductive Silver fabric based electrode

A single lead ECG was chosen for it's simplicity and ease of processing but multi lead ECG can be added to the system for special cases. The ADS1292 ECG Analog Front end was chosen for it's pricing and performance. The chip can be interfaced over SPI for large data access.

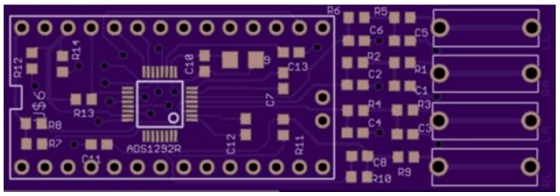

Figure 7: ADS1292 ECG PCB used

The data is acquired over USB to a single board computer for filtering and signal processing.

Figure 8: Processed signal data

A 50 Hz notch filter is used to remove powerline interference and a motion artefacts are removed using a bandpass filter of range 0.5Hz to 60Hz.

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3)Pulse Oximetry:

Pulse Oximetryfor detectinghypoxemia is widely used in hospitals for measurement of SPO_2. There are differences in healthcare between the countries of developed and developing.The oxygen saturation in blood is measured by comparing the light absorbed by blood. The principle that light absorbance by hemoglobin depends upon its level of oxygenation. Oxygenated (HbO) and deoxygenated (Hb)hemoglobin have different light absorbance spectra. Comparison of absorbance allows estimation of the relative concentrations of arterial oxygen saturation (SpO2))[9]. This technique can provide reliable monitoring of the patient. The absorption or reflection of light passing through tissue is measured and it is processed to read the pulse rate and oxygen saturation. The smart sensor MAX30100 is chosen to measure SpO2. By doing this we can detect hypoxia[10].

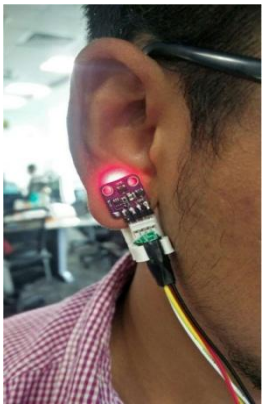

Figure 9: Project member wearing the pulse oximeter sensor

1)Body Temperature:

Babies are not adaptable to temperature change as adults. A baby's body temperature is about three times greater than an adults. Babies can lose heat rapidly more quickly than adults. It is thus important to monitor the temperature of the infant to detect emergencies like hypothermia. The sensor we use is a TMP36 analog temperature sensor.[11]

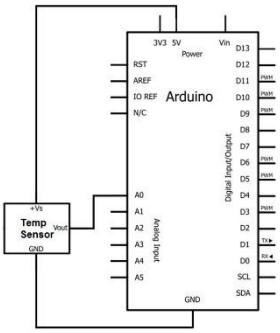

Figure 11: Circuit Diagram for TMP36

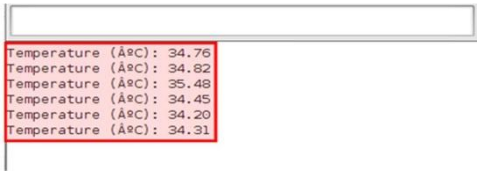

Figure 12: Temperature data from sensor

5) Heating Control:

Hypothermia occurs when the temperature of the body drops below 36.5°C. The body temperature of the newborn infant between 36.0-36.4°C may be under cold stress. An infant with a body temperature of 32.0-35.9°C has moderate hypothermiaand a temperature below 32°C (89.6°F) is to be considered as severe hypothermia [12]. Preterm birth children and low body weight infants lack enough fat tissue to sustain heat and the body heat often gets dissipated as illustrated by the figure below

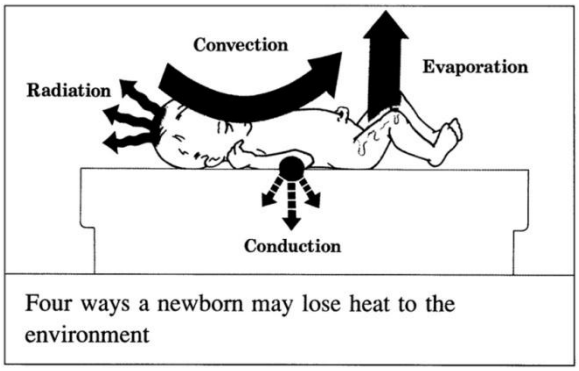

Figure 13: Heat loss in newborn infant

The Heating Fabric is a newly designed electrical heating system for mobile heating and energy saving.The Ultra Heating Fabric isa smart textile technology. A novel conductive yarn made of metal-polymer fiber composite is introduced in the Fabric. This conductive yarn is strong and can be enhanced easily in conductivity, and thermal

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resistance. The composite metal-polymer conductive yarn can be directlyintegratedwith bodysuit of the infant [13].

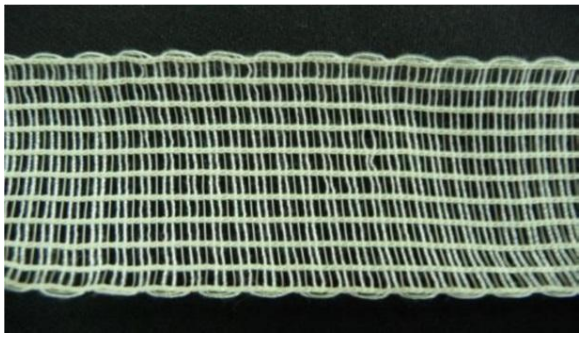

Figure 14: Heating fabric used in device

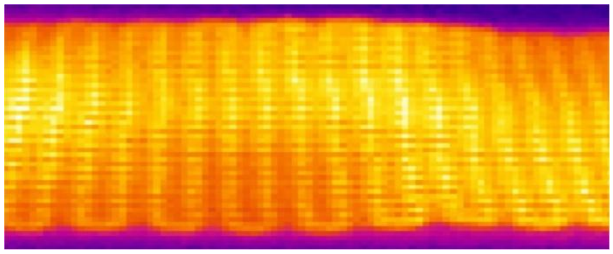

Figure 15: Thermal image of heating fabric

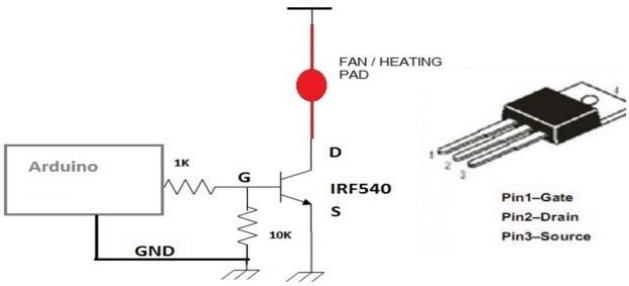

Figure 16: Control mechanism for heating element

Pulse width modulation is used to control the amount of heat given to the child, The gate of an N-MOSFET is driven by the Microcontroller and appropriate protection is given to the I/O pin. The drain pin is connected to one terminal of the heating pad. The Source is connected to the negative pin of the Boost convertor. The other terminal of the heating pad is connected to the positive of the boost convertor. The connection is show in above diagram connecting the MOSFET to the heating pad.

Table 2 Heating characteristics at 9V

Length of the Fabric	8cm	8.8cm	9.6cm	10.4cm	11.2cm	12cm	12.8cm
Input	9V	9V	9V	9V	9V	9V	9V
Current, A	1.3	1.25	1.18	1.1	1.06	1.02	1.0
Temperature, ℃	110	108	100	91	86	82	73

III. SYSTEM DESIGN

Our solution is a smart infant bodysuit that consists of fabric based resistive filaments that safely provide warmth to the neonate as due to preterm birth body is fat is miniscule. The heating is carefully controlled and will use PID control for accurate & safe temperature control. Comfortable textile based electrodes monitor ECG, Respiration Rate, Pulseoximetry would be integrated with the baby's hoodie and would measure the oxygen saturation in blood in the earlobe. Hypoxemia and Apnea can be detected early using Respiration and Blood Oxygenation data to trigger alerts. The Prototype named ADITI consists of sensors for monitoring the parameters like SPO2, Body Temperature, Rate of Respiration and Heart Rate. The schematic of ADITI is given in Figure 17. The sensor’s data are read by a Micro Controller unit and is transferred to server using Wi-Fi. A 3.3 V, 1000mAh Lithium Iron Phosphate battery is used to provide power. This prototype is part of a body suit and is being unobtrusive to the child.

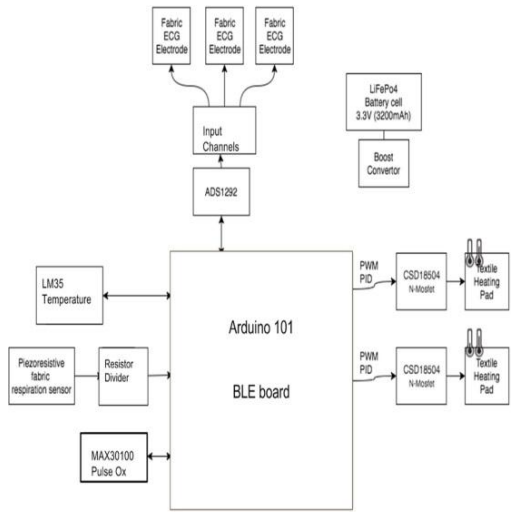

Figure 17: Control mechanism for heating element

Table 3: Specifications of proposed solution

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Specification	Value
Size	81mm x 51mmx20mm
Battery	10000mAh
Power Consumption	1 Watt
Battery Life	2 days
UnitCost (1000pcs)	100$

Data Processing and Communication:

An Intel Curie microcontroller is used for collecting datafrom sensors. Sleep modes could be enabled to increase the life of the battery. An onboard BLE module provides wireless connectivity from the microcontroller. Even though Bluetooth Low Energy is low range we have chosen it to increase safety of the device. To conserve battery, the BLE transmission is done. ADITI is designed using commercially available components. A nRF52832 Micro controller could be used due to its low cost and low power consumption. The data can be transferred through smartphone or through gateway device.

Power Management and Battery:

The prototype is powered using a 3.7 V, 10000 mAh Lithium Polymer battery. A DC- DC converterprovides a 9 V supply to controller circuit and 5V to the power supply circuit.

The current prototype uses a 2 Amp charger. The next version would be using a Lithium Iron Phosphate battery for increased safety. Solar charging would also be explored to recharge the battery in remote areas.

Packaging:

The system is designed to be completely wearable with major sensors being integrated with the bodysuit. The heating fabric would be distributed along the body to enable uniform heating of the infant.

IV. USAGE

The ADITI is designed to reduce intervention ofparents for monitoring health of the child. After primary examination of the neonate, the doctor may prescribe ADITI bodysuit for warming the preterm baby and his continuous monitoring . The device sensors can be dynamically adjusted by the healthcare worker to suit the child. The parent could be given graphical instructions for using the device.

Figure 18: Data visualization for doctor

V. CONCLUSION

The multi-parameter monitoring and controlled heating was achieved using noninvasive and commercial sensors and textile heating element. The data was transferred over Bluetooth Low Energy to a mobile phone which can transmit the data to the doctor over GSM. This data would be vital to assess the condition of the neonate and the warmth would be able to provide sustenance.

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