# Design of Kangaroo Mother Care Device with Integrated Vitals Monitoring Systems as Alternative to Incubators

**John Kutor[1*], Adjoa Oparebea Ansah[1] and Joseph Owusu Afriyie[1]**

[1] Department of Biomedical Engineering, University of Ghana, Legon, Ghana.

***Corresponding author:** jkutor@ug.edu.gh

## ABSTRACT

Prematurity kills more than 8000 babies annually in Ghana since the organs of these babies are often under-developed which renders them vulnerable to various infections. In order to save the lives of these babies, they are often placed in incubators. In situations where incubators are not available, a kangaroo mother care (KMC) approach is employed. The traditional KMC lacks means of monitoring vitals such as the temperature, $SPO_2$ level, heart rate and blood pressure of these preterm babies. The practice of the KMC might also pose some inconvenience to the mother since part of the body is exposed. In this project, we integrated the traditional KMC with electronic vitals monitoring system and also addressed the problem of inconvenience of part of the body exposure of the parent practicing KMC. The engineering design process was followed and a functional mockup was constructed. The mockup was tested by comparing the results generated to the results of an existing calibrated devices and the error margins were calculated as 0.62, 0.52, 0.41 and 0.34 for blood pressure (BP), heart rate (HR), temperature and $SPO_2$, respectively. This device could be an alternative option to baby incubators

**Key words:** Preterm, incubators, Kangaroo, vitals, prototype.

## INTRODUCTION

A premature birth is a birth that takes place more than three weeks before the baby's estimated due date. In other words, a premature birth is one that occurs before the start of the 37th week of pregnancy (Lawn et al., 2013). Historically, the definition of prematurity was 2500 grams (about 5½ pounds) or less at birth. The current World Health Organization (WHO) definition of prematurity is a baby born before 37 weeks of gestation, counting from the first day of the Last Menstrual Period (LMP) (Charpak, Figueroa, & Ruiz, 1998). Such babies are also known as preemies or preterm. Depending on how early a baby is born, he or she can be classified as late preterm (born between 34 and 36 completed weeks of pregnancy), moderate preterm, (born between 32 and 34 weeks of pregnancy), very preterm (born at less than 32 weeks of pregnancy) and extreme preterm (born at or before 25 weeks of pregnancy) (Simkiss, 2004). The 2016 United Nations Children's Fund (UNICEF-Ghana) report says prematurity kills more than 8000 babies in Ghana annually (Veronez et al., 2017). Preterm babies are highly susceptible to difficulty in breathing and infections which are significant threats to their lives. This is due to the undeveloped organs and systems, causing significant mortality rates. Common complications associated with these babies include hypothermia, apnea, hypotension, and slow heart rate or bradycardia, among others (Randis, 2008). Incubators reduce mortality by providing optimum temperature as well as monitoring the vitals of the preterm baby. In the absence of an incubator, a traditional approach known as the kangaroo mother care (KMC) serves as an alternative means of providing optimal temperature for the baby.

KMC emerged in 1984 and was proposed by neonatologists Edgar Rey and Hector Martinez of the Instituto Materno infantile in Bogota, Colombia (Charpak et al., 1998). It was initiated as an alternative approach to traditional Neonatal Intensive Care Unit (NICU) care for low-birthweight infants, in response to overcrowded nurseries, scarce and costly resources such as incubators, and high rates of neonatal infection and mortality (Robert, 2003). It is the practice of skin-to-skin contact between an infant and a mother. The overall approach was termed 'kangaroo mother care' (KMC) (Francis & G.B;Priscilla. W;Robert.C.L, 2016). During the practice of KMC, the baby is clad in a diaper and cap, and held in an upright prone position against the bare chest of the parent (most often the mother) and covered with clothing and/or a blanket. The baby is positioned such that (Robert, 2003);

1. The head is turned to one side and in a slightly upturned position. This position helps in breathing and allows eye-to-eye contact between the mother and her baby.
2. The legs and arms are folded.
3. The abdomen is at level with that of the mother's upper abdomen.
4. The bottom of the baby is supported with a sling/binder.

KMC can be categorized as being continuous (20-24 hours per day) and intermittent (1-3 hours per session in the day).

Frequent and exclusive breastfeeding is enhanced during KMC (O'Brien-Abel, 2016). KMC has proven to be a useful method of promoting the health and well-being of preterm babies due to its effectiveness in thermal control, breastfeeding and bonding between the mother and the newborn. However, it lacks a system for monitoring the vital signs of a preterm baby, unlike baby incubators which provide both thermal and vital sign monitoring system. These vitals include heart rate (HR), respiratory rate (RR), $SpO_2$ level, temperature and blood pressure (BP) (Shaib et al., 2017). In this design, we integrated the traditional KMC with electronic vitals monitoring system and helped reduce the exposure of the mother practicing KMC. This design has the potential of serving as an alternative approach for incubators and can be used in low resource healthcare facilities lacking baby incubators and homes.

Therefore, there is a need to design a device that would address the shortcomings of the traditional KMC, particularly with the ability to monitor vitals such as BP, temperature, HR and $SPO_2$ levels of preterm babies. This KMC approach will also allow mothers to go about their daily activities conveniently.

## METHODOLOGY

The approach used was the Engineering Design Process (shown in Figure 1). According to the Accreditation Board for Engineering and Technology (ABET), engineering design process is defined as the process of devising a system, component, or process to meet the desired needs. It is a decision-making process, often iterative, in which science and mathematics and engineering science are applied to convert resources optimally to meet a stated objective (Haik, 2014).

The project began with problem identification. Before the problem was clearly stated, a comprehensive understanding of literature relating to preterm mortality and how the KMC approach is helpful in the absence of an incubator was studied. Literature review was carried out throughout the project and a need statement was drawn from the problem identified at the hospitals visited. Benchmarking and market analysis were carried out to survey existing products that addressed the project problem in order to avoid replication of existing designs in the market. For customer requirements, needs were surveyed and prioritized into product requirement which essentially identify the objectives of this project. Detailed breakdown of what the project is to achieve was explicitly defined under this section. The customer's requirements, needs or 'wish lists' were converted into engineering terminologies at the function section of this project and ranked in order of importance. Based on the requirements, a detailed functional structure was developed and engineering characteristics were assigned to the various requirements as specifications. Concepts were generated with reference to the functional structure using a morphological chart and then evaluated with decision matrices. Among the concepts, the appropriate one was selected and further developed virtually into three-dimensional models using a Computer-Aided Design (CAD) software. Components were also selected using decision matrices. The best selected concept was further developed using a virtual simulation model which predicted how the device will perform. A mock-up was fabricated and tested. The functional mock-up was then evaluated against stated objectives.

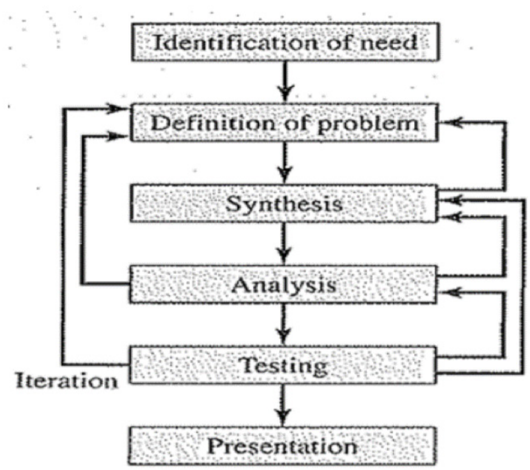


Figure 1:Engineering Design Process (Haik, 2014)

## BENCHMARKING

Benchmarking was done to survey existing products that address the project problem in order to avoid replication of existing designs in the market. This was done with literature. It was discovered that; all the existing devices lacked vital monitoring controls. Some of these devices include:

1. Care Plus preterm wrap is a preterm wrap used in practicing the KMC. This device keeps the baby secured in the correct position during the KMC practice and permits skin-to-skin contact. Even though it allows effective skin-to-skin contact, it lacked vital monitoring controls. (See Appendix 1) shows an image of a Care Plus preterm wrap.
2. Kangaroo Zak is also a preterm wrap used for practicing the KMC. This product comes with multiple wraps which tightly secures the baby in the right position. It also fosters skin-to-skin contact during its use. Main problem of this product is the absence of vital monitoring control as well as its complexity due to its multiple wrap belts. (See Appendix 1) contains an image of a Kangaroo Zak.
3. Piece of cloth is a local preterm wrap also used for practicing the KMC. It involves a piece cloth wrapped round the mother with the baby lying on her chest. This traditional wrap, like the others existing products, enhance skin-to-skin contact and is very simple to use but also lacks vital monitoring controls and can easily untie due to poor or weak fastening. Appendix 1 contains an image of a piece of cloth wrap.

## FUNCTIONAL ANALYSIS AND SPECIFICATIONS

### *THE BLACK BOX MODEL*

This model represents the overall operation of the device. It expresses the relationship between inputs and outputs regardless of the details within the 'black box'. The model comprises of the input (preterm baby) with the corresponding output (baby's vitals displayed ).

Figure 2 below show the black box model of the system.


Figure 2: Black Box Model of the system

## FUNCTIONAL STRUCTURE

The functional structure shows the various stages of operation of the device within the black box. It represents how the inputs are processed and utilized to obtain the desires output as shown in Figure 3 below. Detailed functions of the device were broken down into their respective sub-functions.

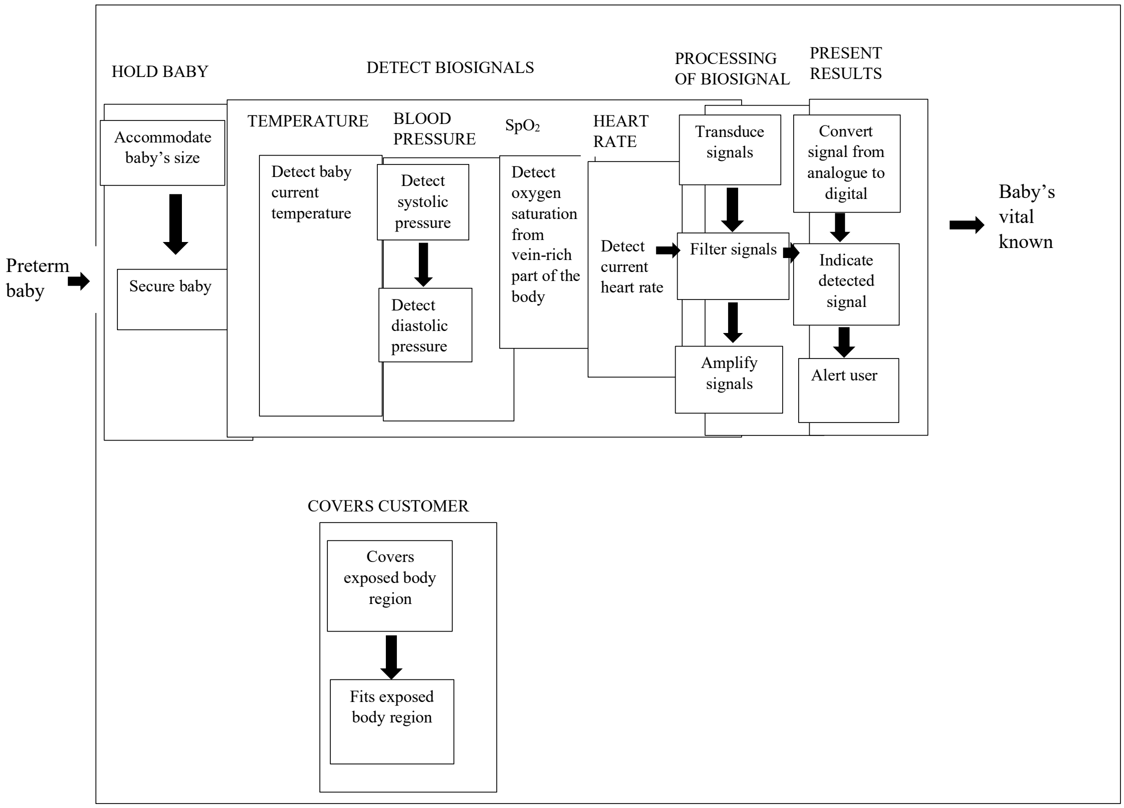


Figure 1: functional structure of device

## SPECIFICATIONS AND JUSTIFICATIONS

A specification checklist was generated from customer requirements so as to relate the requirements to their corresponding engineering parameters. Values for these engineering parameters were drawn from literature, brainstorming as well as information obtained directly from the customers. The specification for the device was grouped into two categories: general and functional specifications. As shown in Table 1 and 2 in Appendix 1.

## CONCEPT GENERATION

Employing creative brainstorming methods, different solutions were generated in order to address the problem at hand. These solutions were narrowed down into three separate concepts, with each offering different and unique approaches to addressing the problem.

These concepts were drawn by considering the main objectives of the project which was to monitor the vitals of the preterm baby and accommodate the baby.

### Concept 1

This concept consists of two separate units: the vitals monitoring unit and the carrier unit. The carrier unit comprises of an adjustable shoulder and waist straps to effectively secure the baby in the fetal position on the abdominal region of the mother (customer). It also has a large padded inner area to accommodate the size of the preterm baby as well as a back- rest, to support the back of the baby when the device is being used. The vitals monitoring unit houses the electronic components needed to monitor the vital of the preterm baby. The monitored vitals are displayed on the LCD screen for the user. The customer is always alerted when vitals deviate from the set threshold limits. The vital monitoring unit is attached to the adjustable waist strap. This concept partially covers the customer abdominal region. Concept 1 is shown in Figure 4 below.

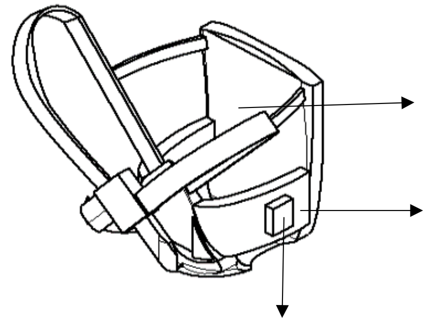


Figure 4: Adjustable strap carrier with vitals detecting unit

### Concept 2

This option (Figure 5) entails three separate units, each performing a specific function; vital monitoring unit, a covering unit and a baby holding unit. The baby holding unit comprises of a holding pouch and safety straps for accommodating and securing the baby in a fetal position on the abdominal region of the mother. It has inner padding for baby comfort during its application and a drawstring to support the neck of the baby as it extends outside of the device. The abdominal covering unit eliminates exposure of the customer's body when practicing KMC.

The vital monitoring unit houses the electronic components needed for the system and also alerts the user when the vitals deviate from the set threshold limits. It is attached to the side of the covering unit, doing (down the waist).

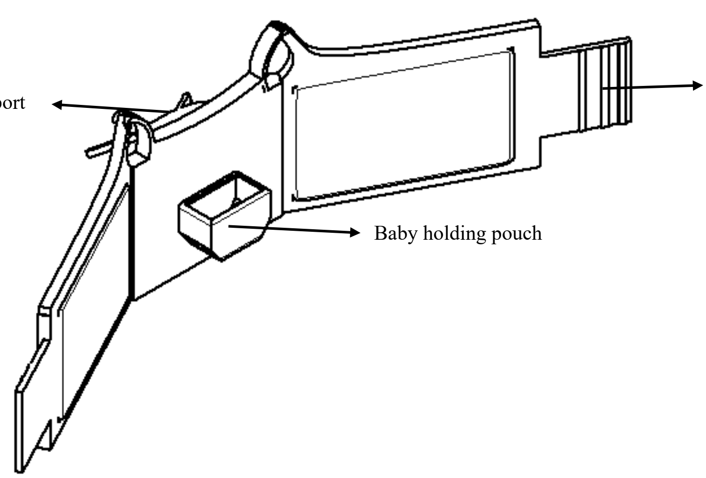


Figure 5: Velcro strap carrier with vitals detecting unit


ISSN: 2821-9007 *(Online)*

**Concept 3**

This option also comprises of three separate units: a vital monitoring unit, carrier unit and an abdominal covering unit. The carrier unit has a padded inner area for accommodating the baby's size and provides comfort. It also has a vital monitoring unit which houses the electronic components. The vitals are displayed, and the unit also alerts the user when vitals deviate from the set threshold limits. The unit is attached to the covering unit. This concept also has an abdominal covering unit that limits body exposure of the customer when practicing the KMC. This concept, however, lacks a structurally defined strap to properly secure the baby even though the baby fits perfectly within the carrier unit. Concept 3 is shown in Figure 6 below.

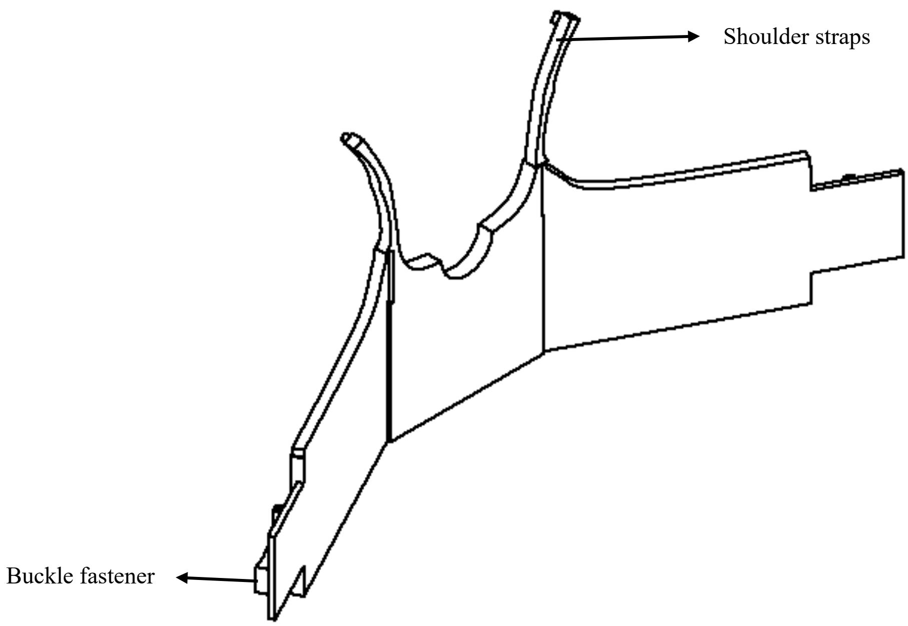


Figure 6: Buckle fastener carrier with vitals detecting unit

## SELECTION OF THE BEST CONCEPTS USING DECISION MATRIX

Using the decision matrix tool, all the various concepts were analyzed in order to choose the appropriate concept that best fits the requirements stated. Concept two emerged as the chosen concept.

## PRINCIPLE OF OPERATION OF SELECTED CONCEPT

The chosen concept comprises of three separate units: vital monitoring unit, a covering unit and a baby holding unit.

**Baby holding unit**

The preterm baby is placed in a baby holding pouch within the device and secured firmly to the device with a strap. A blood pressure cuff is then wrap around the upper arm of the baby with the artery mark positioned directly over the brachial artery of the baby. A temperature sensor is embedded in one Velcro strap, and a particle sensor in the other. The temperature velcro strap is wrapped around the other arm of the baby and the particle sensor velcro strap is wrapped around the foot of the baby. The temperature velcro strap detects the temperature whiles the particle velcro strap detects the SpO2 and heart rate of the preterm baby.


ISSN: 2821-9007 *(Online)*

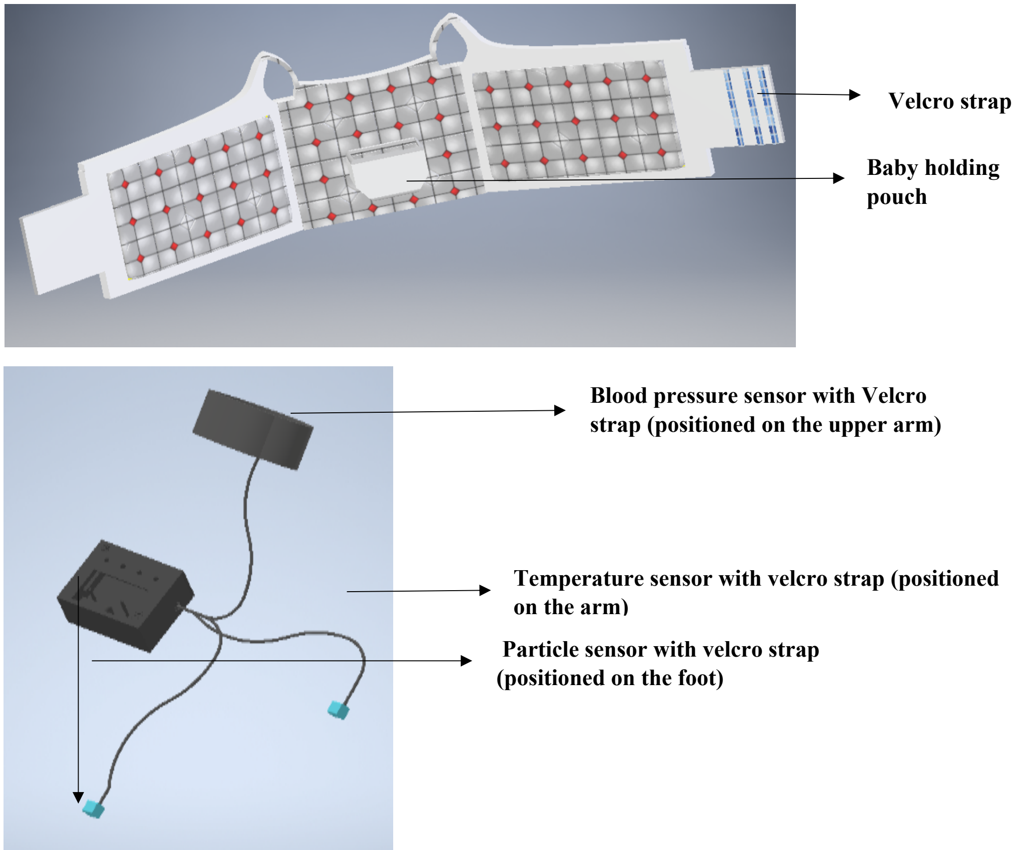


Figure 7a: Different views of selected concept (baby holding and Vital monitoring unit covering unit)

## Vital monitoring unit

Powered vital monitoring unit is turned on to initialize all the sensors.

1. Blood pressure monitoring unit

Upon pressing the blood pressure button, measurement of BP starts; the solenoid valve opens and causes the pressure motor to pump air into the cuff which inflates it and causes the major artery in the baby's arm to be blocked. The pressure sensor detects the pressure at which the artery is completely blocked and stores it as the initial pressure signal. The solenoid valve is then open and allow air to escape from the cuff, causing it to deflate. The pressure at which the artery becomes completely freed is detected by the pressure sensor and stored as the final pressure signal. These pressure signals are amplified, filtered, and transduced by their respective discrete components connected to the microcontroller. The output data is transferred to the microcontroller which read the data and converts it into Binary-coded decimal digits (BCD). The programmed microcontroller then displays these signals as the systolic and diastolic blood pressures of the baby in mmHg on the LCD.

2. Temperature, Heart rate and $SpO_2$ monitoring unit

The temperature, heart rate and $SpO_2$ are toggled by a single button. When the button is pressed, the temperature sensor detects the current body temperature of the preterm baby. The temperature signals are then converted into BCD digits by the programmed microcontroller. The final current body temperature of the baby is displayed in degrees Celsius on the LCD.

Upon pressing the same button, the infrared light from the particle sensor position on the baby's foot passes through the body tissues, enters the blood vessels and measures the amount of light absorbed by the oxygenated blood cells within the blood vessels. The sensor picks up the exact number of times the infrared light was blocked before absorption due to the pulsating flow of the blood. After measurement, the emitted light is received by the sensor and transduced from biosignals into electrical signal before it is transferred to the programmed microcontroller. The programmed microcontroller converts the data into BCD. The amount of oxygen absorbed is displayed as $SpO_2$ level in percentage whilst the number of times the light was blocked is also displayed as the heart rate in bpm on the LCD.

## 3D MODEL OF THE SELECTED CONCEPT

Based on the sketch of the selected concept, AutoCAD Inventor was used to generate a 3D model of the chosen concept. **Figure 7, Figure 8 and Figure 9** represent the different views of the 3D models; the front and inner view of the baby holding unit and the covering unit as well as vital monitoring unit. Detailed drawing of the selected concept with dimensions was done using the same software.

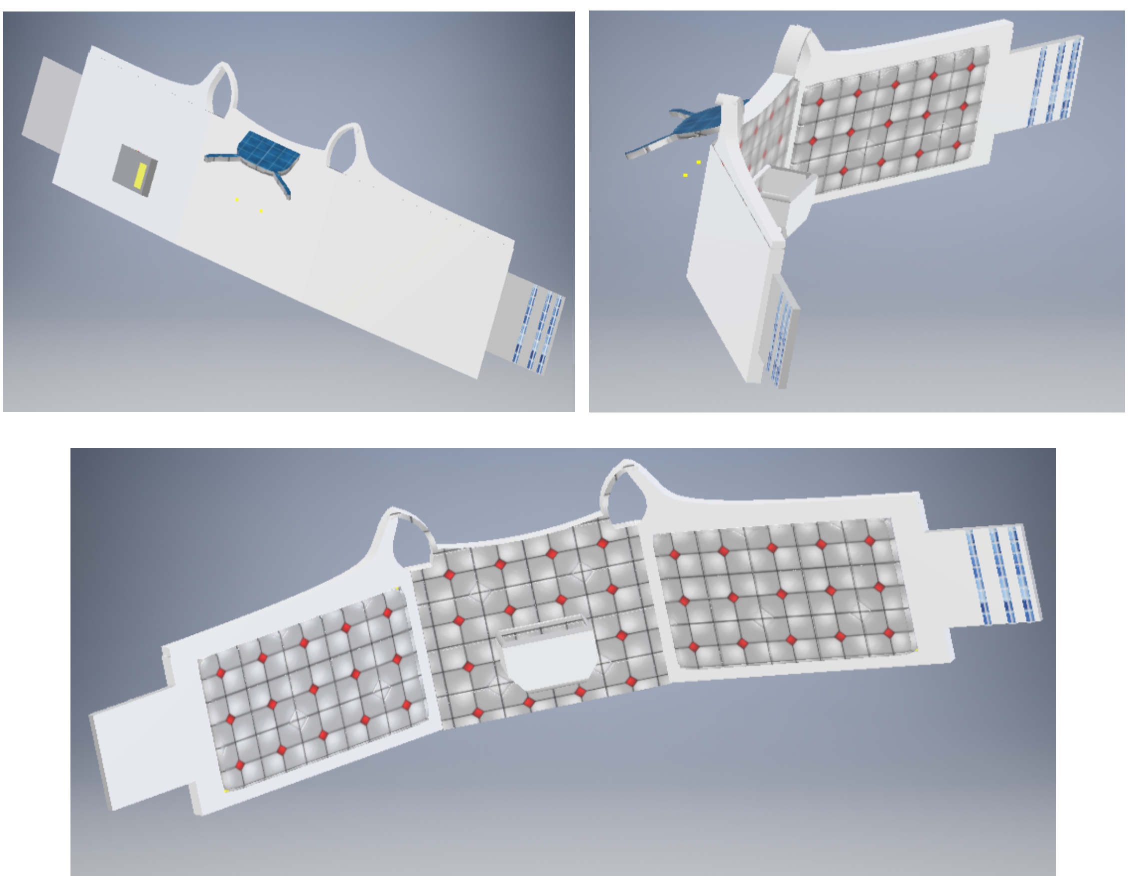

Figure 7b: Different views of selected concept (baby holding and covering unit)


ISSN: 2821-9007 *(Online)*

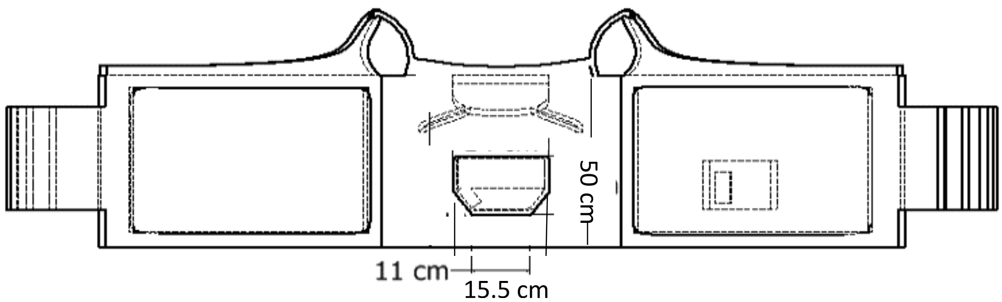


Figure 8: Detailed drawing of selected concept (baby holding and covering unit)

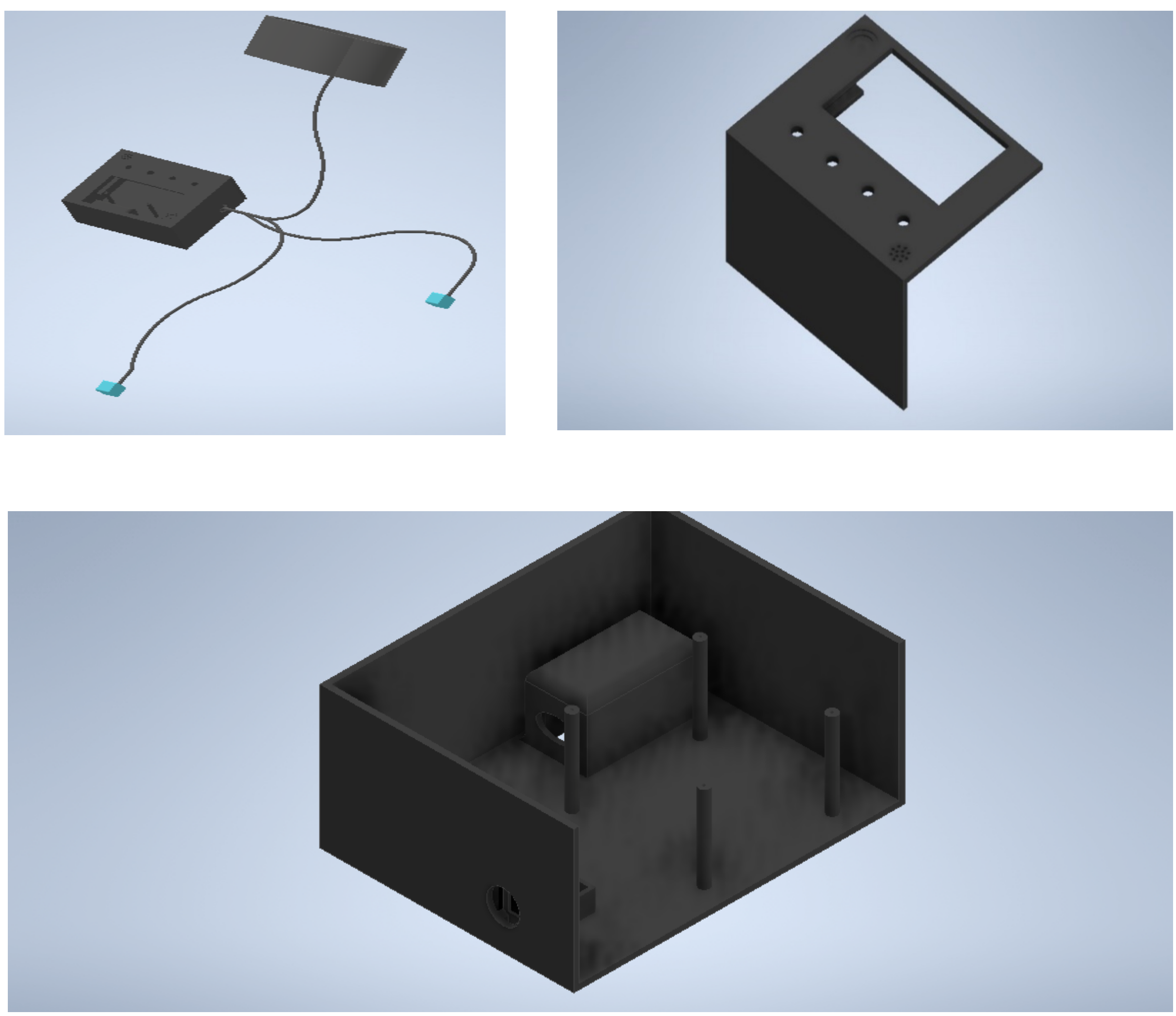

Figure 9: Different views of the vitals monitoring unit

## ELECTRONIC SIMULATION

### *FLOW CHART OF ELECTRONIC UNITS*

The flow charts of the various vital monitoring units of the device are shown in Figure 10, Figure 11 and Figure 12 below. The flow charts illustrate the various iterative processes involved in the electronic circuit of the vital monitoring units in order to achieve the objective of displaying the monitored vitals as well as alerting the customer when some of these vitals deviate from the set threshold limits.

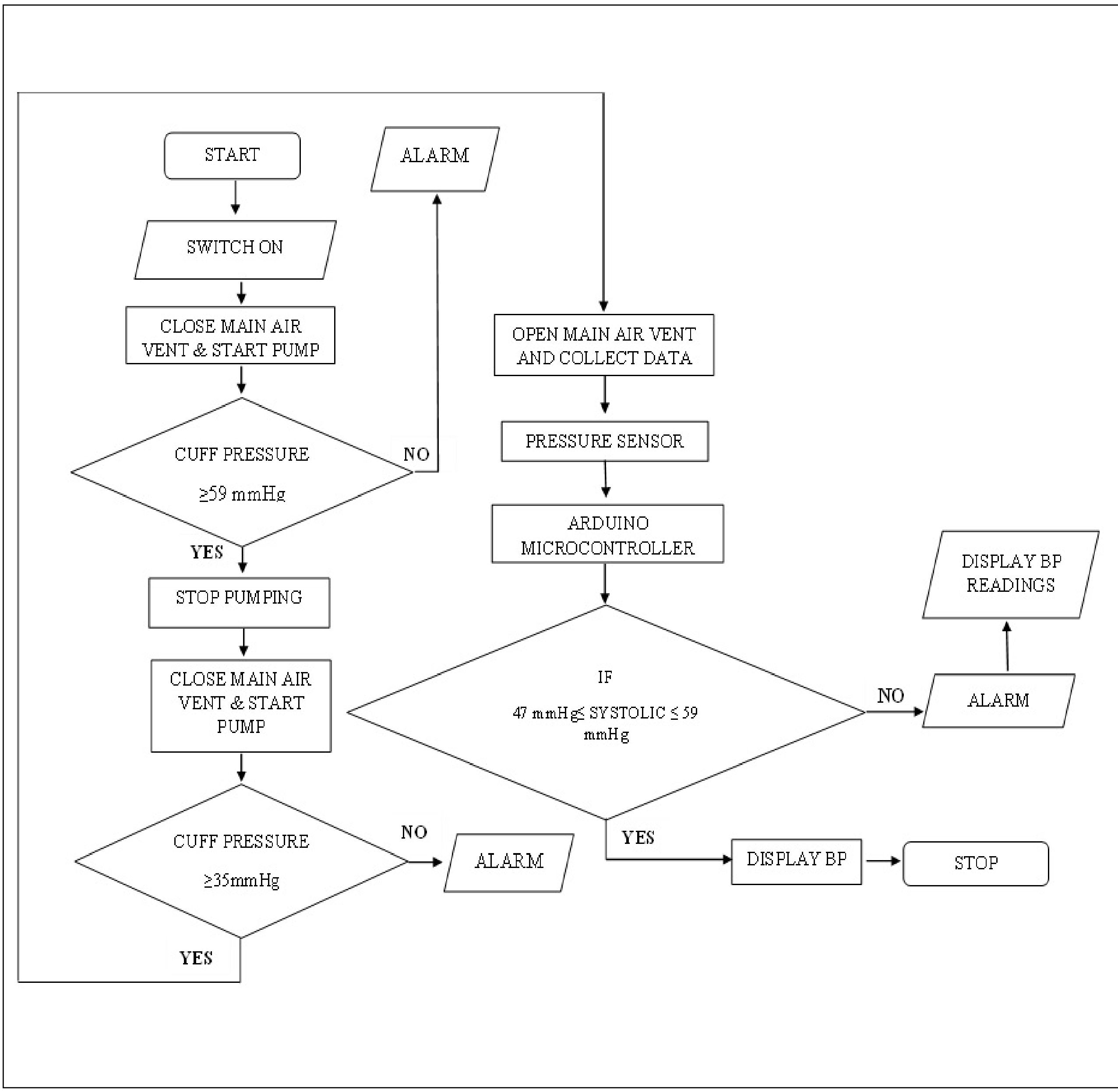


Figure 10: Flow chart of the blood pressure monitoring unit

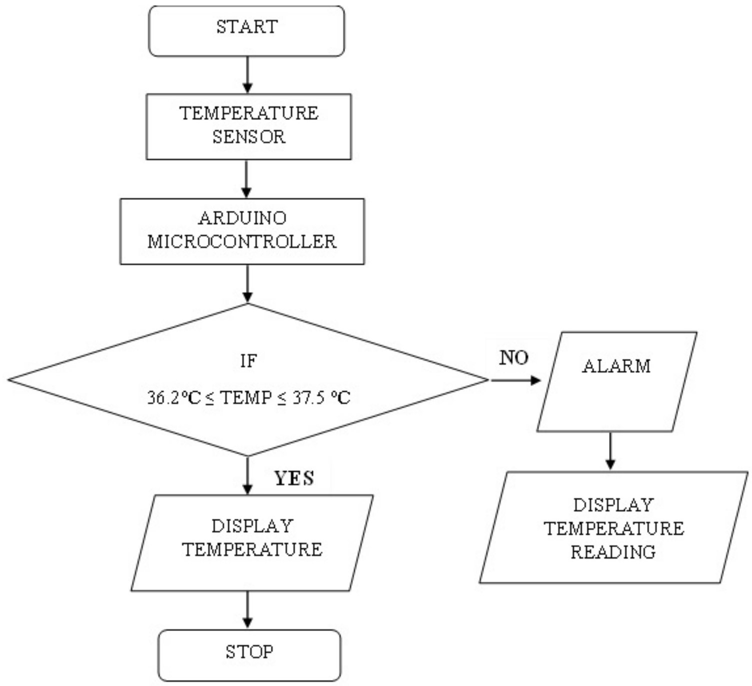


Figure 11: Flow chart of the temperature monitoring unit

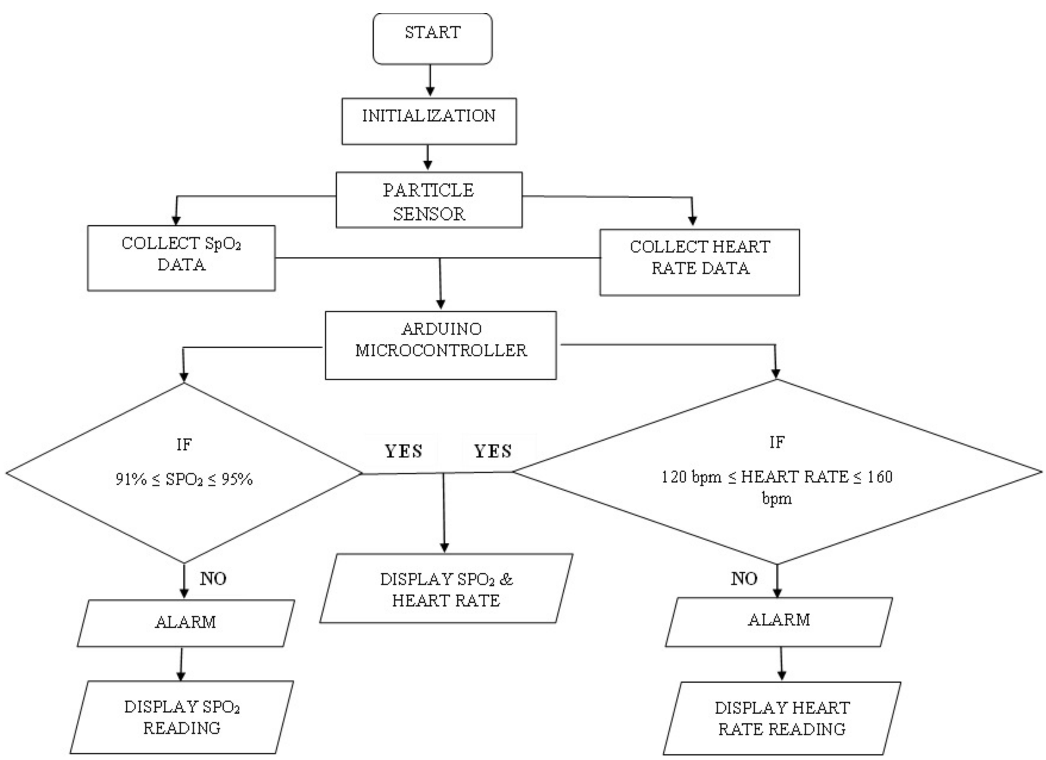


Figure 12: Flow chart of the heart rate and $SpO_2$ monitoring unit

## ELECTRONIC CIRCUIT SCHEMATICS

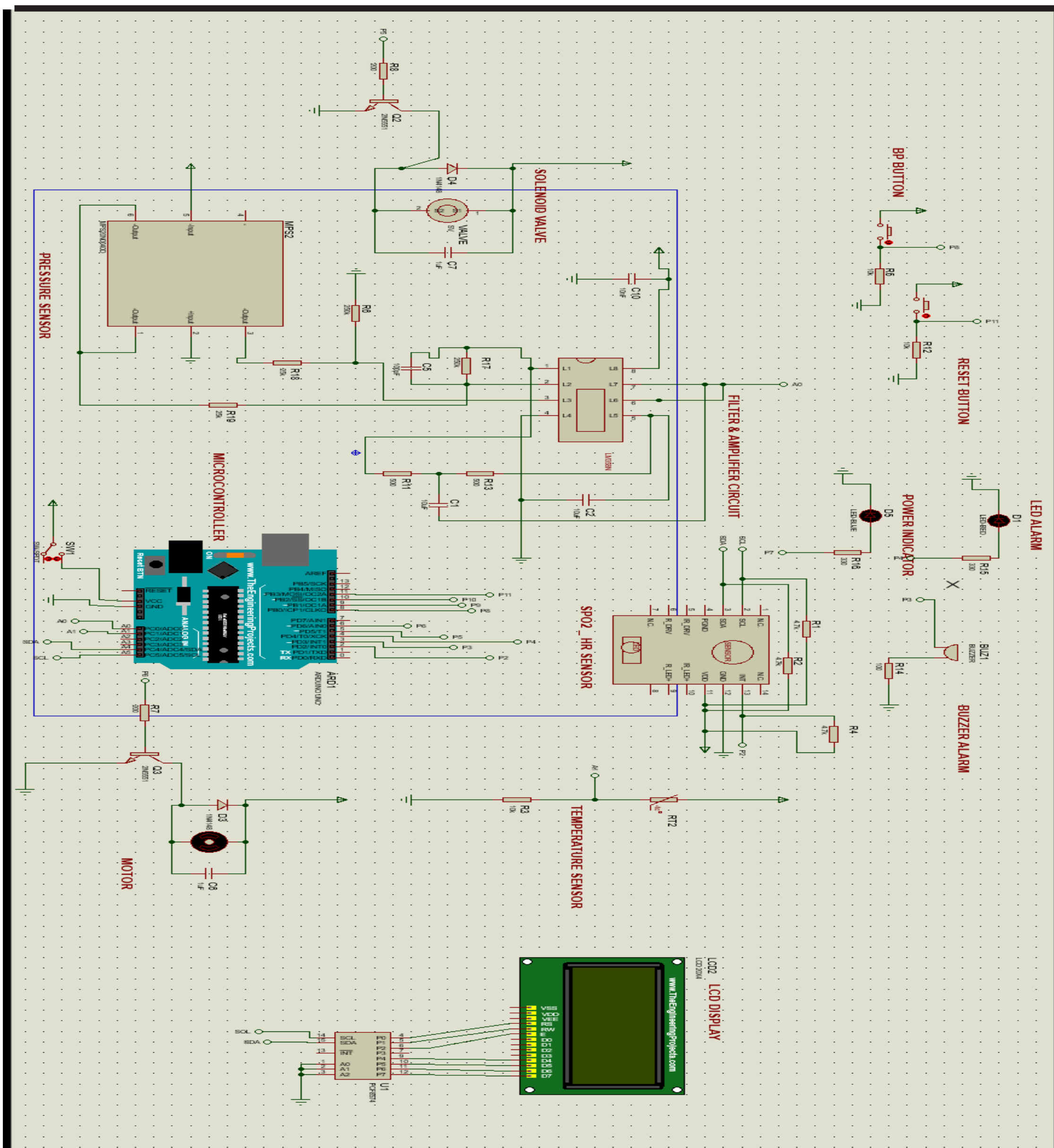


Figure. 13 the electronic schematics circuit

Figure 13 represents the electronic schematics circuit of the vital monitoring units of the mock-up. The device continuously monitors the $SpO_2$ levels and Temperature of the preterm baby while allowing for momentary monitoring of the infant's blood pressure. Upon start up, the device initializes the MAX30102 particle sensor (the $SpO_2$ and Heart Rate sensor) whilst setting all outputs and inputs device pins. After initialization, the first $SpO_2$ and Heart rate readings obtained from the MAX30102 sensor, fastened to the foot of the baby, is displayed approximately every 15 seconds after initialization on the (20x4) LCD screen with an indication of whether or not these readings are in the normal range of the preterm baby ($SpO_2$ > 90%, 60 bpm < Heart Rate < 100 bpm). The temperature reading, taken from the NTC thermistor attached to the peripheral of the preterm baby, is also displayed after a successful initialization every 15 seconds with an indication of whether that reading is in the normal range of preterm babies (36.5 °C < Temp < 37.5 °C)

For BP, the button is pushed and it activates the BP monitoring system. The values of Systolic and Diastolic Pressures, after a period of about 25 seconds after activation are displayed on the screen and the system checks whether the values lie within the normal range. After this, the system resets itself to resume the default continuous monitoring mode. If any of these vitals are above or below the normal for a healthy preterm infant, an LED-buzzer alarm sounds to alert the customer of the situation. A reset button was also introduced for restarting the device where the need be and a power button for turning the device on or off.

## MOCK UP DESIGN

Figure 14 below shows the breadboard electronic circuit design and Figure 15 represents the final mock-up design.

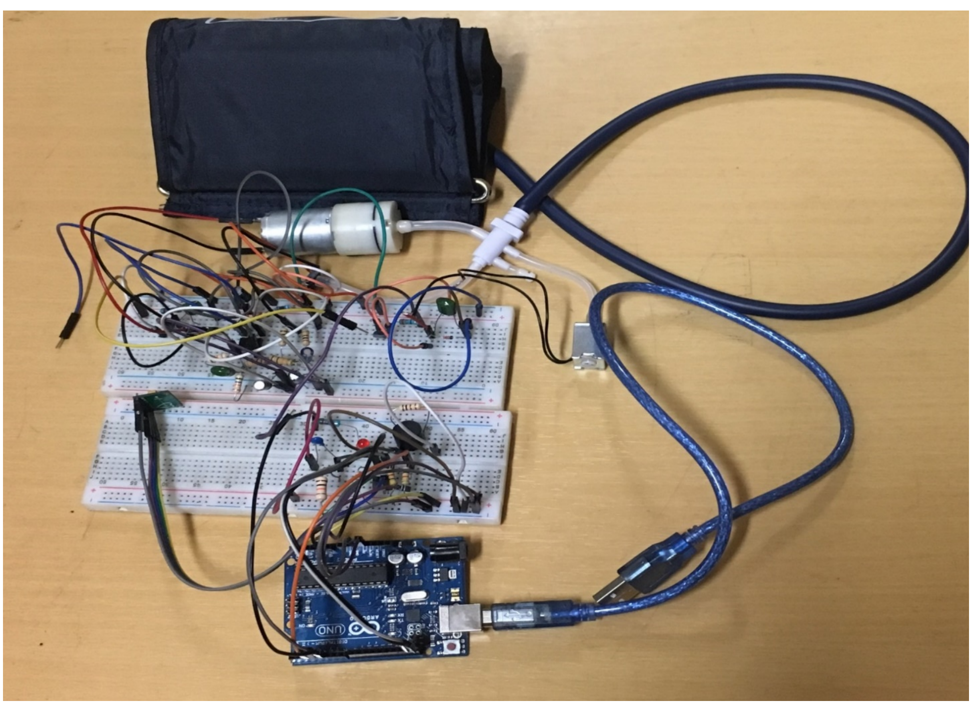

Figure 14: Breadboard electronic circuit design of mock-up


ISSN: 2821-9007 *(Online)*

Figure 15: Final mock-up (Baby holding and vitals monitoring units)

## MATERIALS AND COMPONENTS

Table 1 shows the materials and components selected for the fabrication of the device.

| COMPONENTS | FUNCTION |
|---|---|
| Arduino Uno | Microcontroller |
| NTC temperature sensor | Detects the temperature signals of the baby. |
| MAX30102 particle sensor | Detects the heart rate and SpO2 signals level of the baby. |
| 20 × 4 12C character LCD | Displays the monitored vitals of the preterm baby. |
| Buzzer and LED | Generates audible sound and flashes of lights to alert the customer. |
| MS5803-14BA pressure sensor | Detects pressure signals of the baby. |
| Perfboard | Platform for soldering electronic components. |
| AAA batteries | Energy for powering the electronic components of the device. |

**Table 1: Components used in device fabrication**

In addition to the components listed in the table, other electronic components such as resistors, capacitors, breadboard, solenoid valve, pressure motor, jumper wires and push buttons were used.

### Material selection for the fabrication of the baby holding and the covering unit

The baby holding unit of the device consists of an inner, a middle and an outer part. The inner part of the device houses the preterm baby and due to the delicate nature of a preterm skin, the material to be used for the construction must be soft, comfortable and have wicking properties so as provide a dry feel against the body. The middle part of the device is what provides thermal insulation for the baby. Thus, the material selected should have heat retention properties and be soft. On the other hand, the outer part of the baby holding unit including the abdominal covering unit will support the entire weight of the baby during the practice of the KMC approach. Therefore, the material to be used must be strong as well as tough. In general, the material to be used for the entire units must be workable, easily avaliable, durable, easy to maintain (clean), light in weight, durable and breathable.

After a thorough research and studies, polymers were considered for the fabrication of the device since they possess majority of the material properties needed. Narrowing it down, cotton (natural polymer) and synthetic polymers like nylon, polyester, polyacryl and polyurethane were considered. Empolying a decision matrix, cotton was used for outer part of the device whiles polyacryl was used for the outer covering of the device. Polyester fibre was chosen as the insulating material.


ISSN: 2821-9007 *(Online)*

## COMPUTATIONAL TOOLS

Some computational tools used throuhgout this project include;

**Table 2: Computational tools used for the project**

| Computational tools | Purpose |
|---|---|
| Proteus Design Suite | Simulation of electronic circuit |
| Arduino IDE version 1.8.5 | Programming the microcontroller |
| AutoCAD Inventor | Drawing 3D models |

## FINDINGS AND ANALYSIS

Due to the unavailability of ethical clearance as well as ethical issues associated with performing clinical trials on preterm babies, the team resulted in using its members and other volunteers making a total of 10 as test subjects for validating the functionality of the mock-up. In order to analyze the error margins between the already existing calibrated devices and the developed mock-up, the standard deviations of the values were calculated.

The table below shows the standard deviations calculated for the various vital monitoring units.

## stp

**Table 3: Standard deviations of the various vital monitoring units.**

| Monitoring unit | Standard deviation |
|---|---|
| Blood pressure | 0.62 |
| Heart rate | 0.41 |
| $SpO_2$ level | 0.34 |
| Temperature | 0.52 |

The standard deviation or error margin of the mock-up when compared to existing calibrated devices were between the values of 0.62-0.34.

## CONCLUSION

In summary, the project was a success which led to the fabrication of a device capable of monitoring the vitals of preterm babies during the practice of KMC. The stated objectives of the project were archived by employing and systematically following the engineering design process. During testing of the functional mock-up, promising results were obtained despite the fact that the tests were performed on adults rather than preterm babies due to ethical issues. In general, the device constructed was able to monitor the temperature, heart rate, $SpO_2$ level and blood pressure with minimal error margin (less than 1). It alerted the customer in events that the values did not lie within the threshold values or limits, and the system is also easy to operate, safeand cost effective.

## REFERENCES


Balie, A., Params, A., Collin, B. J. T., Robert, T., & Quit. (2012). *Amplifiers*. 1–26.

Carlos, R., Santos, D., & Pereira, I. M. (2009). Time Response of Temperature Sensors Using Neural Networks. *International Nuclear Atlantic Conference*. Retrieved from http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/41/115/41115778.pdf

Charpak, N., Figueroa, Z., & Ruiz, J. G. (1998). Kangaroo mother care [7]. *Lancet*, *351*(9106), 914. https://doi.org/10.1016/S0140-6736(05)70336-6

Francis, & G.B;Priscilla.W;Robert.C.L. (2016). Infant Incubator. *Premature Baby*. https://doi.org/https://doi.org/10.1016/S0002-9378(40)90876-6

Haik, Y. (2014). *Engineering Design Process Second Edition Yousef Haik Tamer Shahin*.

Kryter, K., Press, A., Lord, H., Gatley, W., Evensen, H., Krieger, R., … Olson, H. (2000). 3 . Human Response To Sound. *Engineering Noise Control, D. Bies and C. Hansen Physics and Engineering, 12*(5), 1–12. Retrieved from www.me.psu.edu/lamancusa/me458/3_human.pdf

Lawn, J. E., Davidge, R., Paul, V. K., Xylander, S. Von, Johnson, J. D. G., & Costello, A. (2013). Born Too Soon: Care for the preterm baby. Reproductive Health. *Reproductive Health*, *10*(Suppl 1), 1–19.

O'Brien-Abel, N. (2016). Kangaroo mother care and neonatal outcomes: A meta-analysis. *MCN The American Journal of Maternal/Child Nursing*, *41*(3), 194. https://doi.org/10.1097/NMC.0000000000000241

Portia, L. O., & Pekky, C. (2018). *Approved by Neonatal Services Quality Committee Approved by Neonatal Services Quality Committee BLOOD PRESSURE MONITORING IN NEWBORN CARE CENTRE cont ' d*. (April).

Ramezani, R. (2014). *Design , Analysis and Implementation of Voltage Sensor for Power-Constrained Systems*. (January).

Randis, T. M. (2008). Complications associated with premature birth. *Virtual Mentor*, *10*(10), 647–650. https://doi.org/10.1001/virtualmentor.2008.10.10.cprl1-0810

Robert. (2003). *Kangaroo mother care: practical guide*. 1–54. Retrieved from papers3://publication/uuid/479e6443-eb86-4d96-99d4-bdf0d462186e

Scopes, J. W., & Ahmed, I. (1966). Range of critical temperatures in sick and premature newborn babies. *Archives of Disease in Childhood*, *41*(218), 417–419. https://doi.org/10.1136/adc.41.218.417

Seaton, S. E., Barker, L., Draper, E. S., Abrams, K. R., Modi, N., & Manktelow, B. N. (2018). Estimating neonatal length of stay for babies born very preterm. *Archives of Disease in Childhood: Fetal and Neonatal Edition*, 182–186. https://doi.org/10.1136/archdischild-2017-314405

Shaib, M., Rashid, M., Hamawy, L., Arnout, M., El Majzoub, I., & Zaylaa, A. J. (2017). Advanced portable preterm baby incubator. *International Conference on Advances in Biomedical Engineering, ICABME, 2017-October*(December). https://doi.org/10.1109/ICABME.2017.8167522

Shastry, C., & Bhat, B. (2015). Anthropometric measurements of newborns. *International Journal of Contemporary Pediatrics, 2*(2), 85. https://doi.org/10.5455/2349-3291.ijcp20150505

Simkiss, D. (2004). Editorial. Kangaroo mother care. *Journal of Tropical Pediatrics, 45*(4), 192–194. https://doi.org/10.1093/tropej/45.4.192

Sinclair, I. R. (2001). *Sensors and Transducers Third edition*. 13–41. Retrieved from http://senofficial.yolasite.com/resources/sensors and transducers.pdf

Singer, J. R. (2008). Operational amplifiers, theory and practice. *Proceedings of the IEEE, 64*(9), 1456–1456. https://doi.org/10.1109/proc.1976.10358

Steven, C., & O'Brien, F. S. (2012). Sensor Sensitivity. *National Electronic Regulations*, 2–4.

Trigoni, N. (2014). *Accuracy estimation for sensor networks. 14*(7), 1330–1343. Retrieved from https://ora.ox.ac.uk/objects/uuid:4ce383e9-7223-48bc-a461-83e19b1afe64

Turley, M. (2008). *Body Size Technical Report: Measurements and classifications in the 2006/07 New Zealand Health Survey*. Retrieved from http://www.moh.govt.nz

Veronez, M., Alves, N., Borghesan, B., Aparecida, D., Corrêa, M., & Higarashi, I. H. (2017). Experience of mothers of premature babies from birth to discharge: notes of field journals. *Rev Gaúcha Enferm, 38*(2), 60911. https://doi.org/10.1590/1983-1447.2017.02.60911

## Appendix 1

Some mothers practicing the kangaroo mother care approach

Source: https://www.graphic.com.gh/news/general-news/ghana-news-increase-awareness-on-kangaroo-mother-care-rise-ghana.html

**Care Plus preterm**

Source: http://www.nurturedbydesign.com/en/kangaroozak/medical-staff_thatis-uses.php

**Kangaroo Zak**

Source: http://www.nurturedbydesign.com/en/kangaroozak/medical-staff_thatis-uses.php

**Piece of cloth**

Source: https://www.mcsprogram.org/march-2-webinar-kangaroo-mother-care-preterm-babies/

## Appendix 2

**Table 4: Specification checklist**

| REQUIREMENTS | DEMAND (D)/ WISH (W) | ENGINEERING PARAMETER |
|---|---|---|
| Monitor vitals | Demand | Detect body temperature, heart rate, blood pressure and $SpO_2$ level |
| Alert user | Demand | Response time |
| Easy to use | Demand | Steps of operation<br>Number of persons to operate |
| Accommodate baby's size | Demand | Volume of device |
| Cover abdominal region of the user | Demand | Dimension of user |
| Portable | Demand | Net mass<br>Dimension of device |
| Quick feedback time | Demand | Initialization time<br>Feedback generation time |
| Easy to maintain | Wish | Number of detachable parts<br>Servicing time |
| Accurate | Demand | Error margin |
| Cost effective | Wish | Production cost<br>Maintenance cost |

**Table 4**

| REQUIREMENT | RANK | DEMAND/ WISH | METRIC | UNIT | TARGET VALUE |
|---|---|---|---|---|---|
| Feedback time | 10 | Demand | Initialization time<br>Feedback generation time | s<br>s | 60<br>60 |
| Easy to operate | 10 | Demand | Steps of operation<br>Number of persons to operate | –<br>– | ≤ 3<br>1 |
| Portability | 10 | Demand | Net mass<br>Dimension of device (L×B×H) | kg<br>m | 2.6 *<br>0.5×0.25×0.25 ** |
| Affordability | 5 | Wish | Production cost<br>Maintenance cost | GH₵<br>GH₵ | ≤ 600<br>≤ 200 |
| Accuracy | 10 | Demand | Error margin | – | 0.1 *** |
| Easy to maintain | 10 | Demand | Number of detachable parts<br>Servicing time | –<br>months | ≤ 2<br>6 |
| Power consumption | 5 | Wish | Energy source<br>Voltage | -<br>V | DC<br>9 |

**Table 5: General specification table**

| | | | | | |
|---|---|---|---|---|---|
| Power consumption | 5 | Wish | 1. Energy source<br>2. Voltage | 1. -<br>2. V | 1. DC<br>2. 9 |

*(Seaton et al., 2018) **(Shastry & Bhat, 2015) ***(Trigoni, 2014)


ISSN: 2821-9007 *(Online)*