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Study on Development of Portable Incubator

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휴대용 인큐베이터의 개발에 관한 연구

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ABSTRACT

Preterm children require a controlled environment that is as close as possible to that inside the womb. Incubators are well equipped to fulfill this requirement; however, they are cumbersome and expensive, thereby restricting their portability and availability in less developed and rural areas. This research comprises the development and system validation of a portable incubator. The system consists of a collapsible baby enclosure that can be stowed inside the system base when not in use. The enclosure is made from acrylic such that it is easy to clean and allows unhindered visual observation of the occupant while being robust enough to withstand transit conditions. The system can be powered either by a mains supply or a 12-VDC automobile power supply. Additionally, it has an onboard battery to ensure a continuous supply during transit. A Peltier plate controlled using a microcontroller ensures the desired enclosure temperature irrespective of the ambient temperature. Built-in sensor probes can measure the skin temperature, pulse rate, blood oxygenation level, and ECG of the infant and display them on the system screen. The system function is validated by testing its peak power consumption and the heating and cooling performances of the environment control system.

Keywords : Portable Incubator(휴대용 인큐베이터), Infant Care(유아 보호), Peltier Plate(펠티어 플레이트)

1. Introduction

A birth is considered preterm when the child is born before completion of 37 weeks of gestation[1]. An estimated 14.9 million preterm babies were born worldwide in 2010, constituting 11.1% of all live births[2]. Leading cause of death in children under five years are complications related to preterm birth[3]. Of the 5.9 million child deaths before age of five years in 2015, 2.7 million were neonates, over 1 million of those died due to preterm birth complications[3]. The world health organization (WHO) recommends using incubators to provide

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thermo-neutral environment to prevent hypothermia in unstable newborns weighing 2kg or less[4].

To provide specialized care for at risk babies, neo-natal intensive care units (NICUs) are used at care facilities. A central element of NICUs is the incubator, which is a system to provide warmth to the infant[5] while allowing monitoring and interventions to be carried out at ease. These systems are usually prohibitively expensive and are thus in very limited supply especially in facilities in rural areas and in the developing world. Another constraint on the use of incubators is their large size which usually limits their use to within hospital. This leaves the baby potentially exposed to the elements during transport to and between care facilities.

To overcome the problem of providing incubation during transport, a number of portable incubator designs have been proposed. Delaporte et al. proposed a modular intensive care system for neonates[6]. A device with an open upper end for receiving a receptacle has also been reported[7]. Another system has features to regulate the admission of air into the infant carrying chamber in addition to controlling the chamber environment[8]. A rugged system for transport has also been reported[9] that can be carried in the back seat of a car. Portable incubator design that allows easy observation of the infant has also been reported[10]. However, all these systems have one common drawback that is their relatively large size. In addition, these systems are not collapsible and thus take up a considerable amount of space even when not in use.

To deal with the issue of compactness, Belval et al. proposed the design of an incubator backpack that can be carried by a person on their back while another person walking behind them can monitor the child through the transparent hood[11]. Although this is a very compact design specifically made for humanitarian crises, it has usage limitations in the ambulance and in-facility environments. One method to make a design compact is to make the system collapsible. One such design[12] consists of a cabin made of a flexible material that is kept in shape by the use of a frame consisting of telescoping members. This design meets the requirement for a collapsible design but does raise the question of hygiene with regards to the prismatic joints in the frame structure. One design that does away with the use of a rigid structure is an inflatable incubator designed especially for use in refugee camps[13]. This particular design is compact, lightweight and low-cost, but it may not be rugged enough for long periods of use in an environment where it is surrounded by a myriad of objects that can very easily puncture it. One recent design consists of a briefcase type system that can be extended to accommodate the baby[14]. The system has a flexible skin that folds up like an accordion and a foldable frame. This system is extremely suited to transport but may not be able to protect the infant from accidental bumps that are very likely to occur in a jerky environment like that inside a fast moving ambulance.

Each of the designs mentioned above provides the basic functionalities of an incubator but lacks in terms of one or more of the qualities that are needed in a low-cost system that is portable while being suitable for use inside a hospital. For a system to satisfy these objectives, it needs to be low-cost, compact, lightweight, and sturdy. It also needs to be collapsible to allow ease of storage while being easy to clean. Therefore, the work presented here involves the design and functional validation of a portable incubator that is specifically designed to meet these objectives.

2. System Design

The system, shown in Fig. 1, consists of a lightweight hollow base with a collapsible acrylic

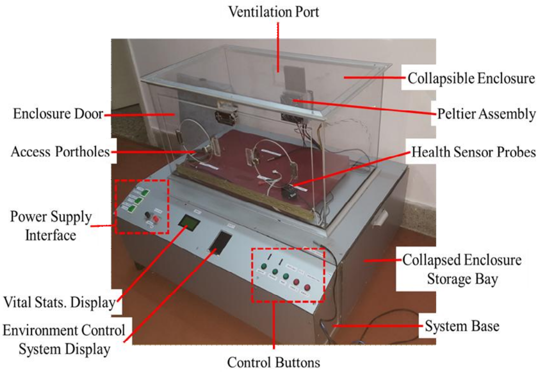


Fig. 1 The developed system prototype

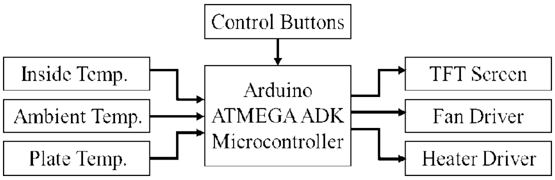
enclosure on top. The base measuring 900×740×250 mm is made up mainly of aluminum to keep the weight low while maintaining the required robustness. The control electronics, backup power source, and monitoring devices are all housed inside the base. The front side of the base contains all the switches, connections, and displays that the operator needs access to in order to use the system. An access door on the side opens up to allow storage of the enclosure structure inside the base. The top panel of the base module houses the structure required to erect the enclosure.

The enclosure structure consists of four separate acrylic wall components and one acrylic roof component with aluminum edging. The overall dimensions of the enclosure are 710×400×350 mm, and the acrylic sheet used is 5 mm thick. Thewalls slot into the support structure provide on the base at one end and on the other end they slot into the aluminum edging on the roof component. The use of this system helped us to reduce the overall system mass and also allows for unobstructed visual inspection of the infant. The front wall of the enclosure has a large rectangular window that can be used to move the infant in and out of the enclosure. There are also two smaller circular windows on this panel to allow easy manipulation of the infant without causing too much variation in the incubator temperature. A waterproof mattress is installed inside the enclosure for comfort of the occupant. The back wall of the enclosure houses the heating, cooling and ventilation system.

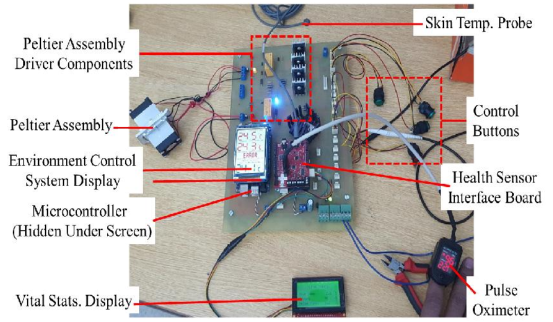
The incubator is designed to be used and transported in a wide range of environments including high temperature tropical environments. To achieve this, the incubator needs to have the capability to warm and cool the inside air to maintain the desired temperature. We have used a thermoelectric peltier cooler (TEC1-12706, Dim. 40×40×3.6 mm) in our system. The peltier cooler utilizes the peltier effect to transfer thermal energy from one surface of the cooler plate to the other when electric power is supplied to it. The direction of transfer of energy can be reversed by simply reversing the polarity of the power supply. The compactness and easy reversibility of the peltier cooler makes it ideal for low-cost compact applications such as ours.

The cooler/heater assembly consists of one peltier cooler plate placed in a window cut out of the back wall of the incubator enclosure. On both sides of this plate aluminum fin blocks are attached, one outside the incubator enclosure and one inside. Each block has a 12V DC fan attached to it. The fans circulate air over the fins, increasing their heat dissipation/absorption to increase their efficiency of moving heat to or from the incubator enclosure. A small window above the peltier assembly allows the introduction of fresh air into the enclosure. The fan speeds and power supply to the peltier plate are controlled by the onboard electronics.

Fig. 2(a) shows the environment control system block diagram. The system is controlled using a Proportional Integral Derivative (PID) controller embedded into a microcontroller (Arduino ATMEGA ADK). The system utilizes three waterproof temperature sensors (DS18B20) to gather data that is used by the controller to manage the temperature control system. There is one sensor inside the



(a) The system block diagram



(b) The assembled electronic hardware

Fig. 2 The environment control system block diagram

enclosure, one outside it, and one on the fins. The temperatures measured by these sensors are also displayed on a 480 pixel x 320 pixel TFT LCD readout placed at the front panel of the incubator base. The temperature is controlled using buttons provided at the front panel of the incubator base. The microcontroller generates Pulse Width Modulated (PWM) signals to control the fans and the peltier plate. H-bridge circuits act as component drivers here and modulate the power sent to the fans and peltier plate according to these PWM signals. To allow ease of use in different regions, the units of temperature display can be easily switched between Celsius and Fahrenheit.

The portable incubator has skin temperature, pulse oximetry, and ECG sensors to monitor continuously the vital statistics of the infant. The sensor probes enter into the enclosure from a small opening in the top side of the incubator base. The sensor signals are interpreted using a signal interface board (e-Health Sensor Shield V2.0, Cooking hacks) and displayed on a graphical LCD placed at the front side of the incubator base. A button on the front panel can be used to toggle this display between vital statistics and ECG output waveform.

To allow ease of transport and to deal with power outages, the system can be powered using a variety of sources. The primary power source is the standard 220V mains supply. There is a regulated power supply fitted into the system that converts 220VAC to 12VDC for use by the system electronics. In case the mains supply is not available, there is a built-in 12V 18AH rechargeable battery installed in the system that can supply power for short periods. Additionally, there are male and female electrical connectors available in the system to connect it to any 12VDC power supply (such as 12V 120W power supply port present in cars) that can support its load.

All major electronic components used in the system have been assembled onto one motherboard to declutter the space inside the base and also to make the electronics robust against mechanical shocks.

3. Testing and Results

The system was tested to determine its performance in two key areas. The first area of interest was the heating and cooling capabilities of the temperature control system. The second area of interest was the electrical power consumption of the system. The electrical power consumption is important because the system has to be able to operate for a practical amount of time using backup power supply. Knowing the maximum power consumption of the system is also necessary to determine which auxiliary power supplies can be used to operate it.

In order to conduct the tests, a single phase energy meter(DDS238-2 SW, Hiking) was attached to the power input of the system. The incubator was switched on and the power consumption was noted. It was found that the system has a maximum power consumption of 95 Watt. This means that the system can be operated using any power supply that is rated at above 100 Watt. Furthermore, with this power draw, the system can be powered by the on board battery for over one hour with only 50% discharge.

The temperature control system was tested by measuring the time it took for it to raise and lower the temperature of the volume of air enclosed inside the baby enclosure to a set value. It was found that the system took 13 minutes to raise the temperature from 27.5°C to 37°C. Resulting in a temperature change rate of 0.73°C per minute during heating. Similarly, it took about 22 minutes to lower the temperature from 37°C to 27.5°C. Resulting in a temperature change rate of 0.43°C per minute during cooling. The results of these tests are shown in Fig. 3. The results of these experiments show that the temperature control system is adequate for the desired application.

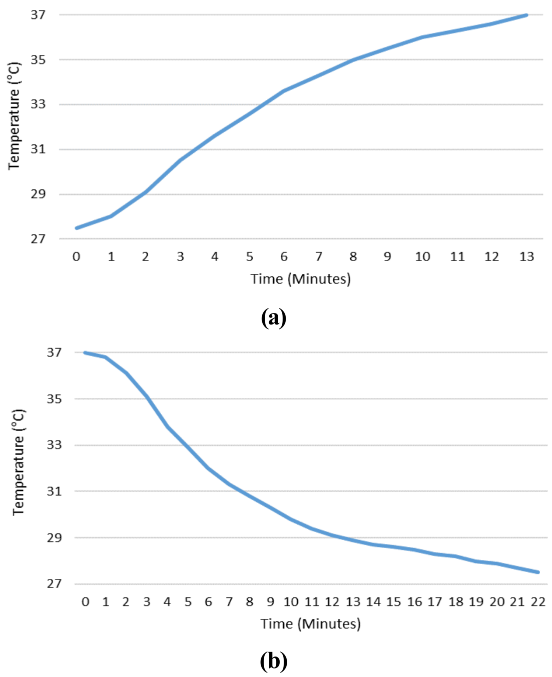


Fig. 3 Testing results, (a) heating, and (b) cooling.

4. Conclusion and Future Work

The system presented here was developed to provide a viable solution for the care of preterm babies, especially during transport and in less developed areas. The baby enclosure is made of rigid plastic to withstand bumps that it may encounter during transit. The enclosure is designed so that it can be stowed inside the system base when not in use. The system is capable of running on different types of power supplies and consumes relatively small amount of power. The temperature inside the enclosure can be adequately controlled to the desired value either above or below the ambient. In addition, the incubator is equipped with sensors for monitoring the skin temperature, pulse, blood oxygenation level, and ECG of the infant.

In the future, certain features may be added to enhance the system's capabilities. Currently, the system does not have an on board ventilator. Although there is space to run ventilator tubes into the enclosure, the addition of an on-board ventilator may make the transport of at-risk infants much easier. Furthermore, the system may benefit from the provision of network connectivity. If a network connection is available, the vital statistics measured by the onboard sensors may be transmitted to the doctors at the hospital so that they are well prepared to receive the baby or can even provide their opinion about the baby's condition.

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