

Original Article

Development of a neonatal incubator with phototherapy, biometric fingerprint reader, remote monitoring, and heart rate control adapted for developing countries hospitals



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ABSTRACT

This paper aims to develop an automatic neonatal incubator equipped with phototherapy, biometric fingerprint reader, remote monitoring and heart rate control modules for developing countries due to the lack of neonatal incubators. The proposed device consists of an acquisition module that senses temperatures (of the enclosure and the baby) and humidity, a biometric fingerprint reader to identify the user, a remote monitoring module in charge of supervising the temperature and the heart rate of the baby, a video surveillance module which allows filming and transmitting the images to the web server in order to give parents and nurses the possibility of being able to visualize whatever their location the newborn baby, a phototherapy module used to treat newborn jaundice by lowering the bilirubin levels in the baby's blood, a digital control module from a pulse width modulation (PWM) signal generated by a microcontroller of Arduino Nano type for system operation monitoring, and a human machine interface module for setting parameters. The equations describing the energy balance and heat transfer for newborn baby (Ostrowski and Rojczyk, 2018) are taken into account for the implementation of power supply and the choice of the heating resistor. The desired temperature of 37 °C was obtained after only a few minutes inside the incubator.

1. Introduction

Over 130 million babies are born every year in the world, and almost 8 million die before their first birthday due to prematurity complications (World Health Organization, 2006). One of the complications is improper thermoregulation which is generally due to the lack of equipment dedicated to this (Osifo and Oriaifo, 2008). Furthermore, it can be noted the lack of finance and skilled personnel for such equipment maintenance in third world countries (Richards- Kortum, 2010). All these factors constitute the causes of neonatal deaths (Word, 2009; Mah-Mungyeh et al., 2014). Therefore, many attempts to develop neonatal incubators have been performed in the literature (Suruthi and Suma, 2015; Tisa et al., 2013; Tran et al., 2014; Sreenath, Kumar, Lohit; Pinto et al., 2015), however the equipment were either highly power consuming or took a long time to reach the target temperature. Recently, a prototype of incubator was designed (Kapen et al., 2018). However, it does not allow supervising physiological parameters of the baby. In this work, an incubator with phototherapy, biometric

fingerprint reader, video surveillance, remote monitoring and heart rate control modules adapted for third world countries health centers is constructed. Energy balance and heat transfer for newborn baby (Ostrowski and Rojczyk, 2018) were considered for the implementation of power supply and the choice of the heating resistor.

2. Material and methods

2.1. Mathematical background of heat transfer for newborn baby

The various types of heat transfer for newborn baby are: Convective, conductive, radiative and evaporative (Fig. 1).

2.1.1. Conductive heat transfer

This type of heat exchange may be occurred between the newborn and the material on which he is placed. In this work, a 6 cm-thick foam mattress of polyether type has been used for its excellent insulating properties. Therefore, the conductive heat transfer for newborn baby

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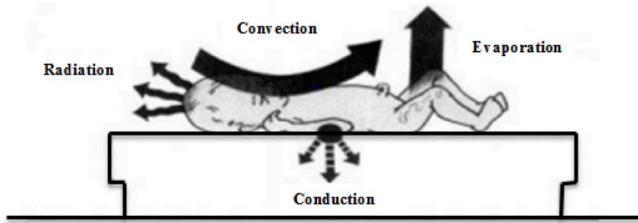


Fig. 1. Different types of heat transfer for newborn baby.

was neglected.

2.1.2. Radiant heat transfer

Radiant heat has been considered between the newborn baby and the inner surface of the incubator (made in plexiglass material). The radiant heat flux for baby (Ostrowski and Rojczyk, 2018) reads

$$\phi_r = A\sigma F_a (T_{bs}^4 - T_{ie}^4) \quad (1)$$

With ϕ_r the radiant heat flux (W), $A \sim 0.167 \text{ (m}^2\text{)}$ the effective surface area (<https://www.calculator.net/body-surface-area-calculator.html?csex=m&bodyweight=2383&bodyweightunit=gram&bodyheightfeet=&bodyheightinch=18.19&bodyheight=42.6&x=69&y=10>) of a prematurely born baby (35th week) (<https://www.baby-center.com/average-fetal-length-weight-chart>), $\sigma = 5.670373 \times 10^8 \text{ (W}\cdot\text{m}^{-2}\cdot\text{K}^{-4}\text{)}$ the Stefan-Boltzmann constant, F_a the transfer factor or emissivity, T_{bs} and T_{ie} are baby surface and incubator enclosure wall temperatures respectively (K). Indeed, the baby surface temperature was measured using the DS18B20 sensor while the incubator enclosure wall temperature was measured using the DHT22 digital sensor.

2.1.3. Convective heat transfer

The convective heat transfer from the newborn baby exposed surface area is a function of baby surface temperature and that of air. It is expressed as follows (Ostrowski and Rojczyk, 2018)

$$\phi_c = \phi - \phi_r \quad (2)$$

Where ϕ is the total heat losses (W) and given by

$$\phi = mc_p(T_{in} - T_{out}) \quad (3)$$

m represents the intra body water mass flow rate (kg/s), $c_p = 4200 \text{ J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$ is water heat capacity ($\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$), T_{in} and T_{out} are thermal baby inlet and outlet water temperatures (K). T_{out} was measured using the DS18B20 sensor. In our computation, we assumed that body water constitutes as much as 73% of the body weight (approximately 2.383 kg) for prematurely born baby (35th week).

2.1.4. Evaporative heat transfer

This type of heat exchange occurs when a wet surface is exposed to the air. Hence, the baby gets colder as the amniotic liquid dries on him. This heat was neglected since air movement in the incubator was assumed to be very low.

2.2. Design of the neonatal incubator

The design of the incubator followed different steps.

2.2.1. Mechanical module

The mechanical module consisted of the base and chamber of the incubator. The incubator chamber dimensions are: $68 \text{ mm} \times 43 \text{ mm} \times 48.5 \text{ mm}$. Fig. 2 shows the enclosure of the locally built incubator. The plexiglass with thickness $e = 5 \text{ mm}$ was used for its design. Fig. 3 presents the base of the incubator made up of wood material.



Fig. 2. Incubator enclosure.



Fig. 3. Incubator base.

2.2.2. Electronic module

When the power is turned on, an operating light is on to testify that the equipment is working. The user after identifying himself via the biometric fingerprint reader defines the control parameters (set temperature). After validation of these parameters, the microcontroller starts by operating the heating resistor and the fan to reach the desired set point. The temperature sensor DHT22 present in the enclosure allows knowing the temperature prevailing in the incubator chamber in real time. A 6 A DC stabilized energy source was chosen in order to take into account the energy balance in Equation (3) and the electric characteristics of electronic components. A 12V fan was used for air homogenization in the enclosure. The operation of the incubator is presented in Fig. 4.

- Temperature and humidity measurement sensors

The DHT22 digital sensor was used for the acquisition of temperature and humidity in the incubator, while the DS18B20 was used to measure baby surface temperature. Fig. 5 presents these sensors.

- Heart rate measurement sensor

The heart activity was measured using a heart rate sensor (Fig. 6).

- Heater

It was used to heat the enclosure of the incubator. Fig. 7 presents a (220 V, 1.58 A) heater.

- Microcontroller

Fig. 8 shows the microcontroller used in this work.

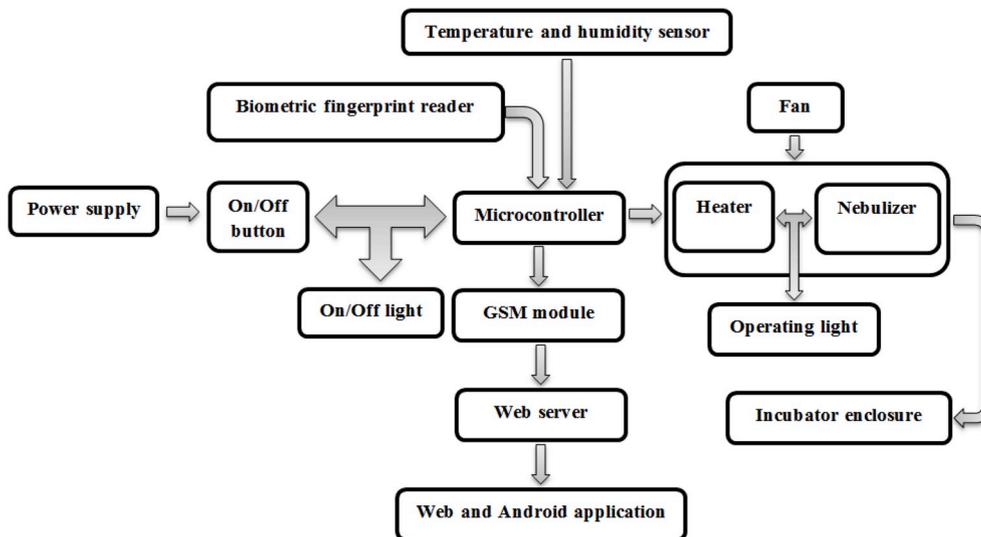


Fig. 4. Operation of the incubator.

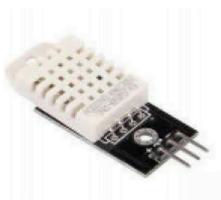


Fig. 5. DHT22 digital sensor (left) and DS18B20 sensor (right).



Fig. 8. 5 V, 0.05 A Arduino Nano microcontroller.



Fig. 6. Heart rate sensor.



Fig. 9. 5 V, 0.9 A nebulizer.



Fig. 7. 220 V heater.



Fig. 10. Triac BT137A.

To control the system, integrated circuits, octocouplers, transistors and resistors of 470 Ohms were used. Fig. 10 presents the Triac BT137A. Fig. 11 shows the electronic control module.

2.2.3. Remote monitoring module

It allows the remote supervision of the equipment.

- Video surveillance

The model used is the wifi camera (Fig. 12) which allows filming and transmitting the images to our web server in order to give parents

- Nebulizer

It is a device that turns water into a cloud of particles cold and extremely fine. It is shown in Fig. 9.

- Power circuit

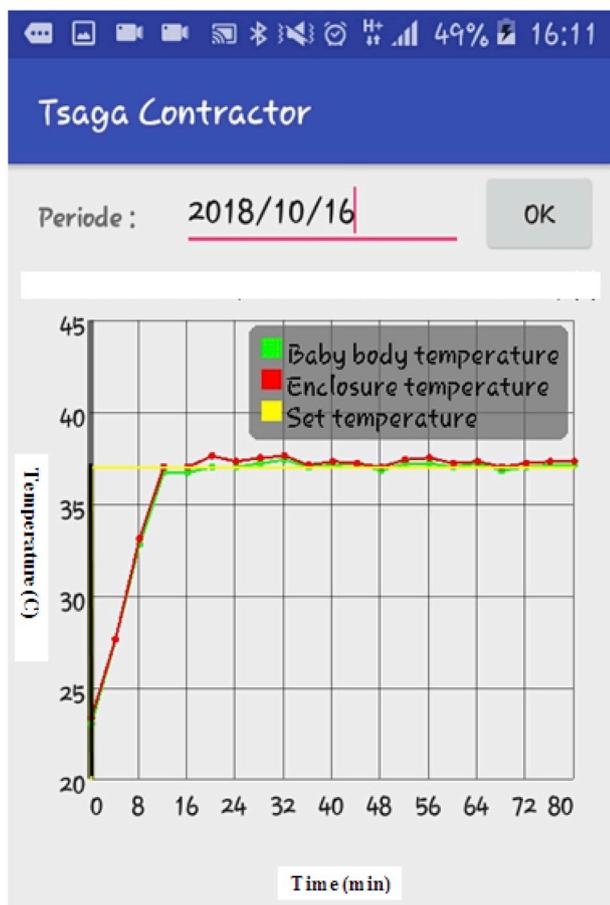


Fig. 19. Recorded temperatures from the Android application.

This device provides the time and date for the microcontroller to synchronize data to the web server (Fig. 14).

- Biometric fingerprint reader

This module allows the identification of the user before any modification of the control parameters in order to limit unwanted

manipulations. In Fig. 15, the fingerprint reader used is presented.

2.2.4. Phototherapy module

To prevent the level of bilirubin becoming dangerous for the child, there is a very effective treatment: phototherapy (treatment with light). It acts directly on the bilirubin at the level of the skin and makes it easier to eliminate. In Cameroon, many hospitals do not have this phototherapy device because of its high cost. Newborn are mostly exposed to the sun for hours, yet this practice can lead to dehydration of the newborn and even cause skin cancer. The phototherapy module used in this work is presented in Fig. 16.

2.2.5. Software module

A web server was used in this work to allow the communication between the incubator and the Android application. It was developed in PHP and integrates a database developed under the MySQL platform to record data that can be accessed at any time.

2.2.6. Android application

In order to facilitate the supervision of the physiological parameters of the newborn baby, an Android application was developed. Once the user is logged in, he chooses the name of the hospital and the index of the incubator which he would like to know the parameters. Thus, a page is displayed and shows the user the physiological parameters of the newborn baby present in the enclosure. It is also possible for the user to view the different curves (temperature and humidity) and to consult their history. The interface of the android application on a smartphone is shown in Fig. 17.

2.2.7. Human machine interface module

This module allows the user to communicate with the system through an interface (Fig. 18). It is made up of:

- An on/off button to turn on the equipment and its operating light;
- Two push buttons to increment and decrement the temperature and humidity;
- A validation button which also ensures the registration of users;
- A fingerprint reader allowing the identification of users;
- A screen to view the device settings;
- LEDs to visualize temperature and humidity operation.



Fig. 20. The incubator system.

3. Results and discussion

The evolution of the temperature as a function of time has been recorded in the server. The plot is shown in Fig. 19. The temperature values are taken every 5 s. The figure shows the data recorded for a set temperature of 37 °C over a period of 80 min from the Android application.

It can be observed in Fig. 19, the plots of the enclosure, baby and set temperatures respectively. It can easily be concluded that the enclosure and baby temperatures reach the set temperature of 37 °C after almost 15 min. The resulting equipment is presented in Fig. 20.

4. Conclusion

An incubator with phototherapy, biometric fingerprint reader, remote monitoring and heart rate control modules has been developed in this work. The equations describing heat transfers for the newborn allowed the implementation of the power supply and the choice of the heating resistor. The variations of the temperature as a function of time for the enclosure and the newborn were recorded over a period of 80 min from the Android application. It was concluded that these temperatures reached the set temperature after almost 15 min. This equipment could improve newborn healthcare in third world countries.

Conflicts of interest

None.

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Ethical approval

Not required.

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