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Original Research

Design and Implementation of Cost-efficient Prototype Neonatal Intensive Care Unit (NICU) for Premature Born Babies

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ABSTRACT

A baby incubator is a device created to give premature infants a safe, regulated environment to live in while their important organs grow. Babies who are born prematurely do so under uncommon conditions, such as when the gestational age is fewer than nine months or the newborn weighs less than the average range of 2500 to 4000 grams. Hypothermia after birth can cause premature newborns' body temperatures to decrease sharply and considerably. Premature deaths are currently more likely to be connected to exogenous socio-environmental causes. The baby incubator is a great solution to this problem. However, the cost of the infant incubator is an issue. According to a study, preterm babies are more likely to die in low-income countries. Premature babies' survival rates in low-income nations are 30% for those born between 28 and 32 weeks and 1% for those born before 28 weeks, compared to 95% for those born between 28 and 32 weeks and 60% for those born before 28 weeks in high-income nations. This is because the infant incubator is too expensive to be employed in low-income nations. In order to solve this issue, we created a low-cost incubator for premature infants. Using an Arduino UNO with sensors: 1. A temperature and humidity sensor; 2. A gas sensor, the low-cost incubator being created can measure the temperature, relative humidity, and carbon dioxide levels in the baby's environment. Then it will utilize a temperature control fan, a humidity control fan, and a gas level control fan to automatically regulate the environment. These affordable incubators can be produced and used in these low-income countries, giving prematurely born babies an opportunity to use them and live.

INTRODUCTION

Infants who are delivered before to completing 37 weeks of the gestation period are sometimes referred to as preterm or premature neonates. These premature babies are babies that are born weigh less than 2500 grams (Lamidi et al., 2021). When a baby is born prematurely, the likelihood of their passing is increased (Lamidi et al., 2021). Because of the high death toll, they pose a significant threat to the general population's health (Costa et al., 2009). To be able to adapt to the outside world, a preterm infant needs to be placed in conditions that are an identical replica of those found in the womb. In point of fact, mammals have the benefit of being homoeothermic, which means that their internal temperature is essentially constant and is maintained in a manner that is independent of the temperature of their surrounding environment. After delivery, the temperature of preterm newborns' bodies can experience a sudden and dramatic drop, known as hypothermia; this condition is associated with an increased risk of both death and morbidity (Watkinson, 2006). Mortalities occurring within this

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timeframe exhibit a higher propensity for correlation with external socio-environmental factors, including but not limited to housing circumstances, the newborn sleep environment, accessibility to healthcare, nutritional provisions, and social services (Kirby, 1993).

The ideal range for the temperature of an incubator housing a baby is between 36 and 37.5 degrees Celsius. Nevertheless, this temperature rises rapidly for a variety of different reasons. Temperature management and changes in temperature need to be noted. Because some infants in a very warm environment (36°–37.5° C.) remain asleep with no immediate rise in the rate of oxygen consumption, despite a rapid rise in colonic temperature, the upper end of the range is not a constant. The temperature at the bottom of the acceptable range is referred to as the critical temperature, and it changes depending on the patient's age, size, and clinical state (Scopes et al., 1966). When a baby is born prematurely, its vital organs and enzymes grow to a much smaller extent, and as a result, they require additional care to adapt to the external physical parameters of the environment, such as temperature, humidity, light, and oxygen level. In addition, premature infants need special care because some of their critical organs, biochemical systems, and enzymes cannot develop as they should, or because fetal growth may be impeded (Musa, 2017) or the effectiveness of this process may also be impeded by disorders associated with unfavorable conditions, such as hypoxia, which refers to below-normal levels of oxygen (Ele et al., 2009). Premature infants necessitate specialized care due to inadequate development of key organs, biochemical systems, and enzymes. Babies born prematurely who have difficulties breathing or maintaining a regular heart rate require proper oxygenation (Mallick et al., 2016; Acta Crystallographica, 1992). When the levels of oxygen saturation in premature babies are low, be alert in case there are abnormalities (Steinburg et al., 2013).

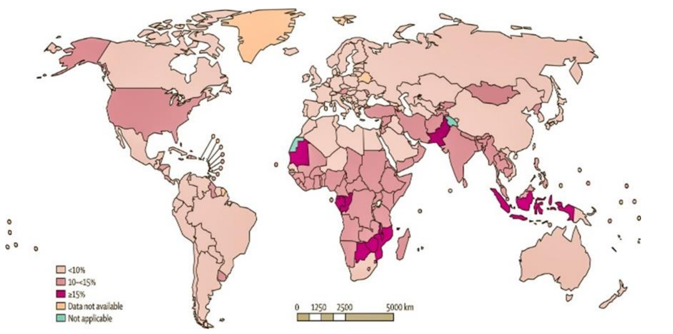

Fig 1. The estimated rates of preterm birth worldwide in 2010. Reproduced from Blencowe et al., 2012.

In a similar vein, it is worth noting that existing research indicates a higher infant mortality rate (IMR), specifically in terms of post-neonatal death, in rural nations as opposed to urban nations. However, it is important to acknowledge that these studies do not account for individual-level variables in order to isolate the specific impacts of the rural-urban divide (Mohamoud et al., 2019). According to statistics collected from 184 countries, the projected global average preterm birth rate in 2010 was 11.1%. This number exhibited regional variations, with northern Europe reporting a lower rate of roughly 5%, while sub-Saharan Africa recorded a higher incidence of 18% (Blencowe et al., 2013). The regions of Southeastern Asia, South Asia, and Sub-Saharan Africa had the greatest rates of preterm births globally in the year 2010. Furthermore, it was projected that 60% of all preterm births took place in sub-Saharan Africa and South Asia and this accounted for little over nine million of the nearly 15 million preterm births that took place in the world in 2010, which resulted in a preterm birth rate of 12.8% in those countries (Blencowe et al., 2013). The global prevalence of premature birth in the year 2010 is illustrated in figures 1 and 2. According to the aforementioned analysis, the ten countries exhibiting the highest prevalence of preterm births are as follows: India, accounting for 23.6% of the global aggregate of preterm births, with a preterm birth rate of 13% in relation to all live births; China, contributing 7.8% of the global total, with a preterm birth rate of 7.1%; Nigeria, accounting for 5.2% of the global aggregate, with a preterm birth rate of 12.2%; Pakistan, contributing 5.0% of the global total, with a preterm birth rate of 15.8%; Indonesia, accounting for 4.5% of the global aggregate, with a preterm birth rate of 15.5%; the United States, contributing 3.5% of the global total, with a preterm birth rate of 12.0%; Bangladesh, accounting for 2.8% of the global aggregate, with a preterm birth rate of 14.0%; the Philipines, contributing 2.3% of the global total, with a preterm birth rate of 14.9%; the Democratic Republic of Congo, accounting for 2.3% of the global aggregate, with a preterm birth rate of 14.9%; and finally, Brazil, ranking tenth, contributing 2.3% of the global total of preterm births, with a preterm birth rate of 9.2% (Blencowe et al., 2013).

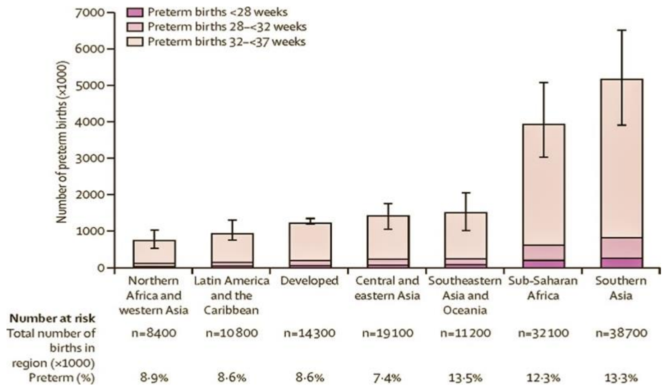

Fig 2. Preterm birth predicted by location and gestational age group for 2010. Reproduced by Blencowe et al., 2012.

Moreover, it is noteworthy that there exists a significant disparity in the prevalence of preterm birth across various areas and countries, which presents a distinct scenario compared to other health disorders. Notably, several high-income nations exhibit remarkably elevated rates of preterm birth. The average rate is highest in low-income nations at 11.8%, then in lower middle-income countries at 11.3%, and it is lowest in upper middle-income and high-income countries at 9.4% and 9.3% respectively (Saigal and Doyle, 2008). In various geographical areas, there exists a notable prevalence of death and illness among infants. However, advancements in medical care have resulted in enhanced survival rates and favorable long-term prospects for extremely preterm infants in affluent nations (Mohangoo et al., 2011). In high-income settings during the year 1990, it was observed that nearly 60% of infants delivered with a gestational age of fewer than 28 weeks managed to survive. Furthermore, it was found that roughly two-thirds of these surviving infants did not exhibit any impairments (Lawn et al., 2013). Nearly 95% of infants born in these high-income countries between 28 and 32 weeks live to adulthood, and more than 90% do so without any disabilities. In comparison, just 30% of babies born between 28 and 32 weeks survive in many low-income nations, with practically all of those born at or before 28 weeks passing away during the first few days of life. These very or extremely preterm infants represent the bulk of those who pass away under all circumstances, particularly in low-income nations where even basic treatment is lacking (Lunze and Hamer, 2012).

Standard incubators range in price from 1,500 U.S. dollars for some transport incubators to 50,000 U.S. dollars for some closed NICU incubators (Braun and Hentschel, 2011; Blencowe et al., 2012). It is assumed that poor communities in less developed countries cannot afford treatment for their premature babies due to this high cost of incubators. But babies that are born too early require more care to ensure their survival. Putting a preterm infant in an incubator is one of the techniques that can be done to try to save the child's life. Because the environment in the womb is quite different, especially in terms of temperature, premature babies can benefit from the use of an incubator, which is one of the tools that can help them acclimate to the outside world (Lamidi et al., 2021). An infant incubator is a piece of equipment that resembles a hard box and is used for the purpose of providing medical assistance to infants by keeping them in an environment that is under strict control. The temperature, relative humidity, and oxygen concentration can all be maintained at constant levels in an incubator for infants. The relative humidity ought to be maintained at the predetermined levels for the duration of the incubation period. In light of the issues and circumstances described above, the objective of this research project is to design and build an incubator that is both cost-effective and efficient for use with preterm infants, with the goal of reducing the likelihood that preterm infants would pass away by a sizeable amount.

In light of the issues mentioned above, the primary purpose of this research project is to create a basic model of a neonatal intensive care unit, sometimes known as a NICU for short. Babies born prematurely in nations with a lower standard of living may be eligible for primary medical treatment if a few key factors in this prototype project are modified.

MATERIALS AND METHOD

A. Block Diagram

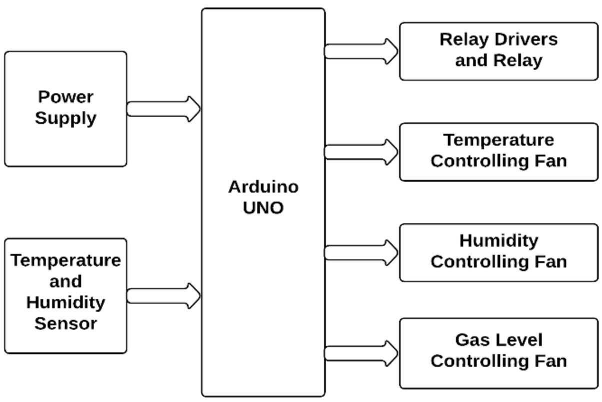

Fig 3 Block diagram of the Neonatal Intensive Care Unit's working process.

In Figure 3, it can be seen that the Arduino Uno, serving as the central control unit. On one side, there is a power supply and a Temperature and Humidity Sensor connected to the Arduino. On the other side, the Arduino interfaces with Relay Drivers and a Relay. The Relay controls various fans: a Temperature Controlling Fan, a Humidity Controlling Fan, and a Gas Level Controlling Fan. The Arduino receives input from the Temperature and Humidity Sensor, processes the data, and activates the appropriate Relay to control the respective fans based on the sensed temperature, humidity, and gas levels. This setup allows for automated environmental control based on the sensor readings.

B. Flowchart

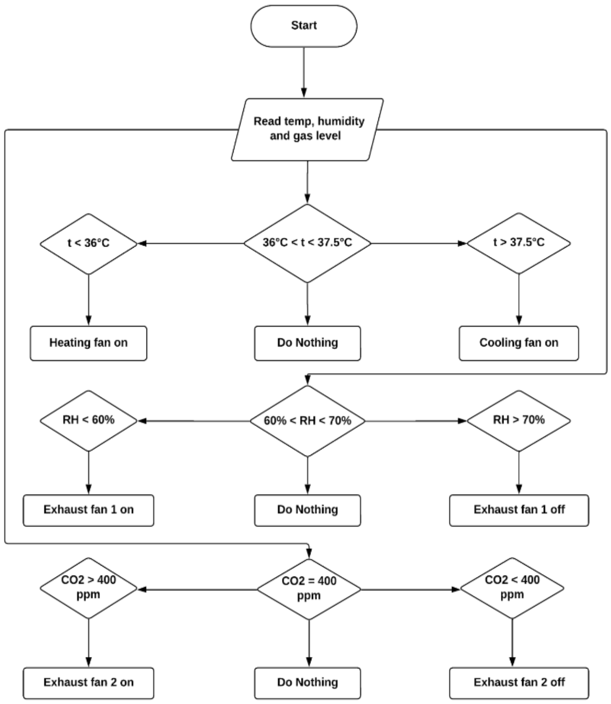

Fig 4 Flowchart of the Neonatal Intensive Care Unit.

A flowchart depicted in Figure 4, which shows a timetable for regulating the operation of the various fans in response to changes in the room's temperature, relative humidity (RH), and carbon dioxide (CO2). The flowchart specifies what must be done in certain situations.

If the temperature (t) is between 36 and 37.5 degrees Celsius, then you don't need to do anything. However, the heating fan needs to be activated if the temperature drops below 36 degrees Celsius. On the flip side, if the temperature rises above 37.5 degrees Celsius, the cooling fan needs to be turned on. Next, if the RH is between 60% and 70%, you can relax. Turn on exhaust fan 1 to remove moisture from the air when the relative humidity drops below 60%. However, if the RH rises beyond 70%, you should disable exhaust fan 1.

Just as no action is required if the CO2 level is precisely 400 ppm, this time as well. Exhaust fan 2 should be turned on to increase ventilation and lower CO2 concentration if the CO2 level rises above 400 ppm. If the CO2 level decreases below 400 ppm, on the other hand, exhaust fan 2 can be turned off.

This flowchart illustrates the necessary steps to take under various circumstances to keep things comfortable. It makes sure the right fans are being used to regulate the environment's climate (temperature, humidity, carbon dioxide levels), so that everyone may breathe easy and breathe clean air.

Hardware Development

A. Circuit Diagram

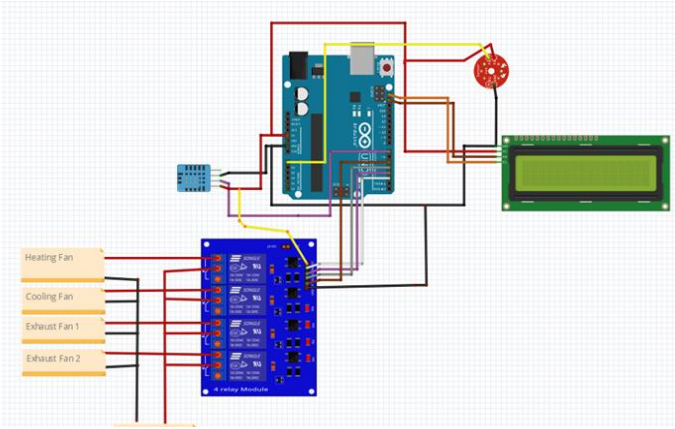

Fig 5 Circuit diagram of the implemented project.

The main task is to automatically control the temperature, humidity, and CO2 levels in the air. The first measurements of these factors were taken with the help of two devices. The MQ-135 sensor for gases and the DHT-22 sensor for temperature and humidity work together. All of the instruments are connected to the Arduino separately.

The red wire from the gas sensor is connected to the VCC pin on the Arduino, and the black wire is connected to the GND pin. Since the gas sensor uses a similar way to measure, you can connect the yellow wire to the A0 pin on the Arduino. The 5 volts power input for the Arduino comes from the outside. Arduino then hooked up the gas monitor and DHT 22 to 5 volts. Both the monitor and the Arduino work with a power source of 5 volts. The four fans on the other side need a DC source of 12 volts. Because of this, if the power drops for a long time, the sensor or Arduino can be lost. In this case, a 4-channel relay module is used. Which, when told to by Arduino, turns on and off the switches of four different voltage fans. Keep in mind that the 12 volts that powered these fans came from a step-down transformer that changed 12 volts to 1000 mA.

B. Working Principle of all components

Table 1 Working principle of all components.

Components	Specification and working
Arduino UNO	Arduino UNO is a compact, comprehensive, and breadboard-friendly board. It was used as the main controller of the project. Arduino UNO can be programmed using the Arduino Software integrated programming environment (IDE), which is common to all Arduino boards and can be used both online and offline.
DHT-22	Supply voltage: 5V, Temperature Range: 0-100℃, Humidity Range: 10-100%, Interface: Digital
MQ-135	Supply voltage: 5V, Range: 0-1000 ppm, Interface: Analog
4 Channel Relay	It was used as automated switch controlling unit by Arduino UNO.
4 Servo Fan	Controlled the environment inside the baby chamber.
Jumper Wire	Jumper wires were used for internal connections.
Transformer (Step down)	Transformer was used to convert the AC current into 12V DC.

C. Project Outlook

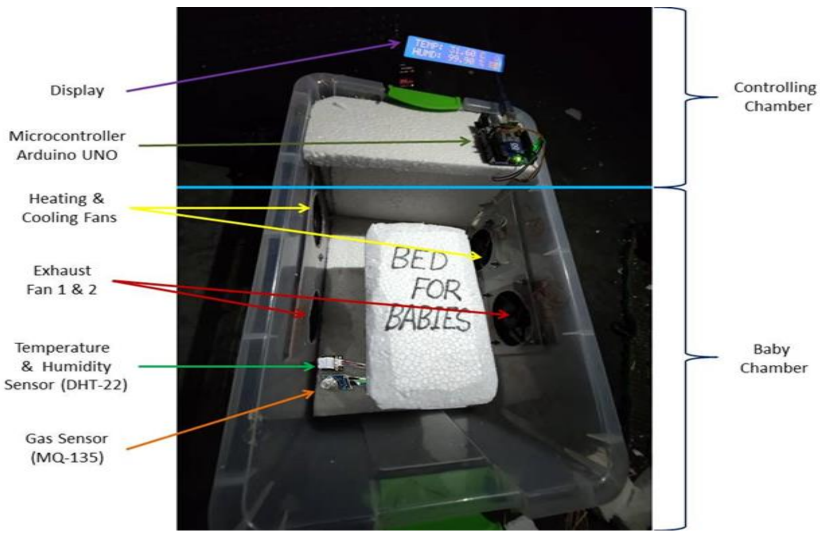

Fig 6 Overall view of Neonatal Intensive Care Unit

D. Cost Estimation

Table 1 Raw material costs of the project

Components	Cost in BDT	Cost in USD
Frame	350	3.25
Arduino UNO	1100	10.22
DHT-22 Sensor	390	3.62
MQ-135 Sensor	190	1.76
Jumper Wire	200	1.86
4 Channel Relay	310	2.88
Transformer (Step down)	400	3.72
Display	550	5.11
Breadboard	200	1.86
Servo Fan – 4 pieces	320	2.97
Cork Sheet	50	0.46
Total	**4060 BDT**	**37.71 USD**

Table 2 provides a breakdown of the cost of the materials used to build the incubator circuit. The total projected cost is 4060 BDT (37.71 USD). All prices reported are based on a single price, not a bulk purchase price. The total incubator cost only reflects the cost of raw materials.

RESULT AND DISCUSSION

Depending on the type of multifunctional incubator that is accessible, the initial expenditure might run anywhere from 1,500 USD to 35,000 USD (Chandrasekaran et al., 2021). In a separate investigation, Fong et al., 2013 introduced an incubator with an approximate cost of 530 USD. The lowest-priced incubator introduced by Tran et al., 2014 was approximately 78.57 USD. Acquiring incubators at the aforementioned prices is a formidable challenge for the healthcare industry in both developing and underdeveloped nations. Because the median gross national income per capita for least developed countries (LDCs) in the year 2020 was 905 USD (Report: 7% growth target eludes most least developed countries, 2023). The projects that have been mentioned are all capable of performing their responsibilities in an excellent manner. When we compare the prices, however, our proposed incubator, which has a price tag of forty dollars, has the potential to be an alternate solution for underdeveloped and developing countries. This project was examined and evaluated multiple times in the laboratory. Throughout that time period, this project was monitored and the required temperatures, humidity levels, and gas values were maintained. Temperature monitoring was performed to ensure the neonate's safety. As this demonstrates, this incubator has the potential to serve as an alternative for all fundamental capabilities.

A. Design

The design of this incubator is handy, light-weight and movable. After being in use for an extremely extended period of time, the controlling chamber had some minor shifts, which were caused by the usage of a plastic frame.

B. Program Listing

In this study using the Arduino program for readings on MQ-135 sensor, and DHT-22 sensor in program listing 1. The program for readings on CO2 in program listing 2. The program for readings on heating fan, cooling fan and exhaust fan in program listing 3. The program to display the sensor readings on the 20 x 4 character LCD is shown in program listing 4.

Program listing 1. Program for sensor reading

```
LOOP
temp = sensor.readTemperature( );
humd = sensor.readHumidity( );
IF (isnan(temp) || isnan(humd))
THEN {lcd.clear( ); Init_System( );};
int valueCO2 = readCO2( );
ENDLOOP
```

Program listing 2. Program for CO2 reading

```
FUNCTION readCO2( )

LOOP index 0 to 10
CO2[index] = analogRead(A0);
delay(200);
trash += CO2[index]
ENDLOOP
raw = trash/10;
CO2comp = raw - CO2_ZERO_LEVEL;
return map(CO2comp, 0,1023,400,5000);
ENDFUNCTION
```

Program listing 3. Program for heating fan, cooling fan and exhaust fan reading

```
LOOP
IF (valueCO2 > CO2_GAS_LEVEL)
THEN{pinMode(SECOND_EXHUST, ON)};
ELSE{pinMode(SECOND_EXHUST, OFF)};
IF (temp >= TEMP)
THEN {digitalWrite(COOLING_FAN, ON);
digitalWrite(HEATING_FAN, OFF);}
ELSE {digitalWrite(HEATING_FAN, ON);
digitalWrite(COOLING_FAN, OFF);}
IF (humd >= HUMD)
THEN {digitalWrite(EXHUST_FAN, ON);
lcd.write(0);}
ELSE {digitalWrite(EXHUST_FAN, OFF);
lcd.write(1);}
IF (current_time + 10000 < millis( ))
THEN {delay(3000);
lcd.clear( );
current_time = millis( );
HomeDisp( );}
ENDLOOP
```

Program listing 4. Program for initial system reading.

```
delay(1000);
sensor.begin( );
lcd.begin( );
lcd.backlight( );
gas.begin( );
LOOP index 0 to 5
temp = sensor.readTemperature( );
humd = sensor.readHumidity( );
ENDLOOP
LOOP WHILE (isnan(temp) || isnan(humd))
temp = sensor.readTemperature( );
humd = sensor.readHumidity( );
ENDLOOP
current_time = millis( );
```

CONCLUSION

To achieve environmental monitoring and control in the infant incubator, we created an intelligent newborn incubator. This project will benefit developing and rural populations. This sort of method is additionally advantageous to small healthcare systems. This project is easy as well as effective when it comes to controlling the temperature of the room and chamber. It will serve as a guide for anyone interested in constructing infant incubators.

The next assignment will be to create a monitoring system that will allow a single doctor or consultant to track all pathological parameters of neonates across every healthcare facility. Future applications could include ECG and EEG monitoring, management of the oxygen supply, and most importantly, automatic activation or deactivation of the regulating system. Since separate parameters will have different set points, the controller will automatically turn on if the measuring value falls below the set value and off if the measuring value rises over the set value. The power source might also be swapped for a solar cell. A significant challenge is the distribution of power in rural areas. Therefore, this problem will also be fixed in later deployments.

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