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Real-time health monitoring system for sick infants– A Capstone project experience

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Real-time Health Monitoring System for Sick Infants: A Capstone Project

Abstract

Caring for an infant who is sick can be stressful for the parents who have to monitor the child constantly. Furthermore, the infant is unable to let the adult know what is bothering them. Any signs of discomfort, like crying or inactivity, can be mistaken for something less serious. So there needs to be an objective system to indicate to the parents or caregiver that the condition of the child is critical. This system is useful as an alert for medical attention.

With the advancement in wireless and medical sensor technology, home healthcare and remote monitoring of physiological data have gained extreme importance. The major advantage of a real-time infant monitoring system is that it continuously acquires physiological data from the infants and keeps track of their health status without requiring the parents to constantly check on their child. Another added advantage of the system is that the parents will receive an alert if the infant is not well so that they can provide appropriate medical attention, as opposed to the traditional way of finding out that the infant is really sick only when checking on the infant.

This report talks about the design of a real-time infant monitoring system which is a capstone design project experience for a graduate student. The system mentioned in this paper uses a microcontroller, several biomedical sensors for sensing vital physiological data from the human body and sending them to a microcontroller such as MSP432 for processing and a wireless module such as ESP8266 that will inform the parents via an email so they can attend to their child immediately. The paper also talks about the experience and challenges the student had while undergoing the project from the brainstorming phase to successful implementation.

Keywords — Microcontroller, System-on-Chip, ARM, C

I. Introduction

With advancements in communication and sensor technologies, healthcare can now include remote monitoring of patients. There are increasing innovative products in remote monitoring that tap into the affordances of the Internet, web technologies, mobile technologies, smart phones and Information and Communication Technologies (ICT) infrastructures. In the Compendium of new and emerging health technologies [1], [10] it is reported that these two products have been commercialized: (i) Medical data communication system that transmits data from the point of care to the doctor's smart phone or computer, and (ii) Mobile technology to connect patients to remote doctors where frontline health workers use the diagnostics application on their smart phones to identify patients' concerns and receive instructions to provide appropriate care or to send information to remote doctors for advice.

Both patients and caregivers can benefit greatly from the use of remote monitoring which occurs in real time. Patients can now be aware of and manage their health conditions outside the confines of the hospital. They can enjoy their normal daily routines or activities using a technological system that senses and alerts them of any critical readings of the vital signs being monitored. A record of the readings can also be fed into a database which can be accessed by a medical team. Caregivers can similarly be alerted when they are connected to this communication network and have access via their smart phone or computer. If they are caring for a bedridden patient or an infant, they do not have to be glued to the bedside or constantly check on the patient. The early and fast detection of adverse conditions of the body such as high temperature or plunging blood pressure will enable the caregiver to administer or call for emergency help in time. The common vital signs monitored include heart rate, blood pressure, temperature and blood glucose level. There are other more complex systems that monitor the conditions of specific diseases or disabilities. Patients using such monitoring systems include the elderly, physically impaired patients, chronically ill patients, infants, fetuses, and others.

Self-monitoring is popular even among those who are not sick but are health conscious and wish to prevent the occurrence of serious conditions such as stroke and other preventable cardiac diseases. Kardia Band is a personal electrocardiogram (ECG) reader for the Apple Watch [12]. This device can capture the watch wearer's ECG and identify if the person has arrhythmia. Another product is the Vital Moto Mod: Mobile Monitoring platform [13] which has the technology to measure five vital signs, namely, blood pressure, heart rate, respiratory rate, pulse oximetry and body temperature. The mobile platform is connected to a phone via Bluetooth and uses an app and the cloud to enable the consumer to track his/her own health signs.

As simplified by [2], the basic components of a remote monitoring system are: data acquisition system, data processing system, end-terminal at the hospital and communication network. The data acquisition system consists of sensors that detect and transmit measurements. The data processing system has the ability to receive and transmit data as well as process data. The end-terminal at the hospital component is the point where data is read and interpreted by medical professionals, or saved in a database. Finally through a communication network the readings or alerts are sent to the patient or caregiver who will take the appropriate action. Figure 1 shows the simplified version of a real-time health monitoring system.

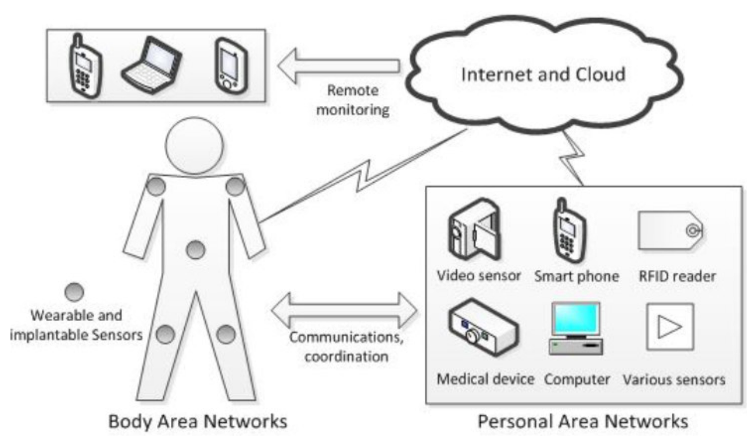

Figure 1: Simplified health monitoring system [3]

The potentials of this basic system are tremendous, and its applications are increasing to serve the many groups of people needing as well as giving healthcare. Monitoring of infants has made use of sensors to send information to caregivers, parents or hospital staff and trigger alerts for immediate action. The design of baby incubators whether in the hospital or at home has been explored to sense door security, light intensity and voice of the infant [14] and temperature [15]. Following this, Daing et al. [16] proposed and tested an infant incubator system that measured the heart rate of the infant and humidity in the incubator. Both parameters were processed by an Arduino microcontroller and data sent to a personal computer for monitoring. For baby monitoring products in the market most devices capture videos and sound from the infant. Only some measure vital signs. For example, TempTraq [17] is a single use, 24-hour temperature monitoring patch which sends alerts to the parent's smartphone when the infant has a fever.

This graduate capstone project is concerned with developing a real-time health monitoring system for infants using a microcontroller as the central processing unit and Wi-fi for communication to the parent or caregiver. It however does not include developing a database to store the data for doctors to view. While this alert system only communicates critical readings of temperature and pulse rate to the person taking care of a sick infant, it has the potential to be developed into a more powerful system where medical experts can monitor the infant as well. The next section talks about the design specifications followed by design implementation in both hardware and software. The paper then talks about results followed conclusion and future work.

II. Design Specifications

The block diagram of the proposed monitoring system is shown in Figure 2 below.

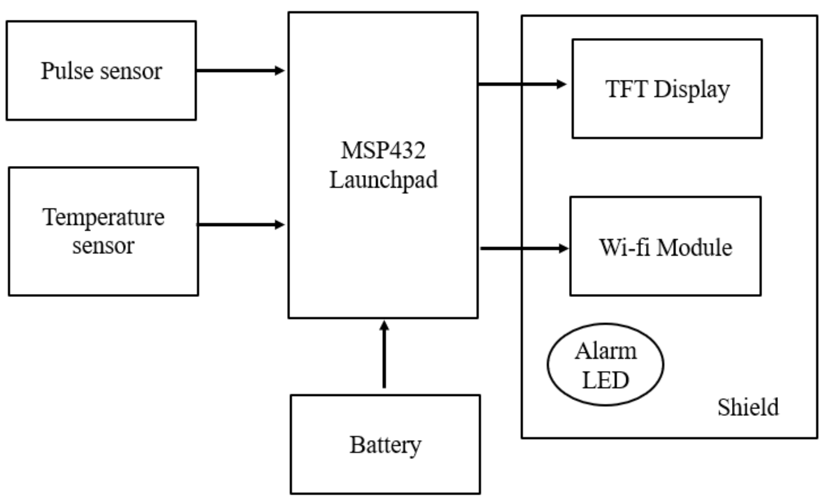

Figure 2: Block Diagram of Monitoring System

A. MSP432P401R Launchpad

The MSP432P401R LaunchPad™ development kit is designed by Texas Instruments that enables users to develop high-performance applications. Included on the Launchpad is an on-board emulator that allows users to do programming and debugging of their projects without using any additional tools [4]. Figure 3 shows a picture of the MSP432P401R LaunchPad. In addition, there is an abundance of resources that users can refer to while developing their project. Support is readily available in the form of documentation (user guides, technical reference manuals, datasheets), sample code in Code Composer Studio, forums, and training videos. All these features make the MSP432 Launchpad a very suitable hardware for this project.

B. Pulse Sensor

The pulse sensor is a low-cost sensor that is designed by World Famous Electronics. It works on the principle of photoplethysmography (PPG) [5] which uses light to detect changes in arterial blood volume. The pulse sensor contains a Light Emitting Diode (LED) as the light source and is designed to be placed on a fingertip or an earlobe, because these are areas where arteries are close to the skin. An ambient light photo sensor is used to detect changes in the LED light reflected back to the sensor during each pulse. According to World Famous Electronics [5], if the sensor receives more light, the voltage signal (output from the pulse sensor) increases. It the sensor receives less light, the voltage signal decreases. These fluctuations in voltage signals give a pulse wave shape as shown in Figure 4. The pulse sensor accepts an input voltage from 3-5.5V according to the specifications. See Figure 5 for the front and the back view of the pulse sensor. For the project, this sensor was used to obtain the heart rate of an infant. The ADC functionality of the MSP432 was used to sample the raw voltage signal and along with some calculations, convert the results to beats per minute (BPM). BPM provides meaningful and quantifiable data on the health condition of a person.

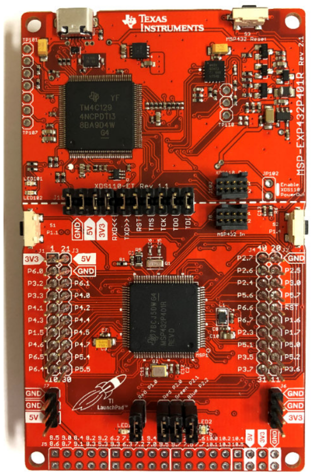

Figure 3: MSP432 Launchpad

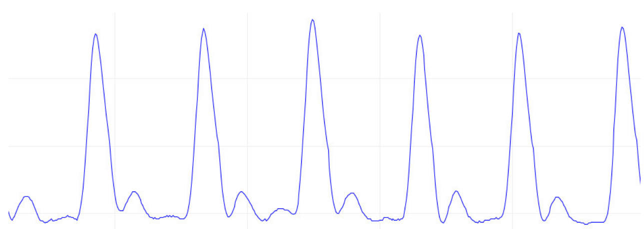

Figure 4: Pulse Waveform

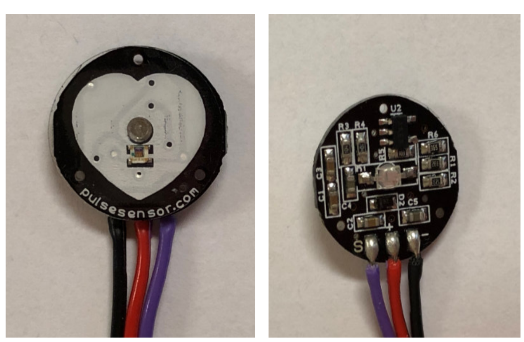

Figure 5: Pulse Sensor (Front) and (Back)

C. Temperature Sensor

The project utilizes the LM35 Temperature sensor which is a low-cost sensor designed by Texas Instruments to measure body temperature. It produces an output voltage that is linearly proportional to temperature (in Celsius). Infants that are sick with fever could have a body temperature of 38°C to even 40°C. With a range of −55°C to 150°C, the LM35 sensor is very suitable for our application. A breakout board designed and manufactured by Keyes [6] was acquired to enable easy connection to the microcontroller. The power required to operate the sensor is 4-30V, which works well for the MSP432 microcontroller as it has a 5V port to provide power. The output voltage from the sensor is then converted to temperature in degrees Fahrenheit using the ADC. Figure 6 below shows a picture of the temperature sensor.

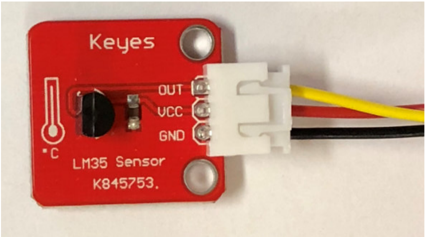

Figure 6: LM35 Sensor

D. MSP432 Shield

The MSP432 shield, also known as the ____ University (___) Motor Driver booster pack [7] was designed by ____ to operate specifically with the MSP432P401R LaunchPad. The shield features a Thin Film Transistor (TFT) Liquid Crystal Display (LCD), gyroscope, accelerometer, motor driver, a Wi-fi module and a buzzer. This project utilizes the TFT LCD to display the information from the sensors in real time and the Wi-fi module.

The Wi-fi module featured on the MSP432 shield is the ESP8266 chip. It allows microcontrollers to have access to a Wi-fi network [8]. The ESP8266 has a full Transmission Control Protocol/Internet Protocol (TCP/IP) stack, enabling microcontrollers to make TCP/IP connections using a style known as the "Hayes command set". The ESP8266 communicates with the microcontroller through UART protocol using its TX and RX pins (TX for transmission, outbound from ESP8266 and RX for receipt, inbound into ESP8266). A pre-installed firmware on the ESP8266 called the AT (attention) command processor allows instructions to be sent to the chip through serial communication.

This project used the ESP8266 to connect the MSP432 microcontroller to a Wi-fi network and communicate with the Simple Mail Transfer Protocol (SMTP) server in order to send emails. To do that it was first configured to be in station mode and to act as a TCP client. What follows then is a conversation between the SMTP server and the client. A typical conversation includes the basic handshake, commands and responses at each step, transmitting the message, and finally closing the client-server connection [9]. Figure 7 below shows the MSP432 shield.

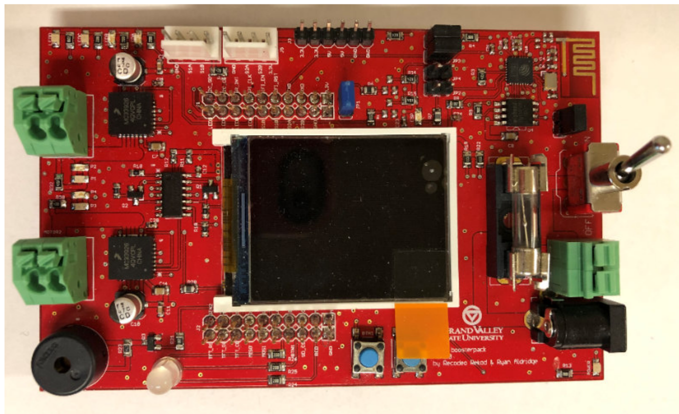

Figure 7: MSP432 Shield

III. Design Implementation

The designed system performs three important functions. It converts the raw data collected from the sensors to meaningful physiological data, continuously checks if the data is within predetermined conditions, and alerts the parents or caregiver through emails and an alarm LED if abnormal conditions are detected. Working of each hardware component is briefly described below.

Microcontroller is configured to generate interrupt at about 2ms to align with the rate of data acquisition for the pulse and temperature sensor. Every time an interrupt happens, the analog voltage is converted to a digital representation to represent temperature and BPM readings. The software finally converts the temperature in Celsius to a temperature in Fahrenheit. Similarly, for pulse reading a threshold value is set to be approximately half of the 10-bit ADC range. The software monitors for each time the voltage exceeds this threshold, and registers a "beat". Each time a beat is registered, a pulse flag is set and the time since the last beat is captured. (this is known as the interval between pulses). The last 10 intervals are kept so that an average value can be calculated. The BPM is then obtained by taking 1 minute divided by the average interval to get the number of beats per minute. After that the software waits until the voltage drops below the threshold. It resets the pulse flag so that the next pulse can be detected, and the cycle repeats itself.

The TFT Display was used to display the body temperature and BPM readings. It uses SPI to communicate with the microcontroller. Communication between the MSP432 and ESP8266 Wi-fi module was performed through the UART serial port. Various AT commands were sent from the MSP432 to the ESP8266 in order for the ESP8266 to connect to Wi-fi, start sending messages to the SMTP server and receiving responses from it. The procedure for ESP8266 to communicate with the SMTP server and send an email is briefly summarized in the flow chart below.

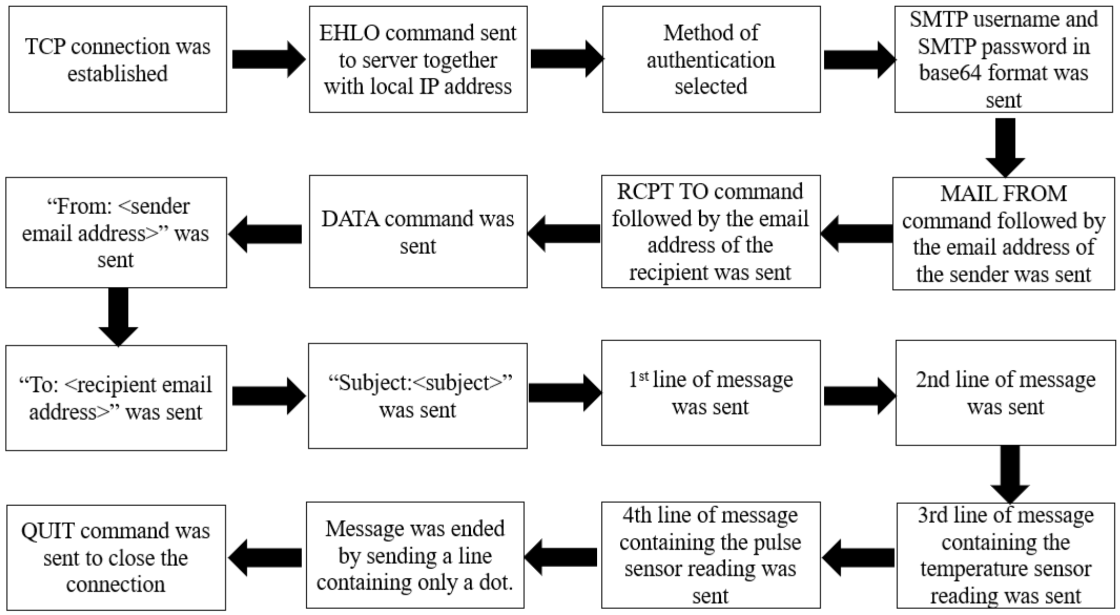

Figure 8: Procedure for Sending an Email

The software uses state machine concept to perform various functions. There are 2 major states: ***Monitor state*** that acquires the sensor data, display it on TFT display and checks if it exceeds trigger limits. And ***ESPReset*** state that configures ESP8266 and send an email. Flowchart in Figure 9 depicts the flow of the software.

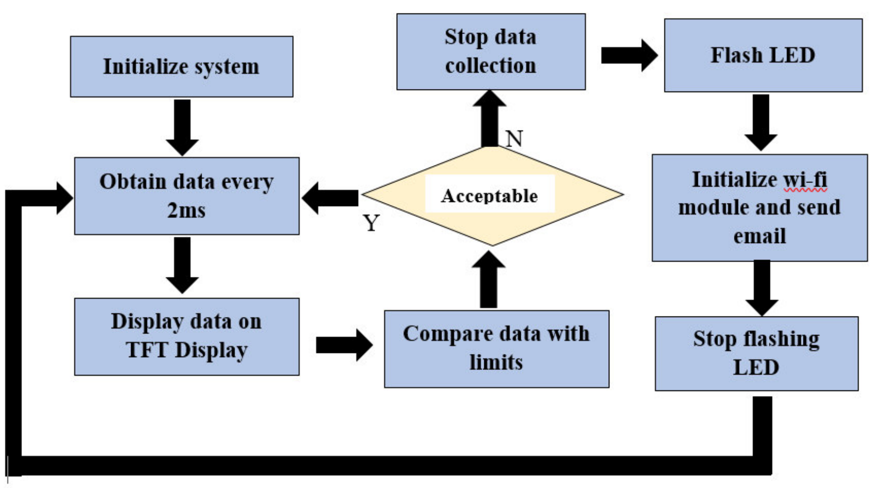

Figure 9: Flowchart depicting software flow

IV. Results

The testing of the monitoring system was performed on an adult instead of an infant because the purpose is to check the functionality of the system first. All human beings have a measurable body temperature and pulse rate, although what is considered as a normal range for adults would differ slightly from infants. The U.S National Library of Medicine [11] states that the pulse rate range should be 80 to 160 bpm for 1 to 11-month old infants. The table below shows the abnormal conditions for body temperature and pulse rate of an infant.

Table 1: Abnormal Conditions

Physiological data	Abnormal condition
Body temperature	>99 °F
Pulse rate	<80 bpm OR >160bpm

The testing was performed under four different scenarios. For conditions requiring an alert email to be sent, the email was sent from one email account to another email account. The data obtained from these scenarios are summarized in the table below.

Table 2: Scenario Details

Scenario	Body temperature (°F)	Within acceptable range?	Pulse rate (bpm)	Within acceptable range?
1	98.78	Yes	92.88	Yes
2	99.36	No	84.46	Yes
3	98.20	Yes	70.80	No
4	99.94	No	62.06	No

Scenario 4 is shown below where both the body temperature and the pulse rate were abnormal according to the limits determined in Table 1. An email was sent as an alert and the alarm LED was flashing. Figure 10 shows the email content and Figure 11 shows the display of the TFT display. Since both physiological parameters were a cause for concern, the email message contained the readings for both body temperature and pulse rate.

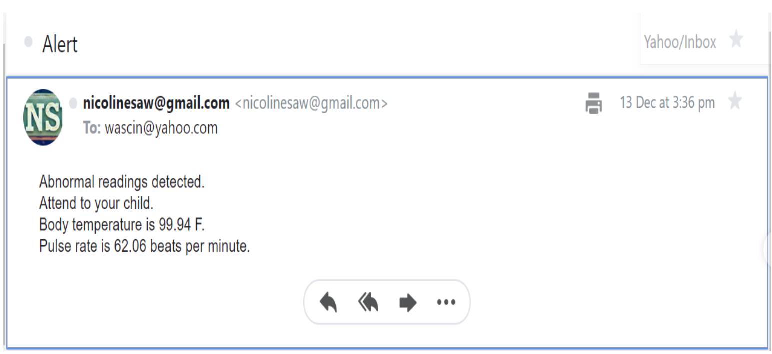

Figure 10: Scenario 4 Alert Email

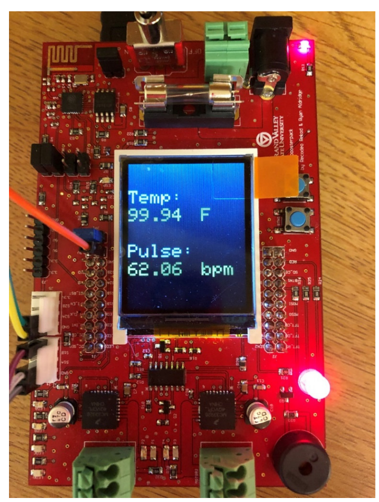

Figure 11: Scenario 4 TFT Display

The system was housed in a small casing so that it could be carried around easily. The casing was designed to allow the TFT and alarm LED to be viewed, and has spacing for the wiring of the sensors. See Figure 12 for the casing of the monitoring device.

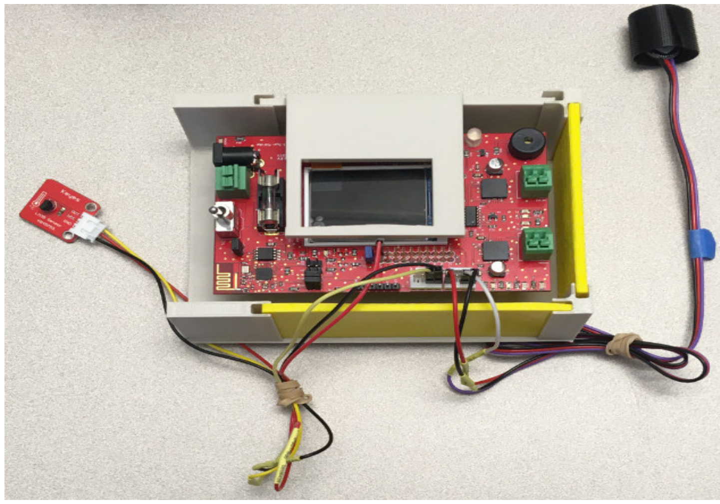

Figure 12: Monitoring Device Casing

A working prototype was developed to verify the proof-of-concept due to which off the shelf components were used. The cost breakdown of the system is shown in Table 3 below. The cost of the system can be optimized by designing a printed circuit board (PCB) that can house only the needed components.

Table 3: Cost breakdown

Components	Cost
MSP432	~ $20
MSP432 Shield	~ $42
Pulse sensor	~ $10
Temperature sensor	~ $2
TOTAL	**~ $74**

V. Conclusion and Future Work

A health monitoring system for sick infants was developed whereby the physiological data body temperature and pulse rate was acquired and continuously checked for any anomaly. The monitoring system was able to detect any anomalies in the data acquired from the sensors, triggering an alert email to be sent out. The email message informed the recipient that the data was outside the normal range and urged the recipient to attend to their child. The vital readings that were not within their accepted ranges were also included in the message. Other than sending an email message, a red LED on the microcontroller flashed on and off whenever the body temperature or pulse rate was abnormal.

Future research efforts should focus on storing all the data collected from the monitoring system into a database so that it could be used for analysis by medical experts. When the infant is brought to see the doctor, the doctor can have a better idea of the infant’s health condition by looking at historical physiological data instead of just having the data taken at the point in time. The parents or caregiver could also view the physiological data occasionally and monitor their infant’s well-being by identifying any worrying trends. Some other improvements to the system would be to allow email transmission to multiple recipients, so that the alert message can be sent to more than one person, ensuring better medical attention.

Furthermore, the monitoring system could be expanded to include sensors to measure other vital signs such as respiration rate, blood oxygen saturation, skin perspiration and many more which are also very valuable in determining the health condition of an infant. Off-the-shelf components were used to develop a working prototype to verify the proof of concept. Cost of the system can be reduced by designing a PCB that would house only the needed components.

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