Smart ASHeR Infant Incubator for Accurate Monitoring and Control

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***Abstract*:** Preterm infant care is one of the most vital and delicate areas in the bio-medical field. This paper aims at tackling the specific needs of an infant to provide utmost care and safety by providing a low budget and accurate monitoring and control incubator model, for reduced risk and effectiveness in neonatal care. The framework of this system implements innovative technology which plays a vital role in reducing the overall cost of the system while ensuring its reliability as well as security. This is done using the Arduino platform, wherein DHT22 is used for sensing the temperature and humidity, accompanied by wireless transmission of the respective parameters through Bluetooth module HC-05.

Keywords - incubator; neonatal; baby; asher; infant; smart; temperature monitoring and control; humidity; sensor; phototherapy; neonatal care, NICU, bluetooth, wireless transmission, DHT22, etc.

I. INTRODUCTION

Preterm baby requires surroundings that replicate the womb to adjust to the external environment. Due to an infant's fragile body system, physiological conditions may have serious consequences on their well-being leading to disorders like hypothermia. However, an excessive amount of heat might lead to hyperthermia in case of high core temperature. Hence, it is crucial that the infant's temperature be monitored and controlled regularly. One methodology of physiological condition management is an incubator, a setup in which an internal device that controls environmental conditions like temperature and humidity, reduces convective and physical changes like heat loss and trans-epidermal water loss (TEWL). Incubators create a suitably accurate atmosphere for neonates, keeping them at a perfect core vital conditions so their bodies will concentrate on other vital functionality for sustenance rather than continuously regulating heat.

Studies have shown that the complexity of design of the standard available incubators are difficult to maintain, and the staff find the incubators too complicated to use. Further, a large portion of prematurely born infants die in transit to hospitals since there is no adequate means to transport these infants in a temperature-controlled environment. There are small companies in the market, who cater to the low budget hospitals, but they are proven to be comparatively expensive and usually the designs are not ergonomically sound [1].

In addition to heat loss, nosocomial infections are an important cause of infant morbidity and early fatality in underdeveloped countries, where reports of neonatal deaths from sepsis reach 29% of total neonatal deaths. Preterm birth occurs in 11% of live births globally and accounts for 35% of all newborn casualties [2]. Alongside this, improper maintenance can result in incubators that are dangerous to the infant since incubators are used for long durations of time, during which they are subjected to considerable shock and vibration [3].

The fetus and newborn face several complicated immunological demands, including protection against infection, avoidance of harmful inflammatory immune responses that can lead to pre-term delivery, and balancing the transition from a sterile intra-uterine surrounding to a world that is high in foreign antigens. These demands shape a specific neonatal innate immune system that is biased against the production of pro-inflammatory cytokines [4].

The stratum corneum (SC) plays a crucial role in maintaining life since it inhibits water loss from the tissues and prevents the entry of harmful microorganisms [5]. In preterm infants, the SC layer is thinner and underdeveloped as compared to full-term infants and adults, leading to high water loss and cutaneous infections, with high morbidity and increased risk of fatality [6]. Therefore, there is a dire necessity of an incubator which caters to the needs of low budget hospitals, thereby ensuring the safety and reliability and hence, saving millions of premature babies' lives. Unfortunately, there is a lack of inexpensive infant incubators in the developing world.

Another important aspect of an infant incubator is its use in phototherapy which is considered the best solution to control jaundice in premature babies placed in infant incubators. Babies with jaundice are usually made to receive the treatment of phototherapy for 4 to 7 days. When ill infants with low birth weight receive phototherapy, their insensible water losses are significantly doubled or tripled. This is caused due to the heat source placed inside the incubator for the purpose of phototherapy [7]. Phototherapy is the application of fluorescent lights over the infant's skin to help reduce serum bilirubin level in the infant's blood. Blue light waves of 425-475 nm from the fluorescent lights are absorbed by the infant's skin and blood which converts the unconjugated bilirubin to conjugated bilirubin which is then eliminated by the body through urine and stool. This reduces the need for exchange transfusion and prevents the onset of kernicterus which is a type of brain damage. The effectiveness of phototherapy depends on the degree of the infant's surface area exposed to

the lights. The light source would be placed as overhead lights and beneath the infant (bili-blanket) [8]. In most cases, in incandescent light bulb is used for this purpose.

The ATmega328 microcontroller used in this paper can be programmed easily using the C or C++ language in Arduino IDE. The code is uploaded onto the board by connecting a Type B USB cable from the PC to the board [9]. The Rx and Tx LEDs on the board will flash when data is being transmitted via the USB to serial chip [10]. The temperature and humidity sensor is connected to this 8-bit microcontroller. This senor includes a capacitive sensor, wet parts and high-precision temperature measuring device [11]. Bluetooth offers the most inexpensive solution for low-to-medium-speed device connectivity. Bluetooth HC-05 module can be easily interfaced with ATmega328 microcontroller [12]. Thus, it is used for transmitting data wirelessly to mobile device. The app used in this work is designed on the MIT App Inventor platform. The user creates applications by dragging and dropping components into a design view and using a visual blocks language to program application behavior [13]. The intensity of the blood decreases and increases with respect to the heart rate, so it is easily found if heart is normal or abnormal [14]. The Heart Rate pulse sensor is connected to the microcontroller for this purpose. For displaying the data, a 16x2 LCD (Liquid Crystal Display) is used. The LCD data register stores data to be displayed. The data is the ASCII value of the character to be displayed on the LCD [15].

This paper discusses the development of "Smart ASHeR Infant Incubator" based on available studies, to tackle the most common irregularities faced in terms of features and discusses steps towards utmost patient safety. In this project, the surrounding temperature and humidity levels in the incubator are monitored wirelessly by the means of Arduino Uno and HC-05 Bluetooth module, used with different sensors like DHT22 and MLX90614 infrared temperature sensor. These parameters are then controlled automatically by the means of temperature limit using conditional functions and relays.

II. METHODOLOGY

The system designed in the paper is an incubator which monitors and maintains the environmental conditions of the newborn babies. It also monitors temperature, air humidity, heart-beat rate value of the baby. In this model, we use sensors and data transfer devices that store the readings and transfer it to the mobile device. The medical data can be viewed from mobile phones wirelessly by the staff, nurses or doctors for ease of use and increased safety.

A. Incubator System

Fig. 1 depicts the block diagram comprising of components and connections to various parts of the incubator system.
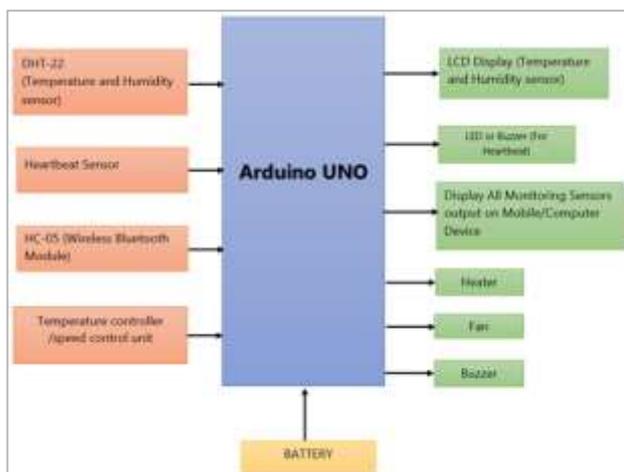

Fig. 1: Block Diagram of the System

B. Flowchart of the system

The microcontroller is supplied with 5V of voltage supply. The code uploaded onto the microcontroller board starts to execute itself upon receiving voltage supply. DHT22s, screen and serial communication device are interfaced with the microcontroller. The DHT22 measures the temperature and humidity inside the incubator. It monitors the parameters from different positions as the sensor placement. The microcontroller will read the temperature and humidity data from the DHT22s data pin and send that information. The Heartbeat Pulse Sensor measures the pulse of the baby. If the Pulse Rate increases or decreases from the preset range, then the LED will turn ON else it would remain OFF. The data recorded by the DHT22, and heartbeat is received by the Serial communication device and further transmitted to the mobile device.
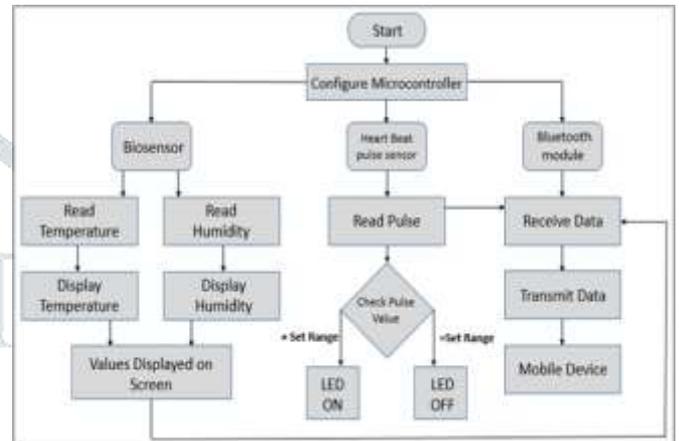

Fig 2 : Flowchart of the system

III. INCUBATOR DESIGN

A. Incubator Model Diagram

In the smart incubator system, the necessary outer covering would be made of transparent plexi-glass material. One side would have an opaque wooden backing in order to place the humidifier setup while accessible holes would allow easy access to the baby. It becomes easier for the doctor to check the baby without being exposed to the outside environment. Exhaust fans allow proper ventilation and help in regulating excess heat. The heating pads, which are placed under the bedding, will help to regulate and provide suitable temperature.
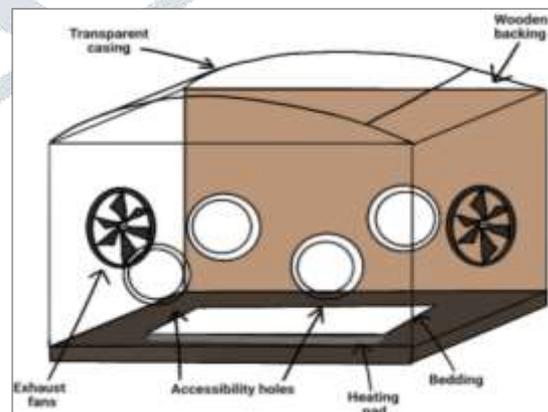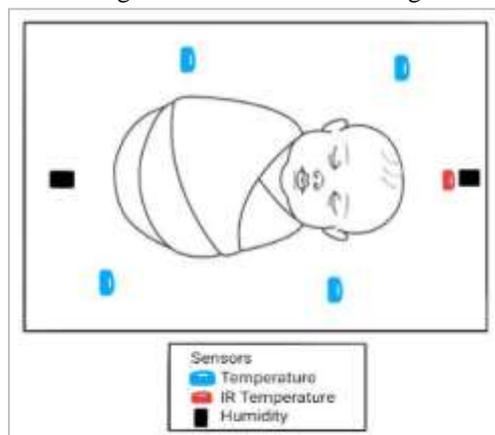

Fig. 3: Incubator design diagram

B. Sensor Placement Diagram

Fig. 4: Sensor Placement Diagram

C. Controllers and Sensors

1. ATmega328 Microcontroller

In this paper, the 8-bit ATmega328 microcontroller is used to process the data received from sensors. There are 14 digital pins from which 6 are PWM pins and 6 analog pins present on board. It uses serial communication protocol where information is transferred bit by bit. The operating voltages on the board are 5V and 3.3V. Once the code is uploaded, power it with an AC-to-DC adapter or battery to get started.

2. Heart Rate Pulse Sensor

The heartbeat sensor checks the heart rate of the infant. It has a photo diode and IR sensor. Once the LED is placed, it starts emitting light. Then there will be a flow of blood within the veins which is caught by the photo diode by receiving the signal and measuring the pulse for 30 seconds. The sensor measure value is converted into analog value and shown on serial plotter of Arduino IDE.

3. Temperature and Humidity Sensor

The temperature and humidity device utilized in this work is DHT22. The DHT22 is an inexpensive digital humidity and temperature sensor. It is a capacitive humidity sensing device that contains a compound that has been calibrated digitally to signal output of the temperature and humidity sensors.

Specifications of DHT22 sensor are as follows:

Table 1: DHT-22 sensor specifications (Source:12)

Model	DHT22/AM2302
Power Supply	3.3-6V DC
Output signal	Digital signal via 1-wire bus
Humidity Operating range	Humidity 0-100% RH
Humidity Accuracy	Humidity ±2% RH (Max ±5% RH)
Temperature Operating range	-40°C to 80°C
Temperature Accuracy	< ±0.5°C
Resolution or sensitivity	Humidity 0.1% RH

D. Heating System

1. Heating Pad

In this system, heating pads will be used to maintain the required temperature of the infant. This heating pad uses AC voltage of 230V and 45W power. The heating pad has a functionality for 3 levels of temperature control where 1 is for minimum and 3 is maximum temperature limit. The heating pads will be placed below the layer of bedding under the baby.

2. Portable Battery

A 9V portable DC battery has been used for this system but a 12V DC battery or power source is recommended for effective functioning of the buzzer, LCD, fan and heartbeat sensor. These recommendations have been made based on observations of connection requirements during system testing. The reason behind the use of portable battery in the basic circuit is for ease of use, especially in the rural areas. The whole system will be battery operated which helps the system to be used as a portable incubator too in remote places during emergency conditions.

3. Fans

Two fans that work on a range of 3.3V to 12V of DC power supply are used in this system. The DC Fan is connected to pin number 9 and is controlled based on the temperature wherein the temperature is maintained at 36 degrees Celsius.

4. Ultrasonic Humidifier

This will be connected externally which will maintain the humidity inside the incubator. Humidifier will be fitted outside, and through a narrow pipeline, the cool humid air will be let into the incubator. The fans will help ensure the uniform distribution of the humid air inside the incubator.

5. Piezoelectric Buzzer

The alarm system being used for this circuit is made of a simple piezoelectric buzzer connected to pin number 6 of the Arduino board and is grounded through a 100 Ohms resistor. It is triggered when the temperature detected by DHT22 exceeds 38 degrees Celsius.

E. Communication System

1. HC-05 Bluetooth Module

Bluetooth Module HC-05 is a type of serial communication device used to transmit voice and data at high speed using radio waves. HC-05 has a range of around 10 meters and data transfer rate of 3 Mbps. A Bluetooth chip takes the information usually carried by the cable and transmits it at a special frequency to the specified receiver. This will then give the information received to the required display device such as phone or PC.

F. Display Devices

1. LCD Screen (16x2)

The screen used in this project is 16x2 LCD. LCD (Liquid Crystal Display) is an electronic display module preferred over seven segments and other multi segment LEDs since it is inexpensive and easily programmable; it can display 16 characters per line.

2. Mobile Device

The Readings of Temperature and Humidity is transmitted to the mobile device on an app developed on MIT App Inventor platform. The transmission of data is done with the help of the communication system used in the project.

3. *Laptop*
The Heart rate is displayed on the serial plotter of the Arduino IDE.

IV. SOFTWARE DEVELOPMENT

A. Arduino IDE

The software used for developing an Arduino sketch is Arduino IDE. Arduino boards can be programmed easily using the Integrated Development Environment (IDE). The Arduino IDE provides a simplified integrated platform which can run on regular personal computers and allows users to write programs for Arduino using C or C++. The Arduino software has a serial monitor which allows simple textual data to be sent to and from the board.

The system code uses three external libraries – SoftwareSerial (for Bluetooth), LiquidCrystal (for LCD) and DHT. Pins 7, 8 of Arduino UNO board are defined as Rx and Tx pins for HC-05, respectively, while pin number 10 is defined as output pin for DHT22. Pins for LCD are defined for use with pin number 6 being used for the buzzer output. The system checks if the values taken for temperature and humidity readings from the DHT22 sensor a valid number and displays an error accordingly. After this, the appropriate readings from the DHT22 sensor are displayed on the LCD as float values.

SoftwareSerial library is used for serial communication on pin number 8 and 9 of the Arduino, using software to replicate the functionality, for printing the values of variables "temp" and "hum" taken from the sensor which is then displayed on the app. The code then checks for the condition of temperature being greater than 37 degrees Celsius, in which case it sends out an alarm through the buzzer to notify the staff. This code runs in a loop.

B. MIT App Inventor

MIT App Inventor is an online platform that is used for development of mobile applications. In this paper, MIT App Inventor is used to make an App which can connect to Arduino UNO using HC-05 Bluetooth Module. MIT App Inventor is an online platform designed to teach computational thinking concepts through development of mobile applications.

In the design editor- Drag and drop interface is used to lay out the elements of the application's user interface (UI). In the Code Blocks Editor- Firstly the blocks are used to connect to Bluetooth using the Bluetoothclient block. In case the Bluetoothclient is not connected, it will display a message "Bluetooth is not Enabled, go to settings to Enable" and it will also display "Disconnected" in red color. But when the Bluetoothclient is connected, it will display "Connected "in green color and will also display the needed output.

In this paper, the code blocks are placed in such a way that if the temperature is less than or equal to 35°C, the output will be displayed in green color. If the temperature is between 35°C to 40°C, the output will be displayed in yellow color else for any other value the output will be displayed in red color. Similarly, for humidity, if it is less than or equal to 40%, the output will be displayed in red color. If the humidity is between 40% to 50%, the output will be displayed in yellow color else for any other value, the output will be displayed in green color. The updated time can be displayed via the Clock1 block, displayed as "Last Updated".

Fig. 5: MIT application design

V. IMPLEMENTATION

1) The Arduino Uno uses DHT22 Sensor to monitor the temperature and humidity parameters inside the Incubator. Using LCD, temperature and humidity of the incubator are displayed as shown in Fig. 6 (fan and buzzer programmed to turn on for temperature greater than 31 degree Celsius in Fig. 9, for demonstration purpose).
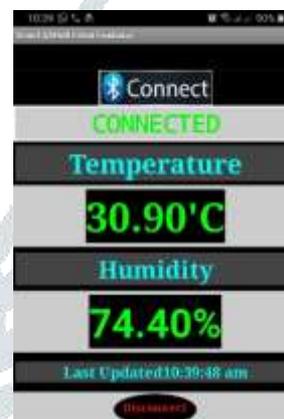
Fig. 6: Complete functioning circuit

2) Then the HC-05 Bluetooth module sends data to the application which displays temperature and humidity of the incubator on the Mobile phone as shown in Fig. 7.
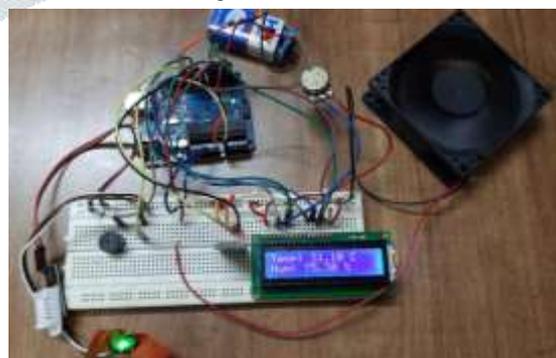
Fig. 7: Readings on mobile application

3) This circuit incorporates a buzzer which is implemented with the Circuit system and the temperature is set at a limit of 37 degrees Celsius after which the buzzer sets ON. The entire circuit system is battery operated at 9V-12V.
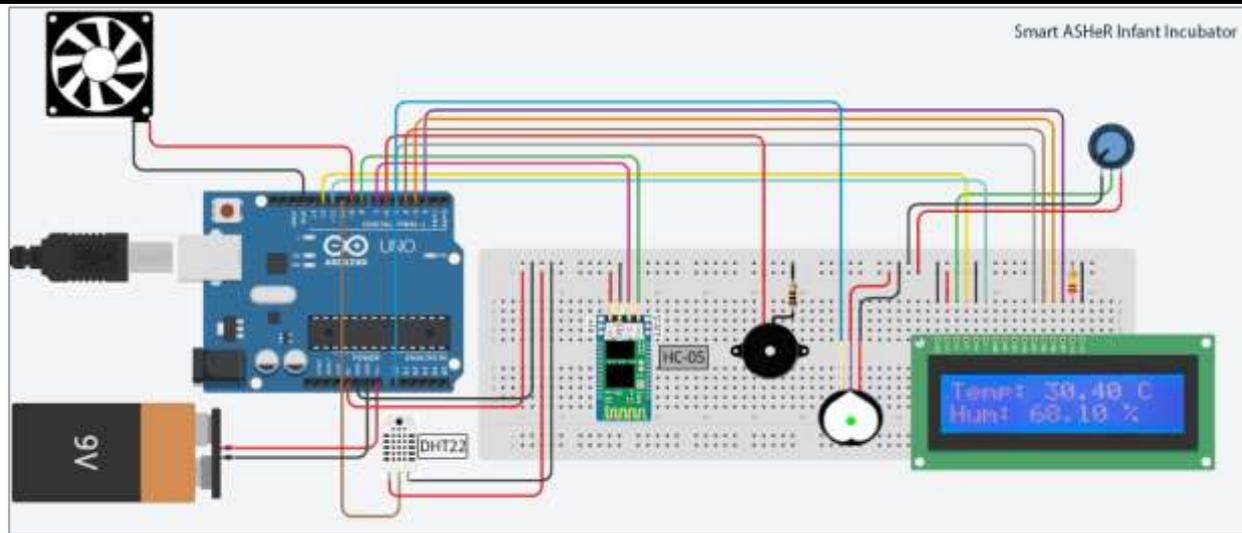
Fig. 8: Simulated circuit diagram of the system

4) Arduino UNO is used for the implementation purpose in order to measure and monitor more body parameters like Heart rate. To control parameters like the heating pad and humidifier a relay module would be used to effectively program them to switch on and off based on the temperature requirement of the system.

VI. RESULTS

Fig. 9: System with readings on mobile application

This circuit incorporates a buzzer which is implemented with the system and the temperature is set at a limit of 37 degrees Celsius after which the buzzer sets ON. The entire circuit system is battery operated. The fan is connected, and it is set to switch on at 36 degrees Celsius.

Fig 10: Output of pulse sensor on Arduino serial plotter

The average heart rate deduced from Fig. 10 is 70 bpm, which lies within the normal range. Hence, from the above results, it can be concluded that the system has been successfully designed for the intended purpose.

VII. CONCLUSION

This system has been developed for a varied number of requirements collected from data and research which has led

to a low-cost incubator model with additional features such as wireless transmission of readings, heartbeat monitoring, and automated temperature and humidity control which increases safety as well as ease of use. It enables the doctor or nursing staff to keep a track on the vital parameters associated with the incubator without any complications. These aforementioned specifications make the Smart ASHeR Incubator model stand out from the ones that are currently available. The advantages for it are as follows:

- Cost effective since basic components which are easily available in the market have been used.
- Portable for increased convenience, especially is cases of emergency.
- Accurate and synchronized monitoring on both LCD and mobile application.
- Fully automatic, smart and easy to use.
- Can be customized according to the needs of a specific area's climatic conditions as well as various parameters like SpO2, ECG, etc.

For further development, the system can be modified by incorporating solar panels instead of batteries to make the infant incubator eco-friendly. Music can also be included in the system which will have a positive effect on the baby.

Furthermore, by giving warmth to the baby physically or through an incubator or open care system, the impact in reducing the neonatal deaths could be reduced. However, in the developing world, currently available incubators are too costly, unsafe, or ineffective for this purpose, as discussed above. Subsequently, Smart ASHeR infant incubator aims at tackling these circumstances to provide an ultimate solution for use in the NICU.

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