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DESIGN OF A WEARABLE HEALTH MONITORING SYSTEM FOR IN-HOME AND EMERGENCY USE

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ABSTRACT

Recent advancements in wearable medical technologies have streamlined health monitoring with simple, non-invasive measurements. These devices, however, are rarely capable of monitoring all the necessary parameters for an accurate measure of health, such as blood pressure, and can cost the user hundreds to thousands of dollars. The objective of this project was to design an affordable, user-friendly, wearable device capable of monitoring multiple parameters: body temperature, blood pressure, heart rate, blood oxygen, and body positioning. By combining wearable sensors with Inter-Integrated Circuit (I2C) technology, the data from many sensors can be transmitted while maintaining a compact size for a wearable. In parallel with this device, a mobile application was designed as an interface to receive real-time comprehensive measurements. This device could be used to reduce monitor application time in emergency medical settings and monitor patients in rural communities who are often hours away from the nearest medical centers.

Keywords: non-invasive, photoplethysmography, wearable devices, health monitoring system, rural health

1. INTRODUCTION

Rural communities face issues with the distance between their homes and the nearest hospital. Approximately 23% of Americans in rural communities consider access to healthcare a major problem in their community [1]. The travel required for something as simple as a health screening makes receiving healthcare even more difficult for rural Americans and, as the population of rural communities gets increasingly older [1], the need for regular checkups is increasing.

Wearables provide an opportunity for rural citizens to regularly monitor their health in one's home. The use of a wearable device to monitor health could remove the need for extensive travel or financial burden for rural citizens. In-home monitoring also encourages rural citizens to monitor their health in a preventative, rather than reactionary, manner.

Without the need for a medical professional to take measurements, wearables are becoming more common for at-home use, with 81% of personal wearable devices being used for at-home management of chronic illness [2]. The increasing popularity of wearables has led to higher sensor availability at a lower cost.

The goal of this project was to design a functional proof-of-concept for a wearable device capable of providing a comprehensive measurement of health while remaining non-invasive and affordable. To achieve this, sensors capable of measuring body temperature, blood pressure, heart rate, blood oxygen, and body positioning were incorporated to work together and take simultaneous readings. Another goal of the project was to include a CPR metronome for potential use in emergency settings.

1.1 REVIEW OF COMPARABLE TECHNOLOGIES

The wearable industry is primarily comprised of consumer products, such as smartwatches or chest straps, and patient tracking devices for medical professionals, listed in table 1.

Consumer products are available in multiple form factors, including wrist-mounted devices and chest strap monitors. Wrist-mounted devices and smartwatches have limited capabilities for measuring health parameters due to their location on the body but are often available to the user at the lowest price.

For instance, the *Apple Watch® Series 5* is capable of measuring heart rate, counting the user's steps, monitoring movements during sleep, monitoring for falls, and taking mobile electrocardiogram measurements. The *Apple Watch® Series 5* requires an *Apple iPhone®* and has a retail price of $399 [3]. A second example is the *OMRON HeartGuide™*, a smartwatch that uses the oscillometric method to measure blood pressure. In addition to blood pressure, the device can monitor heart rate,

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steps taken by the user, distance traveled, and movement during sleep. The *HeartGuide™* has a retail price of $499 [4].

Wearables designed specifically for patient tracking have higher health monitoring capabilities but come at a higher price point.

An example of this is the *Vital Connect VitalPatch®*, a disposable wearable patch for monitoring patients in a clinical setting. The patch is traditionally applied to the chest using adhesive and is capable of monitoring heart rate, respiration rate, body temperature, posture and fall detection, and is able to take electrocardiogram measurements. The price of the *VitalPatch®* is not listed on the manufacturer's website; however, it requires the purchase of the disposable patches and the monitoring system [5].

The *Current Health* all-in-one wearable is another patient monitoring platform. The device is mounted on the patient's upper arm and is capable of measuring pulse, blood oxygen, respiration rate, skin temperature, posture, and patient motion or activity. *Current Health* offers a remote monitoring service, which has a retail price of $199 with a $40 per month subscription for a minimum of 12 months [6].

There is a gap in the market for wearables that offer a comprehensive measurement of user health for use in one's home without an expensive upfront cost or reoccurring monthly fees. This project was focused on developing a wearable capable of measuring many of the parameters measured by the current market while keeping a low cost to the user.

Table 1: Function and price comparison of similar devices

Device	Measurements	Price
Apple Watch® Series 5	Electrocardiogram, fall monitor, heart rate, motion and activity tracker, step counter, sleep tracker	$399 + Apple iPhone
OMRON HeartGuide™	Blood pressure, heart rate, motion and activity, step counter, sleep tracker	$499
Vital Connect VitalPatch®	Body temperature, electrocardiogram, heart rate, motion and activity, respiration rate, posture, fall detection	N/A
Current Health	Blood oxygen, motion and activity, pulse, posture, respiration rate, skin temperature	$199 + $40 per month

2. MATERIALS AND METHODS

The device, Fig. 1, is intended to monitor many health parameters while maintaining a low cost for the user. When considering this device specifically, blood pressure and body temperature were given priority because of the lack of affordable wearables with those features. The intention of this device was to incorporate as many functions as possible. Each parameter seen in Section 2 was considered, though some were not feasible within this device due to the location of the device on the body. The final list of parameters for the device was narrowed to body temperature, blood pressure, heart rate, blood oxygen level, and body positioning to be processed using an Arduino Mega microcontroller.

Body temperature and blood pressure were both the highest priority to incorporate and the most limiting parameters for the device regarding design. In order to achieve accurate data, measurement of body temperature is traditionally taken by mouth, rectum, or axilla [7] while blood pressure is typically taken by compressing the brachial artery in the upper arm [4]. These limitations determined the location of the device on the upper arm.

2.1 HARDWARE

Body temperature at the axilla was the first measurement to implement in the device. A healthy body temperature traditionally correlates to proper organ function, so it is regularly monitored. To accurately measure and transmit body temperature values, the Maxim DS18B20 Programmable Resolution One-Wire Digital Thermometer was used within the device. The DS18B20 uses an analog thermometer and converts the input to a digital signal. This signal is then sent to the processor and translated using an algorithm designed specifically for Arduino by the manufacturer. The waterproof version of the DS18B20 has a rugged design and will be protected if the device comes in contact with water or perspiration.

Hypertension affects roughly one in three adults [9], making the measurement of blood pressure a priority for the device. To maintain accuracy and low cost, a Konquest KBP-2704A was used to measure blood pressure using the oscillometric method, which is common for at-home blood pressure monitoring. Oscillometric blood pressure devices take measurements by compressing an artery past systolic pressure and monitoring the vibrations of the arterial wall as pressure is released and blood begins to flow [8]. The Konquest blood pressure monitor is FDA approved and sits at a lower price-point than other devices in the same accuracy range.

The blood pressure monitor was modified so the interpreted blood pressure data could be sent to an input of the Arduino. The Konquest KBP-2704A has UART communication pads to output blood pressure data, and when an additional wire is connected the data can be received by the Arduino.

Heart rate is traditionally measured by manually applying pressure or by utilizing a stethoscope to count the number of pulses over an interval of time. However, the development of photoplethysmography (PPG) has allowed the monitoring of heart rate by wearable devices, such as modern smartwatches. PPG measures heart rate by projecting light into the blood vessels and monitoring how the light is diffracted using a photodetector [10].

PPG heart rate sensors are consistent when comparing cost and accuracy, so the ease of implementation into the wearable was the highest priority when sensors were compared. The Maxim Reference Design 117 (MAXREFDES117) was chosen for the device because its compatibility with the Arduino microcontroller, ease to attach to the wearable, capability of monitoring heart rate and blood oxygen levels in one package.

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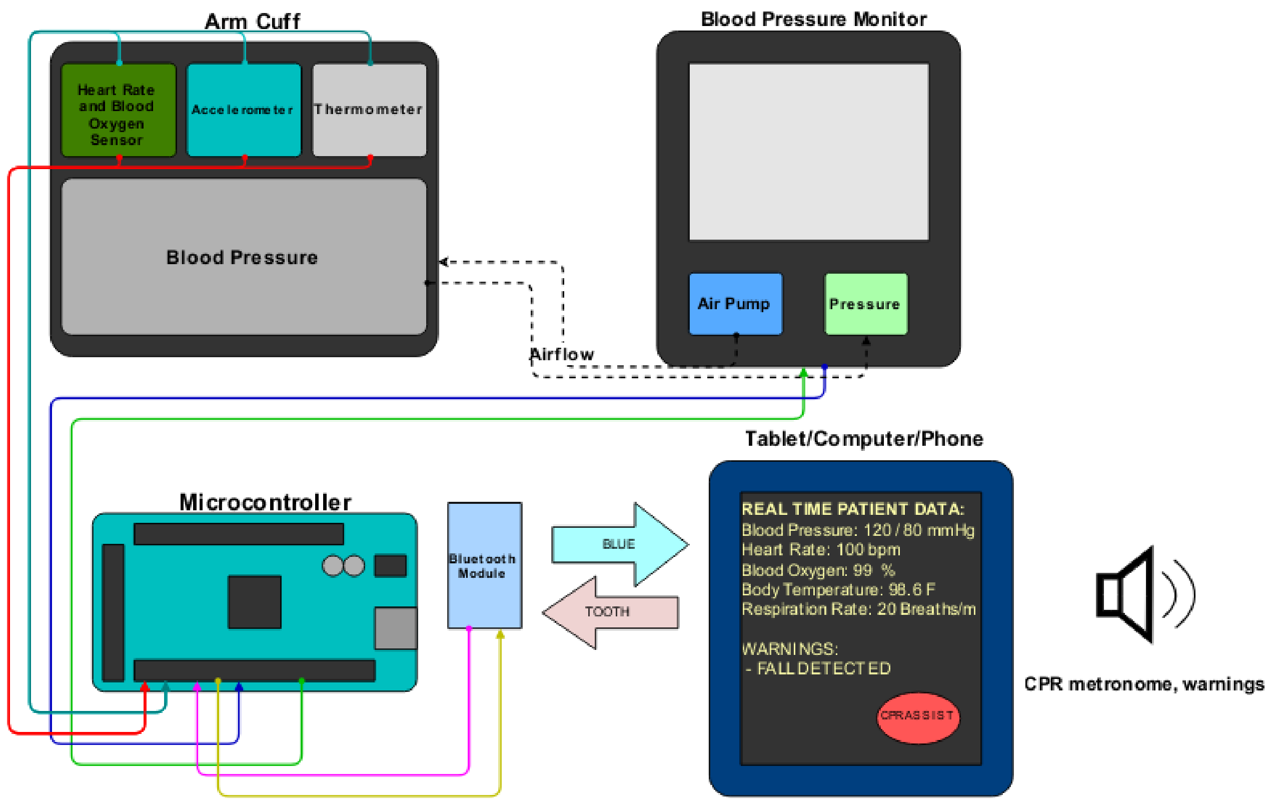

FIGURE 1: DESIGN OF WEARABLE DEVICE

The MAXREFDES117 utilizes two different types of light, red light and infrared light. The light sources and photodetectors in the MAXREFDES117 make it possible to monitor both heart rate and blood oxygen levels at once within the same package. Though not considered a vital sign, blood oxygen tests for conditions such as hypoxemia and is an important parameter of health.

Monitoring the body position of the user is especially important when considering at-home use of the device. Over 800,000 people are hospitalized each year due to falling, [11] so having a device capable of monitoring for falls is crucial. The Adafruit MMA8451 is a three-axis accelerometer with a built-in orientation detector. This accelerometer could be used to track the orientation and acceleration of the device and detect the occurrence of falls for elderly or at-risk users at a low price point.

Wireless capability of the device is necessary to ensure convenience and comfort for users. Bluetooth connection is a consistent and cost-effective method and does not require an internet connection. The HC-05 Bluetooth Module was selected to attain a connection between the Arduino and the user's device for the proof of concept design.

The wearable device operates in various capacities, such as at-home health monitoring and emergency care. When looking at care in an emergency setting, an important element is speed. To ensure the fastest possible application of the device, all sensors were connected to a simple Velcro fastened armband alongside a traditional blood pressure cuff. This design allows the device to be applied quickly and easily.

The CPR metronome was designed to aid users in emergency situations. The CPR metronome switch activates a consistent 100 BPM to assist with accuracy and ensure proper compression rate in high-energy situations.

2.2 SOFTWARE

Continuous readings are taken by the different sensors in the device and output to the user through the serial output of the Arduino. The Arduino Integrated Development Environment (Arduino IDE) was used to program the Arduino microcontroller.

Overall, the program, Fig. 2, runs in a repeated loop, including a timer to ensure certain functions are completed in the proper time increments. A new blood pressure reading is activated in 3.5-minute intervals, body temperature, heart rate, and blood oxygen levels are recorded every 5 seconds, and orientation readings are taken every second. Sensor data is then transmitted to the Bluetooth module using the serial data ports of the Arduino. If a sensor detects unsafe levels, an additional warning is transmitted.

To receive this data, an Android-specific mobile application was designed using MIT App Inventor. The application can be downloaded onto any Android device or used on an Android emulator on a computer simply by scanning a QR code.

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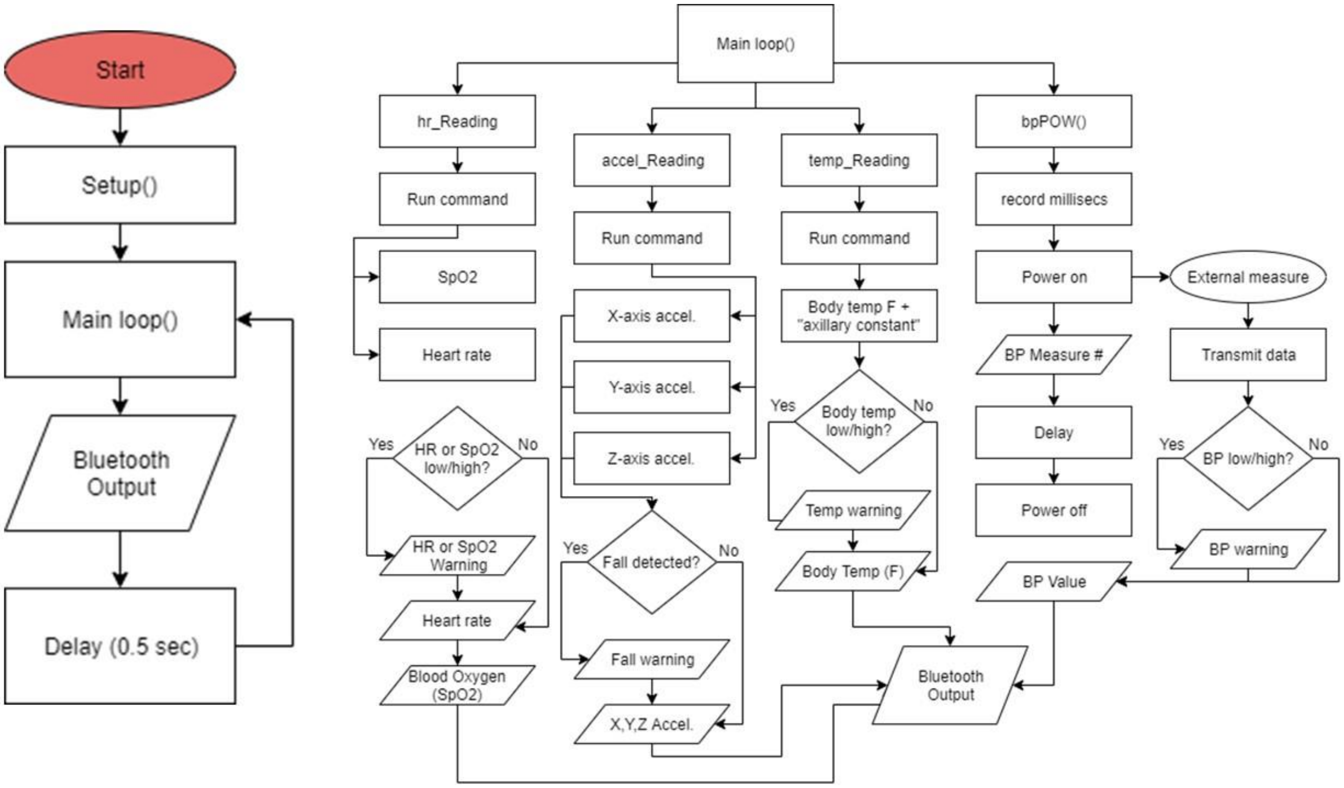

FIGURE 2: ARDUINO CODE FLOWCHART

Additionally, a switch was programmed into the application to activate the CPR metronome. Once the switch is activated, a sound file containing a 100 beat per minute metronome pulse plays on a loop until the switch is turned off.

3. RESULTS

The device, Fig. 3, is fully operational and successfully measures body temperature, blood pressure, heart rate, blood oxygen, and body positioning of the user and transmitting data to the application, Fig. 4, without requiring any user input.

In the event of a value being measured outside of the specified range for a given parameter, "2000" is output to the application. This typically occurs when the device does not have proper contact for the heart rate or blood oxygen sensors.

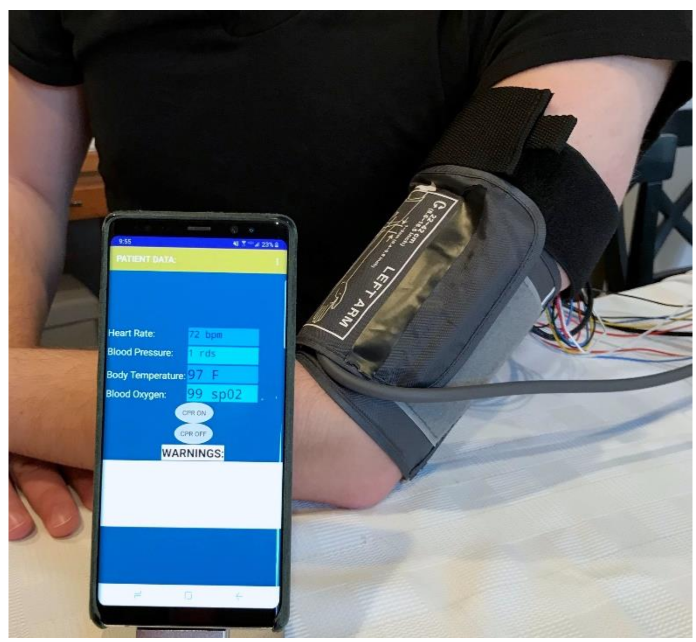

FIGURE 3: DEVICE IN OPERATION

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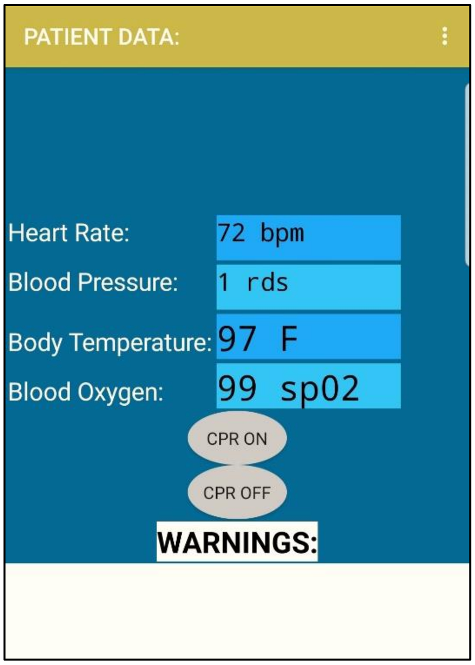

FIGURE 4: OUTPUT RESULTS OF THE DEVICE IN USE

4. FUTURE DEVELOPMENTS

In order to make the device viable for the intended users, rigorous testing must be completed to ensure accuracy and proper function in different scenarios.

Additionally, the packaging of the device will need to be modified if it is to be comfortably used as a wearable. Modifications may include removing the unused components from the Konquest blood pressure monitor, creating a housing for the controls, and applying the sensors to a form-fitting armband to reduce bulk and increase ease of application.

Furthermore, within the device, PPG is currently used to monitor the heart rate and blood oxygen levels of the user, but this technology can be expanded to calculate the rate of respiration [10]. Respiration rate, the only vital sign currently not being measured by the device, can be applied if the PPG components are further explored.

There are also several issues with data security that will need to be addressed to protect the privacy of the user. If personal health information is included in a mobile application, certain standards and security measures must be in place.

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