Design of direct early detection device of Apnea for Preterm babies

John Kutor[1]*, Emmanuel Baiden Acquah[1], Kuma Medrack Afatsao[1], Gloria Otema Agyapong[1], Akosua Lily Odoom[1] and Maxwell Amoah[1]

[1]Department of Biomedical Engineering, University of Ghana
***Corresponding author:** jkutor@ug.edu.gh

ABSTRACT

Apnea in preterm babies is the cessation of breath for a short period usually between 6-15 seconds resulting from undeveloped lungs and respiratory centre. It is the cause of most primary disorders like cerebral palsy, sensory defects and respiratory illness. Detecting and monitoring apnea in developing countries like Ghana is usually through indirect methods. These methods give results that are normally too late for the resuscitation to revive the baby. In this paper, we designed a cost effective direct apnea detecting system at a very early stage by following the engineering principles. The system comprises of a signal acquisition unit, a central processing system and a display unit, a power source and an alert system coupled with a storage functionality. The system acquired temperature using silicon bandgap sensor LM 35 and breathing rate signal using force sensitive resistor FSR. The breathing rate signal was analyzed using MATLAB. The system followed an operational logic which is incorporated into the programming of the microcontroller. A prototype of the device was fabricated, with wood used as the casing. The device was tested on a normal adult and the temperature and breathing rate were displayed on an LCD screen.

Key words: apnea, preterm, cerebral palsy, resuscitation, microcontroller, prototype, sensor, resistor, logic

Introduction

Gestation and Prematurity

Gestation period in humans usually ranges from 38 to 40 weeks (Daily *et al.*, 1969; Saigal & Doyle, 2008) cutaneous stimulation resulted in resumption of breathing. However, 8% of the episodes required resuscitation with oxygen by bag and mask. Apneic episodes of 45 or more seconds' duration resulted in mottling, cyanosis, hypotonia, and unresponsiveness to stimulation suggesting that early intervention is required to prevent significant hypoxia and central depression from apnea. In six additional infants having apnea, higher environmental temperatures (near the upper limit of the \"thermoneutral zone\". Due to a number of reasons, not all pregnancies last the 38 to 40-week period, implying that some children could either be delivered before or after the stated duration elapses. In instances where the birth of a baby is less than 37 weeks gestation age, the birth is termed preterm birth or premature birth. The babies delivered within these periods are referred to as preterm or premature babies (Goldenberg & Rouse, 1998; Saigal & Doyle, 2008; Torpy *et al.*, 2005) the baby grows in the mother's uterus (womb.

Prematurity and low birthweight account for 29% of the top five causes of neonatal mortality globally(Ramaiya *et al.*, 2014). Among the remaining factors are neonatal infections contributing 25%, birth trauma or asphyxia constituting 23%, congenital anomalies for 8%, neonatal tetanus contributes 2% and diarrheal diseases making the last 2%(Ramaiya *et al.*, 2014). Currently, prematurity is responsible for three-quarters of neonatal mortality and one-half of all child long term neurologic impairments(Lee *et al.*, 2006; Tume, n.d.). There are devices designed for pediatric monitoring and have the potential of detecting 87% of infants that are prone to developing disorders(Tume, n.d.). This is however difficult to achieve most of the time, owing to the fact that it requires rapt attention during the monitoring period(Torpy *et al.*, 2005; Vento *et al.*, 2008)the baby grows in the mother's uterus (womb. It is estimated that with the appropriate treatment, 75% of preterm babies would survive(Torpy *et al.*, 2005; Vento *et al.*, 2008)the baby grows in the mother's uterus (womb).

Modern and advanced medical facilities employ the use of incubators in their neonatal intensive care units (NICU) in treating preterm babies. These devices have functions like monitoring, oxygenation, protection from cold temperature, the use of intravenous catheters to provide nutrition and administration of medications, and the maintenance of fluid balance (McClain, 2002; Tume, n.d.).

Preterm health challenges

The challenges faced by preterm babies at the early stages of their lives include but not limited to inability to breathe regularly on their own since their lungs might have been underdeveloped; body temperature regulation; feeding and growth problems due to immature digestive systems, intracranial hemorrhage, jaundice and anemia (McIntire *et al.*, 1999). Other NICU diagnoses include apnea, bradycardia, bronchopulmonary dysplasia, hydrocephalus, intraventricular hemorrhage, and sepsis among others (McIntire *et al.*, 1999). As they grow older other complications such as hearing or vision problems, developmental delays, and learning disabilities could also arise(Perlstein *et al.*, 1970; Ramaiya *et al.*, 2014).

Apnea

Apnea is the most common and usually the primary cause of the many disorders of prematurity(Goldenberg & Rouse, 1998; Kurth *et al.*, 1987). Apnea in preterm babies is defined as the cessation of breath for a period between resulting from the respiratory center being underdeveloped (functional impairments relating to lungs and upper airways in infants)(Künzel *et al.*, 1996; Kurth *et al.*, 1987). A study on Apnea and its possible relationship to immunization in ex-premature infants, revealed that 37% of 47 preterm infants less than 60 weeks had prolonged apnea (greater than 15 seconds), and 14% had short apnea (between 6 and 15 seconds) (Cooper *et al.*, 2008). It also came out that gently rubbing of the back and changing the sleeping position of the baby may revive the baby (Cooper *et al.*, 2008). 8% of the episodes of apnea require resuscitation with oxygen bag and musk (Daily *et al.*, 1969; Varshney, 2007). The onset of apnea is associated with a rise in temperature (Perlstein *et al.*, 1970) and nearly all infants born at less than 29 weeks of gestation or weight less than 1000 g will experience apnea(Engmann *et al.*, n.d.; Sosa *et al.*, 2015).

Physiology of preterm babies

The preterm infant weighs about 1000 g or less and has a length of about 40 cm(Hassanian-Moghaddam *et al.*, 2013; McIntire *et al.*, 1999). The skin is delicate and almost transparent with a bright red color during the early fetal life with very little subcutaneous tissue (Hassanian-Moghaddam *et al.*, 2013; McIntire *et al.*, 1999). The outline of limbs is lacking with underdeveloped nails that do not project beyond the tip of the finger (Hassanian-Moghaddam *et al.*, 2013; McIntire *et al.*, 1999). In male premature babies the testicles may be identified together as the scrotum or may be pressed back into the abdominal cavity while in females, the labia are underdeveloped and may have a gaping appearance (Hassanian-Moghaddam *et al.*, 2013; McIntire *et al.*, 1999). Considering their lungs, the alveoli in preterm lungs are underdeveloped and fewer in number compared to that of normal babies, resulting in ineffective gaseous exchange(Ramaiya *et al.*, 2014). In addition to having fewer alveoli, the preterm lung weighs less, adding to the low weight of the baby(Saigal & Doyle, 2008). Despite these discrepancies, following proper care and treatment protocol enables the preterm lungs to develop both in function and in appearance(Saigal & Doyle, 2008).

Problem Identification

Improving neonatal health in underdeveloped countries is a crucial requisite for global development. The devices for effective monitoring of premature babies in

Ghana are inadequate and expensive. This was observed through internship experiences with Korle-Bu Teaching Hospital in Accra, and Komfo Anokye Teaching Hospital in Kumasi – the two leading health facilities in Ghana. It was realized that among the healthcare challenges as far as monitoring is concerned, these facilities and other lower health facilities in the country lack standalone devices for direct detection of apnea in premature babies. Patient monitors are used in conjunction with the incubator and radiant warmers for indirect detection of episodes of apnea. This employs the use of pulse oximeter and electrocardiogram (ECG) electrodes to detect apnea. The ECG – pulse oximeter approach to detecting apnea in most hospitals in Ghana is less effective due to a delay in the detection of the condition. This is because the detection method utilizes the changes in concentration or saturated partial pressure of oxygen (SPO_2) in the blood which occurs only after the baby has stopped breathing for a while (Rigatto & Brady, 1972) apnea, and hypoxia. For this purpose we compared ventilation/apnea (V/A). The condition would even be more serious in rural health centers where there are inadequate funds to procure patient monitors that come with these accessories. Furthermore, the few clinics that have some of general parameter monitoring devices lack the required specialists to operate appropriately. All these result in a situation where the rural health centers resort to unrefined methods for monitoring the health of premature babies and apnea detection.

The paper presents the design of a cost effective and direct apnea detecting device to address the problem of mortality among preterm babies in Ghana and other low or middle-income countries. The design seeks to directly detect and alert care givers that there is an apnea onset. Proof of concept was done which involves signal acquisition from the chest of an adult (instead of a child) due to the mechanical activity of the chest during breathing which is a measure of the heart rate and the result was presented. An adult was used because we could not get ethical clearance to test the device on children due to time constraint at the time the project was being done.

Materials And Methods

Data were collected from medical practitioners and preterm parents, then followed by bench marking which involves the comparisons of existing devices in the market for apnea detection. This enables us to come out with the specifications of the design.

These specifications informed the functional structure of the system as well as the concepts generation. Several concepts were analyzed using decision matrices to get the best concept that marches the design objectives, the product specifications and the customer requirements. Following this, was the simulation of a virtual model of the system and then the construction of an archetype for simulation and testing.

Overview of the apnea detection system

The system comprises of a signal acquisition unit, a central processing system and a display unit, a power source and an alert system coupled with on-board storage. The system employs the use of a two-way input – the temperature and breathing rate of the preterm baby and gives feedback via a buzzer, an LCD display and LEDs. The inputs are acquired using sensors and the signal is fed into the CPU for logics comparison in order to give the desired outputs . The sensors used are interfaced with the central processing unit which does the decision making and display the correct feedback. The breathing rate is acquired using a forced sensitive resistor (FSR) while the temperature of the baby is acquired using silicon band gap resistor (LM35). The central processing unit (CPU) is a microcontroller unit comprising an Arduino Uno board with digital and analog pins. This board reads the analog inputs from the sensors via their connection with the analog pins.

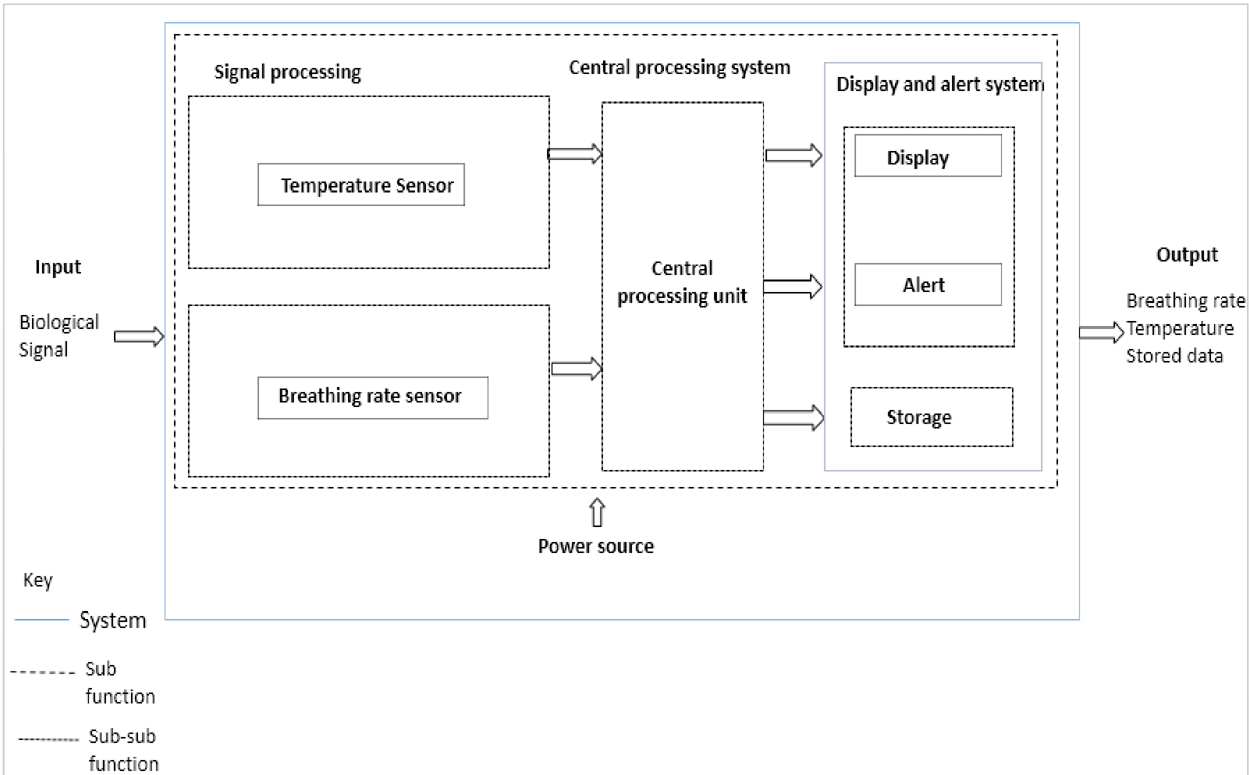

Fig. 1. Schematic representation of the apnea detection system

Display and alert system

The physiological data from the preterm babies after processing are displayed continuously on an LCD screen. These are numerical values that represent the breathing rate and temperature. The breathing rate is displayed as breathe per minute (bpm) while the temperature is displayed in degree centigrade (°C).

Power supply and signal acquisition

The power source provides energy for the functioning of every part of the system. The primary power source used is a 9 V nickel hydride cell. In latter configurations an alternating current (AC) source can be used. This would need to be stepped down to the required voltage needed and then rectified to a direct current (DC) mode. The CPU then allocates the needed amount to different components for smooth operation.

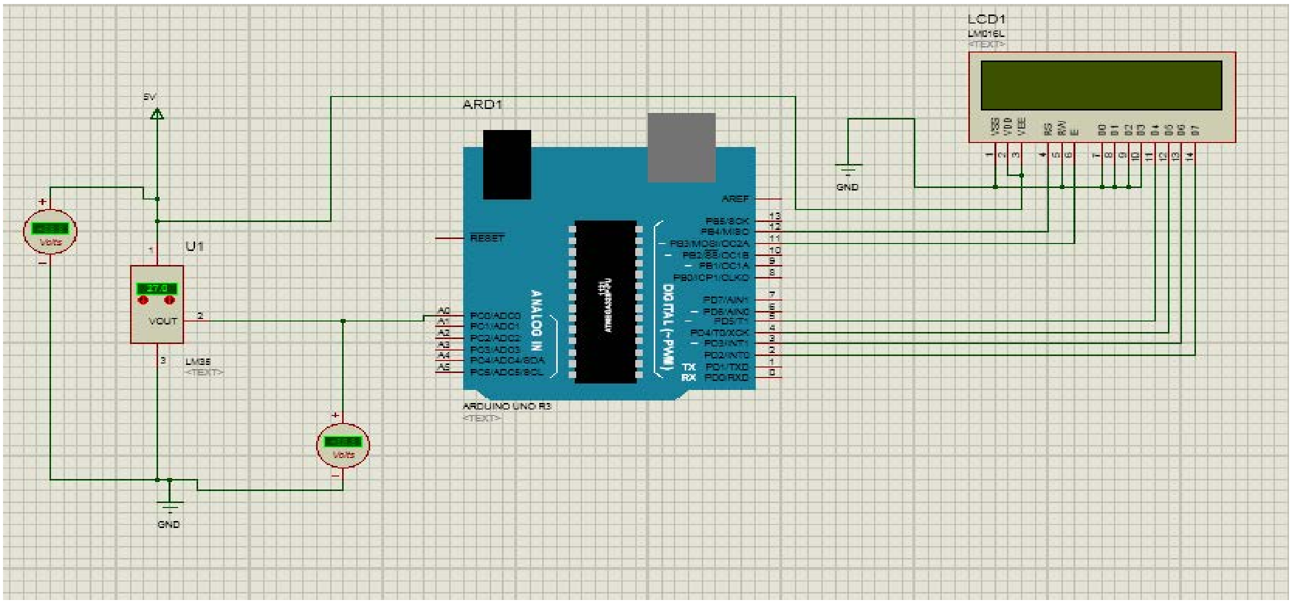

Fig. 2. System component integration

Operational logic

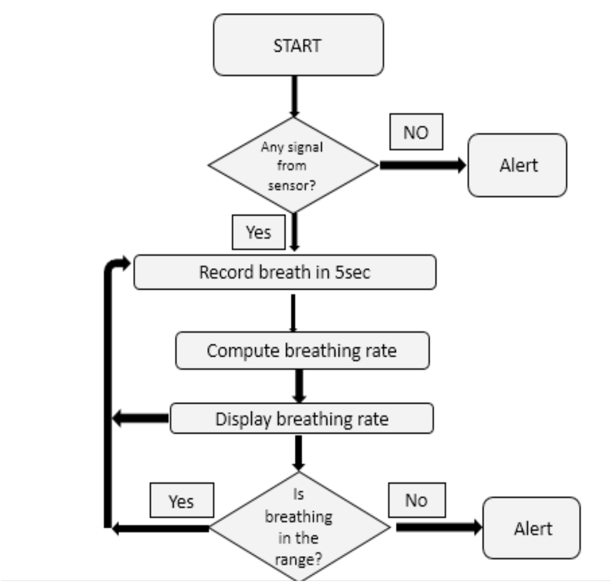

Fig. 3: Operational logic flow chart

The flow chart shows the operational logic of the apnea detection system. As indicated, the power button powers the system by allowing voltage supply from the battery to the board. The microcontroller board check for signals from the analog pin leading to the force sensitive resistor (FSR). The signal from the FSR is used in recording the number of breaths in 5 seconds. The number of breaths in 5 seconds is required for computing the breathing rate of the child and this rate is displayed as a function of time on the LCD display. An alert is sounded by the buzzer, LED and LCD displays if no signal is detected from the FSR sensor. In the event that the breathing rate is not in the normal range for a preterm baby which is between 30 and 40 breaths per minute (Joshi *et al.*, 2018), the system gives an alert by way of a display, sound and light alerts.

Fig. 4: 3d model of the system

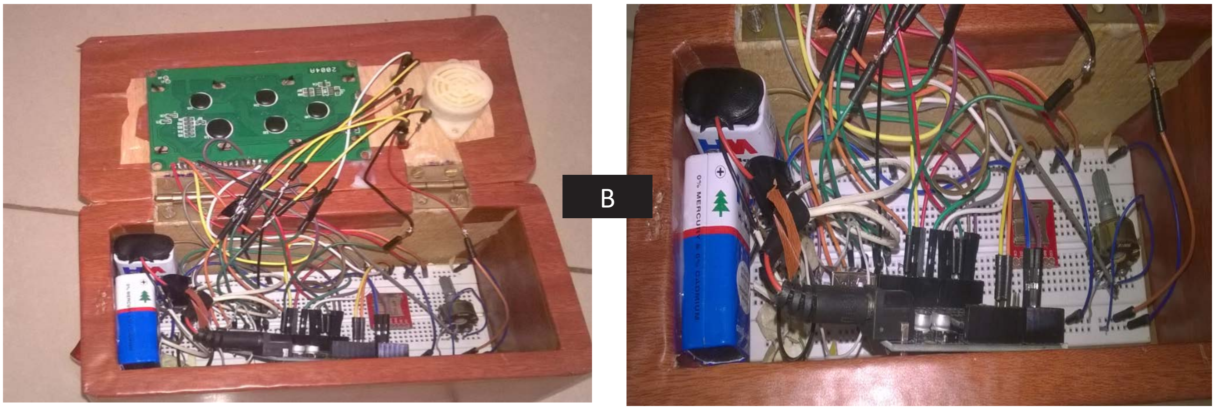

Fig 5. (A) External features and (B) circuit components of the construction

The picture to the right in Fig 5 (A) shows two ports, one serving as connection point for the lead to the FSR for measuring the breathing rate and the other is for the lead to the temperature sensor. These leads are detachable to enhance portability, as well as ease of cleaning and maintenance. There are three LEDs, red, yellow and green. The red LED light signals the onset of apnea, yellow signals the calibration process when the system is taking breathing signals from the FSR in order to calculate the breathing rate of the patient. The green LED signals that the preterm baby is in good conditions and the breathing rate is within the normal range. There is also a buzzer on the board that also gives a sound alert in times of crisis.

Results from Physical Testing

An adult male subject was used for the testing the prototype. This was done by letting the subject to lie on the FSR and the system was allowed to do the initial calibration to determine the breathing rate.

As shown in Fig 6, an initial high voltage was recorded as a result of the impact of the subject on the force sensor, after which the graph shows the system response to the chest activity of the subject due to breathing. Arduino is a 10-bit analog to digital converter and so it calibrates the analog read input in bit sizes of 0 to 1023. This yields a resolution between 4.9 mV (0) and 5 V (1023). The weight of the subject on the force sensitive resistor provides a preload that keeps the signal between 200 and 350 mV. Increase and decrease in the chest volume by inhalation and exhalation respectively result in corresponding increase and decrease in the amplitude of the signal shown on the graph in Fig 6. This amplitude, however, never falls below the preload amplitude (which depends on the weight of the patient and therefore vary from one patient to another). Based on this signal, the system calculates the breathing rate as:

$BR = N(C)/60$;
BR = Breathing rate,
N(C) = number of crests in 60 seconds

Apnea is the cessation of breath for a short period and since the system can calculate the breathing rate, a breathing rate that does not fall within the normal range of 30 to 40 breaths per minute gives an indication of apnea set in.

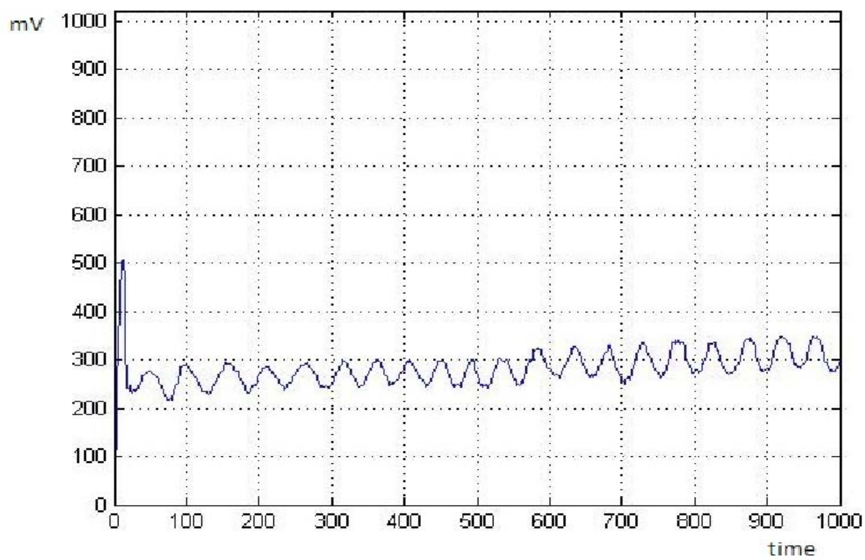

Fig. 6. A voltage response of the system to the mechanical activity of the subject.

Discussion

It is very crucial to monitor the breathing rate of preterm babies since their lungs and respiratory tract are underdeveloped (Ramaiya *et al.*, 2014). The use of indirect monitoring approaches to apnea detection is very likely to give responses at a time that is too late for resuscitation to revive the baby. The ECG – pulse oximeter approach to detecting apnea provides accurate result but depends on signals from the reduction in the concentration of the oxygen in the blood of the preterm and consequently, the drop in the saturated partial pressure of oxygen (SPO_2) (Rigatto & Brady, 1972) apnea, and hypoxia. For this purpose we compared ventilation/apnea (V/A). This occurs after the baby has stopped breathing and the baby's system has used up the available oxygen in the blood. The pulse oximeter detects this drop in SPO_2 and gives a signal. The drop also affects muscle activity and so will show on ECG outputs if the appropriate leads are connected to the baby to monitor heart activity.

In this design the system readily calibrates and measures the breathing rate of the subject, once the subject is placed on the force sensor. The system monitors this value of breathing rate and compares it against the standards which is incorporated into the programed microcontroller. When a breathing rate is observed below the allowable limit, an alert is given to prompt the care giver of an apnea episode onset. This makes the detection method in this design a direct method as compared to the conventional approaches seen in the hospitals visited. For resource limited settings, this system was designed to run on a 9 V battery and so does not require an external power source.

The main objective of this design, which is to develop a more direct means to detecting apnea in preterm babies in order to deliver timely interventions was therefore achieved. There is however, room to improve the design by adding a real-time display of the breathing signals aside the usual feedbacks of LCD, LED and buzzer alerts to the care givers. Also, intensive testing and prototype optimization as well as intensive clinical trials with the target subjects (preterm babies) need to be done.

Conclusion

Following the identification of the problems associated with pretern babies, the Engineering design principles were followed to design and construct a prototype of an early apnea detection device which is cost effective and simple to use. The design consists of a power supply unit, temperature measurement unit, signal acquisition and processing units and a display unit. The operational logic of the system was represented by a flow chart. The design was tested on an adult male and the results meet the objectives of the design though there is still room for improvement. Recommendations or suggestions were also made for further works on this project.

References

Cooper, P. A., Madhi, S. A., Huebner, R. E., Mbelle, N., Karim, S. S. A., Kleinschmidt, I., Forrest, B. D., & Klugman, K. P. (2008). Apnea and its possible relationship to immunization in ex-premature infants. *Vaccine*, 26(27), 3410–3413. https://doi.org/10.1016/j.vaccine.2008.04.037

Daily, W. J. R., Klaus, M., Belton, H., & Meyer, P. (1969). Apnea in Premature Infants: Monitoring, Incidence, Heart Rate Changes, and an Effect of Environmental Temperature. *Pediatrics,* 43(4), 510–518.

Engmann, C., Matendo, R., Kinoshita, R., Ditekemena, J., Moore, J., Goldenberg, R. L., Tshefu, A., Carlo, W. A., McClure, E. M., Bose, C., & Wright, L. L. (n.d.). Stillbirth and early neonatal mortality in rural Central Africa. *International Journal of Gynecology & Obstetrics*, 105(2), 112–117. https://doi.org/10.1016/j.ijgo.2008.12.012

Goldenberg, R. L., & Rouse, D. J. (1998). Prevention of Premature Birth. *New England Journal of Medicine*, 339(5), 313–320. https://doi.org/10.1056/NEJM199807303390506

Hassanian-Moghaddam, H., Farajidana, H., Sarjami, S., & Owliaey, H. (2013). Tramadol-induced apnea. *The American Journal of Emergency Medicine,* 31(1), 26–31. https://doi.org/10.1016/j.ajem.2012.05.013

Joshi, N. S., Kamat, R. K., & Gaikwad, P. K. (2018). FPGA based Breathing Rate Detection System for Preterm Neonates. *International Journal of Electronics, Electrical and Computational System*, 7(4), 124–131.

Künzel, W., Herrero, J., Onwuhafua, P., Staub, T., & Hornung, C. (1996). Maternal and perinatal health in Mali, Togo and Nigeria. *European Journal of Obstetrics and Gynecology and Reproductive Biology,* 69(1), 11–17. https://doi.org/10.1016/0301-2115(95)02528-6

Kurth, C. D., Spitzer, A. R., Broennle, A. M., & Downes, J. J. (1987). Postoperative apnea in preterm infants. *Anesthesiology*, 66(4), 483–488.

Lee, Y. M., Cleary-Goldman, J., & D'Alton, M. E. (2006). Multiple Gestations and Late Preterm (Near-Term) Deliveries. *Seminars in Perinatology*, 30(2), 103–112. https://doi.org/10.1053/j.semperi.2006.03.001

McClain, A. (2002). *Incubator system with monitoring and communicating capabilities* (United States Patent No. US6409654B1). https://patents.google.com/patent/US6409654B1/en

McIntire, D. D., Bloom, S. L., Casey, B. M., & Leveno, K. J. (1999). Birth Weight in Relation to Morbidity and Mortality among Newborn Infants. *New England Journal of Medicine*, 340(16), 1234–1238. https://doi.org/10.1056/NEJM199904223401603

Perlstein, P. H., Edwards, N. K., & Sutherland, J. M. (1970). Apnea in Premature Infants and Incubator-Air-Temperature Changes. *New England Journal of Medicine*, 282(9), 461–466. https://doi.org/10.1056/NEJM197002262820901

Ramaiya, A., Kiss, L., Baraitser, P., Mbaruku, G., & Hildon, Z. (2014). A systematic review of risk factors for neonatal mortality in Adolescent Mother's in Sub Saharan Africa. *BMC Research Notes*, 7, 750. https://doi.org/10.1186/1756-0500-7-750

Rigatto, H., & Brady, J. P. (1972). Periodic Breathing and Apnea in Preterm Infants. Ii. Hypoxia as a Primary Event. *Pediatrics*, 50(2), 219–228.

Saigal, S., & Doyle, L. W. (2008). An overview of mortality and sequelae of preterm birth from infancy to adulthood. *The Lancet,* 371(9608), 261–269. https://doi.org/10.1016/S0140-6736(08)60136-1

Sosa, C. G., Althabe, F., Belizán, J. M., & Bergel, E. (2015). Bed rest in singleton pregnancies for preventing preterm birth. *The Cochrane Database of Systematic Reviews*, 3, CD003581–CD003581. https://doi.org/10.1002/14651858.CD003581.pub3

Torpy, J. M., Lynm, C., & Glass, R. M. (2005). Premature Infants. *JAMA,* 294(3), 390–390. https://doi.org/10.1001/jama.294.3.390

Tume, L. (n.d.). The deterioration of children in ward areas in a specialist children's hospital. *Nursing in Critical Care,* 12(1), 12–19. https://doi.org/10.1111/j.1478-5153.2006.00195.x

Varshney, U. (2007). Pervasive Healthcare and Wireless Health Monitoring. *Mob. Netw. Appl.,* 12(2–3), 113–127. https://doi.org/10.1007/s11036-007-0017-1

Vento, M., Aguar, M., Leone, T. A., Finer, N. N., Gimeno, A., Rich, W., Saenz, P., Escrig, R., & Brugada, M. (2008). Using Intensive Care Technology in the Delivery Room: A New Concept for the Resuscitation of Extremely Preterm Neonates. *Pediatrics,* 122(5), 1113–1116. https://doi.org/10.1542/peds.2008-1422