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Remote Coach: A Remote Health Sensor Data Monitoring System

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By

Vinh Tran

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The thesis of Vinh Tran is approved:

Shan Barkataki, Ph.D.	Date
Michael Barnes, Ph.D.	Date
Ani Nahapetian, Ph.D., Chair	Date

California State University, Northridge

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ABSTRACT

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A key challenge in wearable health systems is obtaining continuous blood pressure information. This thesis presents a mobile wireless cuff-less blood pressure system for continuous monitoring. The system-level solution takes advantage of biometric data as well as location data to extrapolate blood pressure data in a non-obtrusive manner. It infers blood pressure information from heterogeneous sensors, notably electrocardiogram (ECG) sensors and pulse oximetery readings, linked with GPS and accelerometer data extracted off the mobile phone gateway. The various features of the system are presented, along with the implementation challenges and details. Additionally, the underlying Remote Coach infrastructure is detailed, both in terms of its system details, as well as its usefulness for fast health sensor system deployment and component reuse.

1 INTRODUCTION

This thesis presents the Remote Coach infrastructure, as well as the Wireless Cuff system that applies the larger Remote Coach framework for use in specific application area, namely cuff-less blood pressure monitoring. The Remote Coach provides a common framework for connecting health sensor devices to a mobile gateway and a remote server for storing, accessing, and visualizing the data. With reusable components, such as an Android application, and a remote database, and a web interface, wireless health development is aided considerably.

The presented infrastructure has the potential to accelerate changes taking place in the interactions among patients, healthcare professionals, and patients' own health practices, as it makes information derived from the health computing infrastructure, including data from wireless health devices readily accessible to patients. With this infrastructure, individuals can obtain the necessary information to make desirable behavioral changes and thereby achieve healthier lifestyle choices.

There can be a large shift in the locus of action and control, from the physician's office to the patient's home. This shift will result in more individualized healthcare when medical care is necessary, and the societally significant change of increased patient focus on prevention and the enhanced ability of patients to change their own health prospects. In fact, there is a huge shift going on in the doctor's office in terms of the patient's access to medical information independent of the physician. Currently, by using multiple sources of medical information to validate medical consensus and by relying on proven sources of reliable information, such as the government and the Mayo Clinic, the public has unparalleled access to highly reliable medical information. Taking full advantage of this available information, and its fusion with wireless health monitoring data, can have a significant impact on the prevention steps and individual lifestyle choices that patients make.

One such application is the Wireless Cuff, which is a system implemented on the Remote Coach framework that is used for a cuff-less blood pressure application area. One of distinct challenges in wireless health systems is the desire to capture continuous blood pressure information. With rare exception, it has been impossible to obtain blood pressure (BP) data continuously from patients outside the clinical setting.

Among the large patient population with chronic high blood pressure, monitoring spikes in blood pressure levels can lead to precise tailoring of medications. Additionally, classification of patients with ‘white coat’ hypertension, those people whose BP rises sharply due to the stresses of seeing a physician, can be carried out accurately. The Virtual Cuff system presented in this work can addresses the situation, similar to Schroedinger cat thought experiment, where determining patients true BP is impossible, since the very act of seeing a physician or using a BP cuff artificially raises their blood pressure. Finally, continuous monitoring of blood pressure can enable users of the system to modify their behavior through behavioral cueing. Alerting a person that their blood pressure is going up, for example when they are driving can help people calm down and improve their heath.

The standard approach for obtaining blood pressure involves inflating and deflating a blood pressure cuff, when a reading is desired. This action can wake up patients from their sleep, present embarrassing situations to uses during social interactions, and turn off many potential users.

The Wireless Cuff system with the Remote Coach infrastructure is presented, with their system-level architectures and some initial results from a small case study.

2 Related Work

There exists various classes of health sensor systems, including health care and fitness related systems highlighted below.

2.1 Health Care Related

There are a range of systems that examine remote monitoring system for healthcare applications. There are systems used for rehabilitation [1] and those use for modifying diet [2][3]. Other applications use proprietary or in house sensors to monitor gait [4][5][6][7][8], biomarkers for cancer patients [12], biomarkers for heart failure patients [13][14][15], and other general health parameters [9][10][11][16].

2.2 Fitness Related and Activity Monitoring

With fitness application, remote monitoring system have included the interval training systems, including those that use adaptive techniques to tailor workout [17][18].

There are also a wide range of papers that examine activity monitoring and classification, including those that use accelerometers on smart phones [19][20][21][22][23][24][25].

2.3 System-Level Issues

Some also consider system-level issues such as middleware [26][27] or power minimization [26]. There has also been examinations of networking issues, specifically with body area networks used in health applications [28][29][30][31][32][33][34][35][36][37][38].

3 Physiological Parameters

There are four primary vital signs that are measured by health professionals to give an assessment of the overall health of the patient. They are temperature, blood pressure, pulse, and respiratory rate [43]. These vital signs may indicate if an athlete is overworking themselves. The physiological parameters that this project uses are blood pressure (estimated), ECG and heart rate, volume of oxygen being consumed (VO2), and pulse rate.

3.1 Temperature

Temperature is important in an athlete. Heat is generated when a person exercises. The body tries to keep the core temperature the same through sweating. It can also cause dehydration as the body sweats to keep its core temperature in a good range. Temperature affects the time to fatigue in an athlete.

There are some disorders that are associated with heat. Heat exhaustion and heat strokes are two of them. Heat exhaustion is when the athlete cannot perform any longer due to "any combination of heavy sweating, dehydration, sodium loss, and energy depletion." Heat exhaustion usually happens when the body core temperature is between 97 and 104 degrees Fahrenheit. Heat stroke happens when core temperature is greater than 104 degrees. Heat stroke can be deadly and is associated with signs of organ system failure [40]. Heat related injury is a concern of many trainers.

3.2 Blood Pressure

Blood pressure is the pressure on the walls of blood vessels when the heart beats. Systolic and diastolic readings are measured in millimeters of mercury (mm Hg). The systolic reading is the maximum blood pressure of the person. And the diastolic reading is the minimum blood pressure of the person. Blood pressure decreases as the blood travels further from the heart. That is why a blood pressure measurement is usually taken on the brachial artery, the major artery in the arm [44]. A sphygmomanometer is commonly used to measure the blood pressure of a person. Blood pressure will increase during exercise as the heart will be beating faster to supply the body with sufficient oxygen.

3.3 ECG AND HEART RATE

The electrocardiogram, or ECG, is used to measure heartbeats. It detects the electrical activity of a heart using electrodes attached on the skin. The ECG can also detect arrhythmias. An arrhythmia is a disorder in the heart beat: too fast, too slow, or irregular.

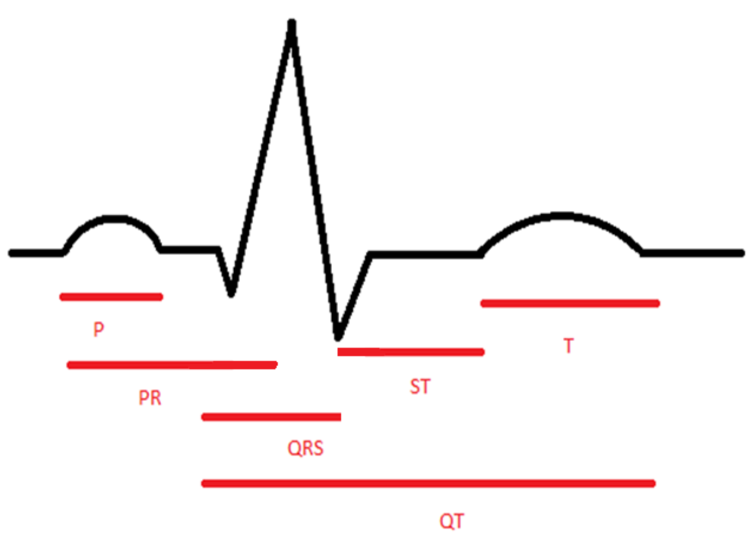

Figure 3.3.1 This is an illustration of a ECG graph with its parts labeled.

The ECG works by detecting the electrical activity of the phases that the heart goes through to pump blood. The ECG works because the cells in the heart use a Sodium-Potassium pump to create polarization using the sodium (Na) and potassium (K) ions. The part labeled P is called the P Wave. That is when the atria in the heart depolarize; it lets the Na+ ions in to the cell causing equilibrium. The part labeled QRS is the QRS wave. This is when the ventricle of the heart depolarizes. The part labeled T is the T wave. This is when the ventricle repolarizes using the Sodium-Potassium pump fueled by adenosine triphosphate (ATP). It pumps the Na+ ions out of the cell and K+ ions back in to the cell. This creates the imbalance needed for the next heartbeat.

Arrhythmia can be detected by irregularities in the ECG graph. An irregularity in the ECG graph is when the wave falls out of the regular pattern of the ECG graph. Many professionals take several courses to identify and diagnose arrhythmias.

R-to-R is the time/distance from the peak of the QRS wave to the peak of the next QRS wave.

Many athletes in different disciplines train using heart rate information. They categorize certain heart rate levels in to zones. Zone 1 is 50% to 60% of the athlete's maximum heart rate, Zone 2 is 60% to 70%, Zone 3 is 70% to 80%, Zone 4 is 80% to 90%, and Zone 5 is 90% to 100% of the athlete's maximum heart rate As athletes get more fit, their heart rates become lower for a certain activity than an unfit athlete. In cycling, during the winter, many cyclists train their endurance. They keep ride for extended periods of time in Zone 2 [49].

In this project, the Zephyr Bioharness is used. It provides useful information about the vitals of the wearer. Some of the information it provides are heart rate, respiration rate, and skin temperature. This sensor is connected to the smartphone using the Bluetooth protocol.

Figure 3.3.2 This is a photograph of the Zephyr Bioharness.

3.4 VO2 AND VO2MAX

VO2 is the volume of oxygen consumption that a person is breathing (liters of oxygen per minute). VO2Max is the maximum volume of oxygen consumption of that person during rigorous activity. VO2Max is widely accepted as a measure of maximum aerobic output of an individual. VO2Max varies from person to person.

The respiration rate and VO2 of an athlete are closely related as when a person breathes in, they breathe in a volume of oxygen. Using this information, it is possible to estimate the VO2 of an athlete [51].

3.5 PULSE OXIMETRY

The pulse oximeter is used to measure the level of oxygen saturation in the sensor wearer's blood. The pulse oximeter works by shining a light through the wearer's blood to a photo detector on the other side. The light source illuminates at two different wavelengths (red and infrared LEDs) to distinguish between oxyhemoglobin (HbO2) and deoxyhemoglobin (Hb). The pulse oximeter rotates through those two light sources and with them off (to account for ambient light) [47]. The result is the percentage of oxygen saturation (SpO2). The heart rate is also measured with the pulse oximeter.

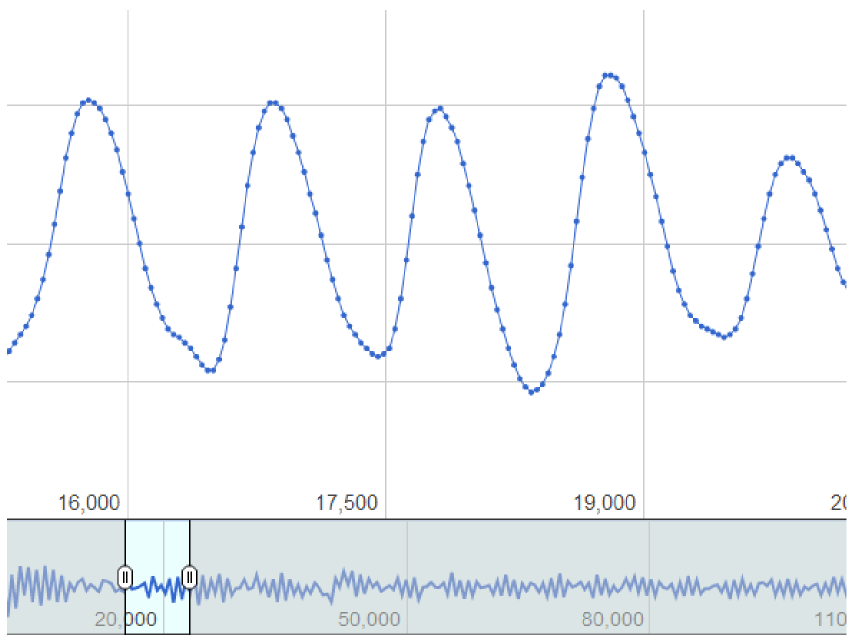

Figure 3.5 This is a graph of the plethysmograph trace from a pulse oximeter.

In this project, the Nonin Onyx II 9560 finger tip pulse oximeter is used. The display on the device shows the SpO2 and the heart rate of the wearer. This sensor is connected to the smartphone using the Bluetooth protocol.

Figure 3.5 This is a photograph of the Nonin Onyx II 9560 pulse oximeter being used. It is showing a 96% SpO2 level and a heart rate of 66 bpm.

3.6 MET

The metabolic equivalent of a task (MET) is the measure of how much energy a certain task takes. One MET is the energy equivalent of an adult sitting which approximates to 3.5ml of oxygen per kilogram of body weight per minute [45]. Activities that are between 3.0 and 6.0 METs are considered moderate activities. Examples of moderate activities include recreational swimming, gardening, and square dancing. And any MET greater than 6.0 is considered vigorous activities. Examples of vigorous activities include bicycling faster than 10mph, jogging or running, and most competitive sports.

The Compendium of Physical Activities has a list of over 700 MET values for different activities. They are listed in 21 different categories such as bicycling, dancing, music, and yard work. The MET value is used as a relative measure; the amount of calories burned is different from person because of age, fitness, weight, and other physiological factors [45].

Using the MET value of an activity, it is possible to calculate an estimate of calories burned during the activity. This is the formula that many fitness equipment and websites use to calculate the estimate. The following is the formula:

Kcals burned = (MET * 3.5 ml/kg/min * weight in kg's) / 200 * duration in minutes

3.7 Estimating Blood Pressure

It is possible to estimate the blood pressure of a person using an electrocardiogram (ECG) and a pulse oximeter sensor attached to the user. This is by measuring the distance between the peaks in the R-to-R graph from the ECG and the peaks in the plethysmograph waveform [46] The advantage to this are that the user does not have to wear a bulky constraining cuff which makes the user is more mobile. All the user has to wear is a ECG monitor around their chest and a pulse oximeter sensor on their finger.

4 SYSTEM OVERVIEW

4.1 REMOTE COACH INFRASTRUCTURE

The Remote Coach infrastructure was built to support fast and convenient health sensor system, as that employed in Wireless Cuff research project. It is composed of various heterogeneous hardware components, the sensors deployed on or around the body, the smart phone gateway, and the remote server. These hardware components and their interface are highlighted in Figure 4.1.

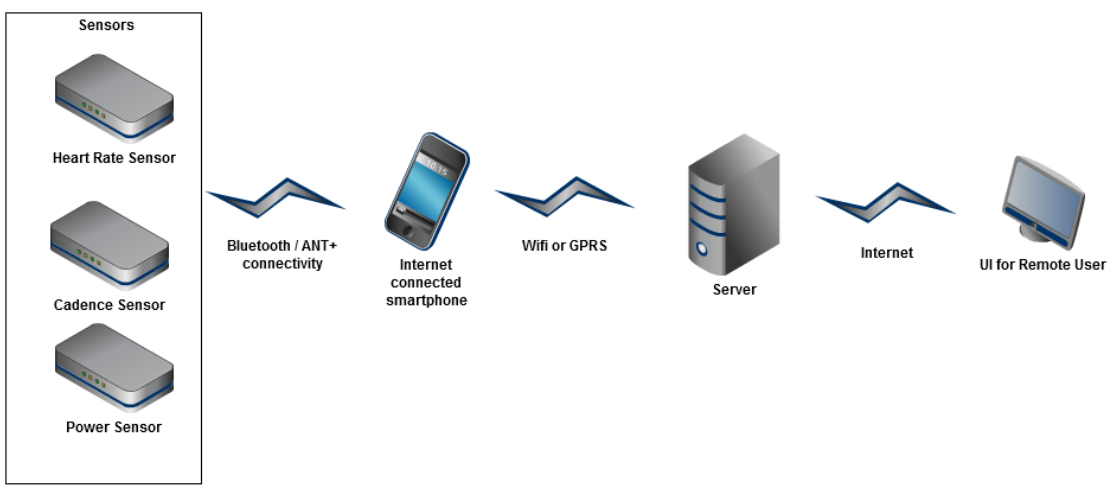

Figure 4.1. Hardware system components and interfaces, including the sensors connected wirelessly to the gateway, the smart phone that senses, collects data, and sends off data to a remote server, and the server and its web interface for accessing the collected data.

The underlying software architecture of the remote coach separates the data collection and the data hand-off and processing components. There are various heterogeneous interfaces between the sensor devices and the smart phone gateway. For example, in the Wireless Cuff system there are three different sensors from three different manufacturers, whose data must all be fused, in addition to the data collected for the sensors housed on the smart phone itself.

Each connection with a health sensor is modeled as a “driver.” Separate software is written to collect the data, than is developed to transmit and process the data, hence the advantage of the Remote Coach infrastructure over ad hoc development.

The other key part of the infrastructure is the remote server and its web interface. The web interface allows for customization of the data displayed. Figure 4.2 provides a web interface developed for testing the Remote Coach. As shown, data from different sensor devices is displayed, as well as interfacing with APIs such as Google Maps.

The data processing, either for heterogeneous data or for single signals is carried on the remote server, in the most part. There is some local processing of data on the phone by the app, as well.

Figure 4.2 Prototype web interface for the Remote Coach infrastructure and its testing

4.2 WIRELESS CUFF SYSTEM COMPONENTS

The Wireless Cuff system is composed of ECG and PPG sensor devices wirelessly connected to a mobile phone. The mobile phone acts as the gateway transmitting the data to the remote server. Additionally, data regarding accelerometer and GPS information is collected from the phone and used in the processing of the blood pressure information and validation. Data collected from the sensors can be accessed in real-time through a web interface. Some feedback is provided to the user via the mobile phone.

Once data is transmitted off of the phone to the remote server, the data can be accessed remotely through a user-friendly web interface.

The web interface has various components.

4.3 ANDROID PLATFORM

The mobile gateway, in our system is an Android-enabled smart phone. The system users are expected to carry the phone with them throughout their day's activities, as is mostly the case already.

There are a few platforms available for the mobile environment: Android, iOS, Rim (Blackberry), Windows Mobile, and others. According to the NPD research firm, the leading North American market research company, the Android platform has the largest market share (53 percent) in the US [48].

Android has a built in SQLite database server. With the storage needs of this project, the built-in database was a great advantage.

The smart phone gateway has an Android application that users launch to start the data monitoring. Feedback in the form of summary data regarding activity is provided to the users. A screen shot of the app is provided in Figure 4.3.

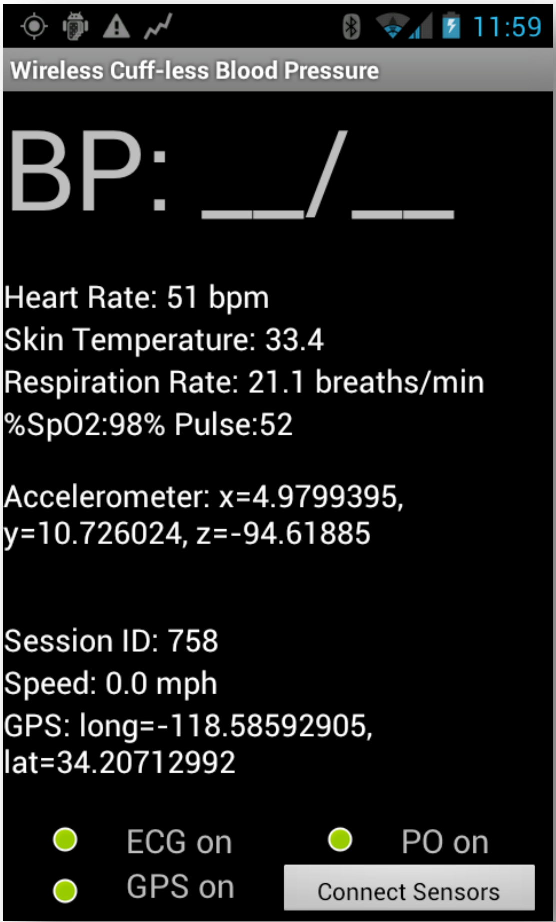

Figure 4.3. Android application interface screen shot.

4.4 Sensors

Android has built in support for many types of sensors. It supports GPS, accelerometer, temperature, gyroscope, light, linear acceleration, magnetic field, orientation, pressure, proximity, humidity, and rotation sensors. The type of sensors that can be used depends on which ones the Android device has built in.

There is also support for external wireless sensors. They can be anything as long as there is a way to connect them to the phone using a protocol that Android supports (e.g. Bluetooth). Examples of these sensors can be heart rate monitors, ECG, pulse oximeters, speed/cadence/power meters for bicycles, weight scales, blood pressure, blood glucose monitors, and others.

The Wireless Cuff project makes use of a GPS, the Zephyr Bioharness, and the Nonin Onyx II 9560 Bluetooth pulse oximeter. These sensors are placed on the body and are necessary for the extraction of blood pressure information.

4.5 WEB INTERFACE

Users can access the data collected and stored on the remote database, via a web interface. The website displays both archived data and real-time data in a user-friendly interface. Figure 4.4 gives a screenshot of the Wireless Cuff web interface.

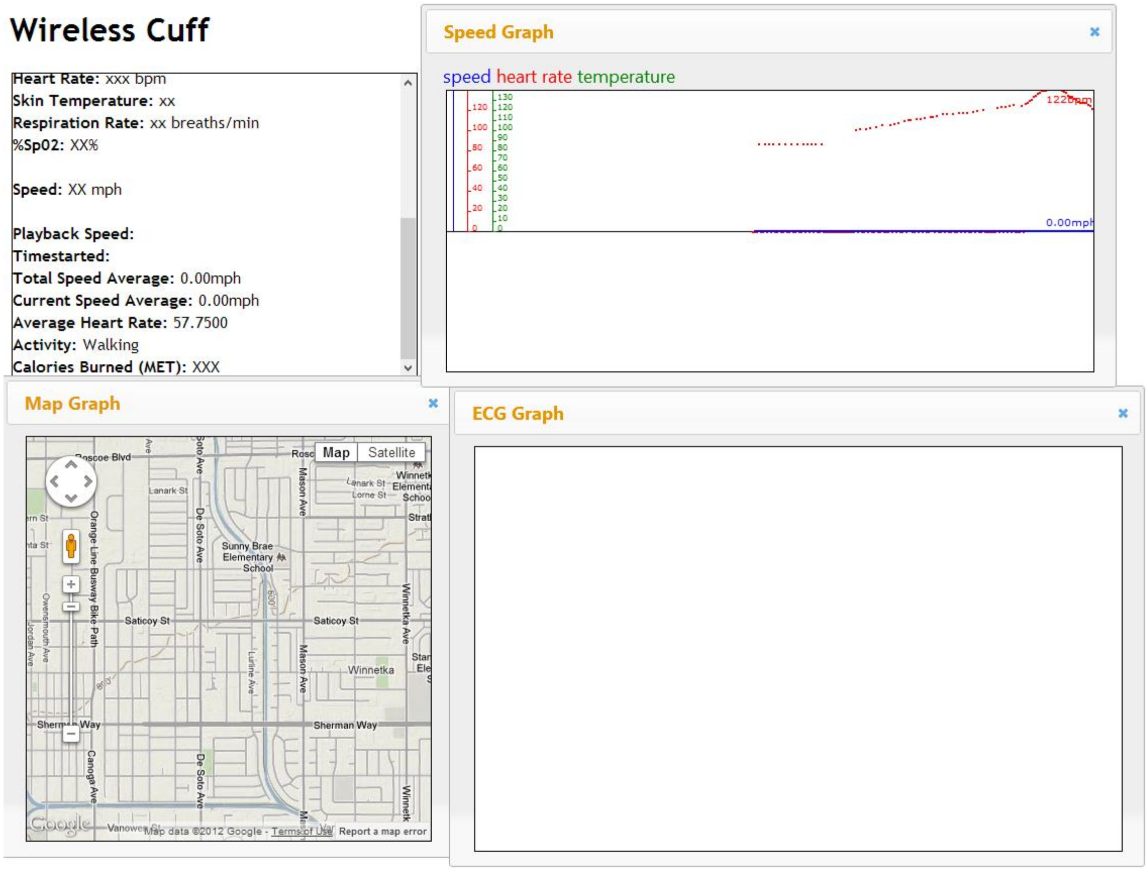

Figure 4.4. Screenshot of the frontend of the website where the collected data is visualized and made accessible for remote access.

The website has various data displays and visualizations forms. These include the Google Maps interface for displaying the GPS data from the user's smart phone. This data is used for evaluating the environment that a user is in. For example, in a park it is not alarming to have high blood pressure. In an office building on the other hand, that is unusual. Therefore, geocodes derived from the smart phone can be used to validate the blood pressure measurements extracted from the sensor devices.

There is a drop down box where the session id can be selected. The default session is always the latest session.

The accelerometer data is used processed to produce the speed information presented in another corner of the webpage. That information is useful again for determining the validity of the blood pressure information.

The ECG information is graphed in another part of the site, along with PPG information extracted from the pulse oximeter.

5 SYSTEM IMPLEMENTATION

This project was implemented as an Android application and a Web application that uses a MySQL server. The details of the system are highlighted in this chapter.

5.1 OVERALL SYSTEM ARCHITECTURE

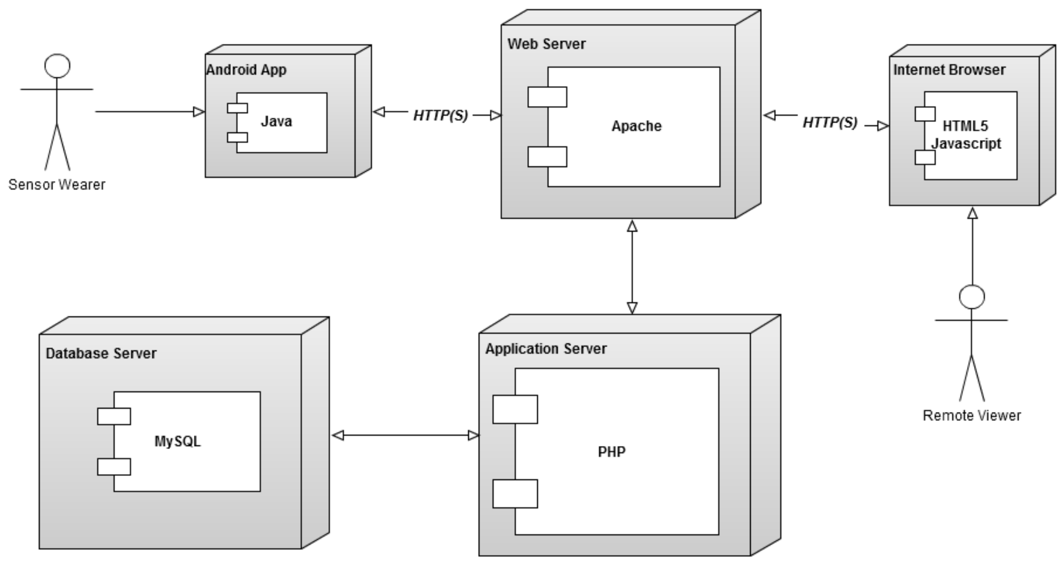

Figure 5.1. This is a UML diagram of the overall system architecture and its components

The components of the system that were developed are the Android application, the web interface, and database server. The web server that was used for development was shared hosting on an apache server that supported PHP. The database used for storage was a MySQL server.

5.2 MOBILE SYSTEM DEVELOPMENT

The embedded side of the system is written in Java for the Android 2.2 platform as it is the most widely supported version of the Android operating system.

5.2.1 ANDROID DEVELOPMENT

Programming for the Android operating system is done using the Eclipse IDE with the Android Development Kit plugin installed. The Android application starts with a blank screen with a button labeled "Start". When hitting start, the application connects to the webserver and retrieves a session identification number and then transitions to the main screen.

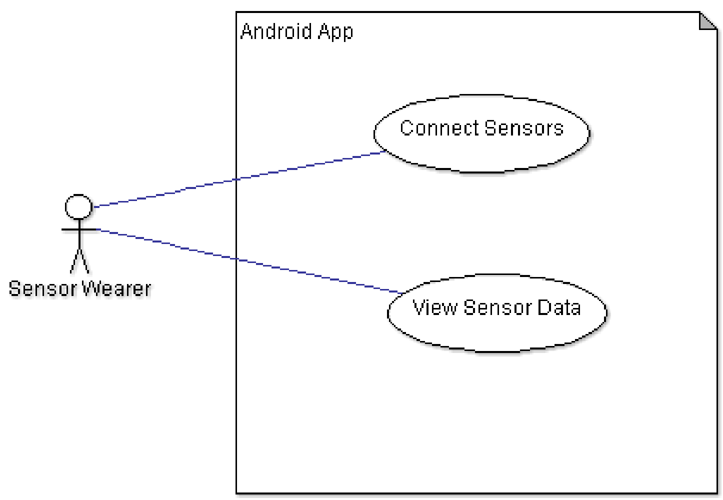

Figure 5.2.1. Use case diagram depicting the use of the main screen of the Android application.

On the main screen, there are fields that display the data from the connected sensors. There is also a button to connect the sensors.

5.2.2 Sensor Communication Development

The Android Development Kit gives developers access to sensor information from sensors that are built in the mobile device. One of these sensors is the GPS and accelerometer sensors. This project records the longitude and latitude and the x, y, and z data from the sensors. This is achieved by creating listeners for both and registering them with the Android API.

There are also other sensors that are connected to the mobile device using the Bluetooth protocol. Android exposes an API to the Bluetooth communication functionality for developers.

The GUIDs for both sensors are hard coded for those specific brands and models.

Steps for connecting the two devices are:

1) Get the Bluetooth adapter
2) Search through connected Bluetooth devices for the two we want
3) Set up read/write sockets
4) Run loop to listen on the read/write channels of the sockets on a separate thread that calls handler when there is information

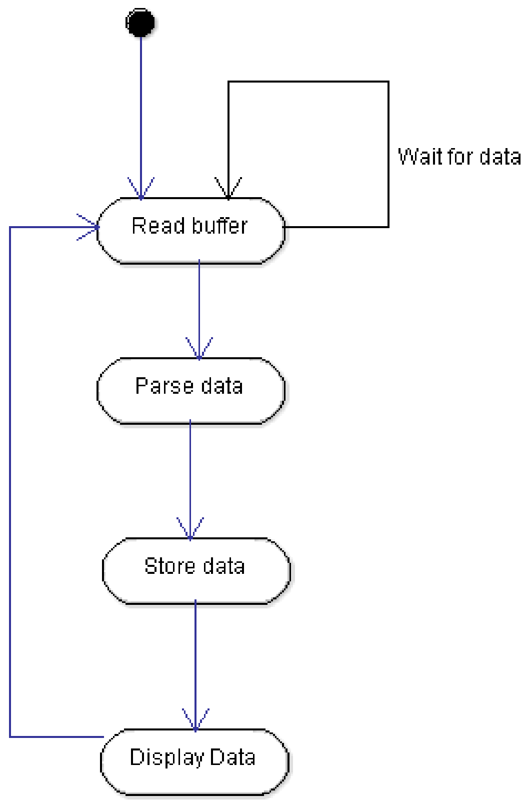

Figure 5.2.2 This is an activity diagram of how the Android Application handles incoming data from both devices

5.2.2.1 ZEPHYR BIOHARNESS

Thankfully, the Zephyr Bioharness came with an example application, API, datasheet, specifications sheet, and utility tools which made implementing support for this device very easy. Whenever there is information for the handler, the byte data is parsed in to custom objects created by Zephyr provided by their API. Much of the event handling and data parsing is hidden from the developer. The project implements a handler to handle the messages from the Zephyr API. The information that is retrieved includes skin temperature, heart rate, respiration rate, ECG data, and R-to-R data. This information is stored for the thread that sends data to the web server every second.

5.2.2.2 NONIN ONYX II 9560 FINGERTIP BLUETOOTH PULSE OXIMETER

The Nonin Bluetooth Pulse Oximeter was not as easy to implement support for. The datasheet and specification sheet is not published on their website, but I emailed the company and they provided them.

There are four data modes that the device has. Each mode sends different kinds of data over the Bluetooth connection. Using the datasheet, I created a quick utility application that connects to the device to set the data mode that I want by sending a specific byte sequence. For example, the utility application can send the bytes [02, 70, 04, 02, 0D, 00, 83, 03] to the device to set it to the default data mode (data format 13).

The first data format is data format 13. Data format 13 only sends data to the mobile device only when there is a SmartPoint measurement. A SmartPoint measurement is a SpO2 reading estimated by a proprietary algorithm written by Nonin. The data sent by this format is date and time of the measurement, status flags, pulse rate, SpO2, and the serial number.

The second data format is data format 2. When using data format 2, the device sends a continuous data stream of 5 byte data (a frame) 75 times per second. A packet consists of 25 bytes, so the device sends 3 packets per second. The data transmitted includes the plethysmograph, pulse rate, SpO2, status flags, and a lot of other information.

The third data format is data format 3. Data format 3 is the same as data format 2 except that it provides a higher resolution for the plethysmograph data.

The fourth data format is data format 8. Data format 8 sends data once a second. The data it sends is the data that is displayed on the actual device.

This project uses data format 2. My implementation for support of data format 2 is a loop that goes through the available frames and a function that parses and processes each frame depending on the index of the packet. In the loop that reads the read socket of the Bluetooth connection, whenever there is data read, a message with the data is sent to the processing loop for the Nonin device. The function only saves data from the frames with the information we want.

Each frame of the packet has pleth information, so the function saves that data. Frame 1 and 2 has heart rate data. And frame 3 has the SpO2 reading. The other information is ignored. This information is stored for the thread that sends data to the web server every second.

5.3 Web Interface Development

There is a website that a health care professional can remotely view to monitor the sensor wearer's vital signs, position, and speed. The data from the sensor wearer's session is stored in the database using the wearer's smartphone's internet connection. The website periodically retrieves the data in JSON format from this database every 500 milliseconds. The website sends and processes a HTTP request to the webserver using jQuery. Each request retrieves all of the events that happened between the last request time and the current request time. The web interface is updated with the retrieved information.

5.3.1 Web Interface Implementation

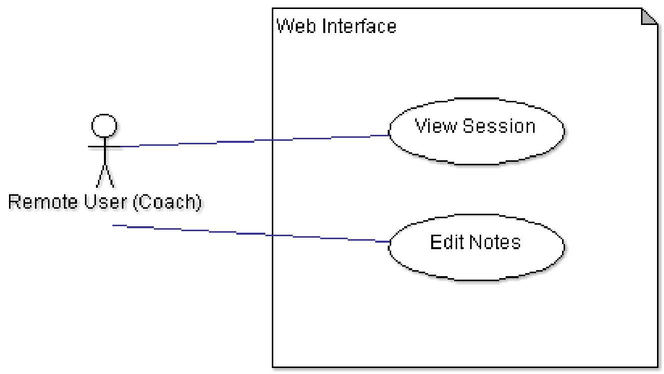

Figure 5.2. Use case diagram depicting the use of the Web Interface by the Remote User.

In the left panel, in addition to controls for the session, there are statistics that are being displayed. Those statistics are the total speed average, current speed average, average heart rate, activity classification, and estimated calories burned based off of a MET estimate. This information is calculated from data from the database. There is also a notes section where the Remote Professional can write notes about the session.

In the middle panel, there is a chart that shows the sensor wearer's heart rate and speed information. It is drawn using HTML5's canvas element and javascript. The axes are graduated from zero to the max value of the data being drawn with a little white space added to the top. The graph data points are stored in to separate circular queues; one for each line. Every time new data comes in, the data points in the queue are shifted to make room for the new information.

In the bottom left, there is an interactive map that shows the sensor wearer's GPS information during the exercise session. This map uses the Google Maps API and javascript to draw the map and route. The Google Maps API allows the website to draw the map using the current longitude and latitude of the sensor wearer. It also allows the website to draw the line/path of the wearer overlaid on top of the map.

In the bottom right panel, the sensor wearer's ECG wave is displayed using a smoothed line chart drawn using the Google Charts API.

5.3.1.1 Activity Classification

A thresholding algorithm was used to carry out activity classification. Using this activity classification, the system can choose the appropriate MET value and calculate an estimate of the amount of calories burned during the exercise session. The algorithm is based on the heart rate and speed of the sensor wearer. One of the flaws in the algorithm is that it needs physical movement, so running on a treadmill or riding an indoor bicycle will not work.

```
if (heart_rate < 120) {
    if (average_speed < 5) {
        // user is walking
    } else {
        // user is driving
    }
} else {
    if (average_speed  < 10) {
        // user is running
    } else {
        // user is cycling
    }
}
```

Figure 5.3. Pseudo code of the activity classification algorithm

5.3.2 DATABASE BACKEND

The backend of the web application uses MySQL to store the data from the Android application. There are two tables in the database. One is named saved_sessions and the other is named sensor_data. The schema could have been normalized in to a normal form, for example Boyce-Codd Normal Form (BCNF) or the third normal form (3NF), but this schema is more straightforward and easier to work with for this project. Normalizing a database schema minimizes redundancies and dependencies [50]. The downside to using the schema I have is that it does not scale well if I decide to add more sensors to the system. To add an extra sensor, I would have to add a column to sensor_data. If the database was normalized, for example, I would simply add new records to a "sensor_type" and "sensor_parameters" table. Also, some of the records in the sensor_data table can be blank and waste space.

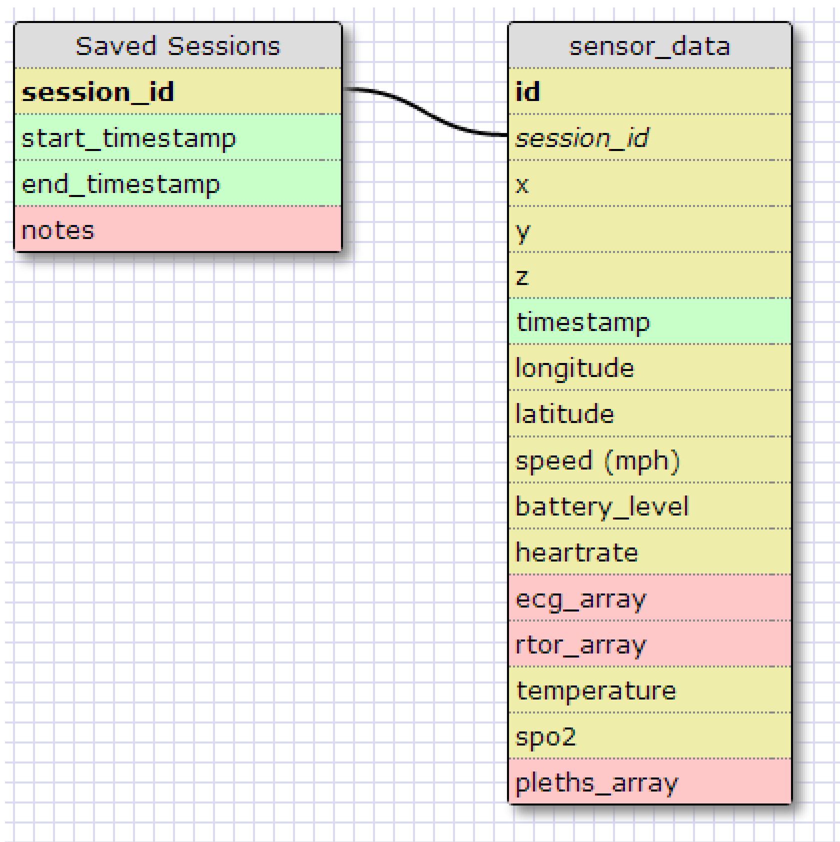

Figure 5.4. This diagram represents the schema of the database. Yellow fields are integers. Green fields are time. Red fields are text.

This is a description of the fields in the saved_sessions table in the database:

Field Name	**Description**

Session_id (primary key)	Session_id is the unique session identification number that is assigned when the Android application starts.
Start_timestamp	When the Android application requests a new session_id, the start_timestamp field is set to the current timestamp.
End_timestamp	End_timestamp is set when the Android application exits normally; it can be blank.
Notes	The notes field is for the Remote Professional to write notes about the session for later review. The notes field is accessible through the web interface.

This is a description of the fields in the sensor_data table in the database:

Field Name	Description
Id (primary key)	Id is the unique record

	identification number for the entry.
Session_id	Session_id is the unique session identification number of the saved session that this record belongs to.
X	X is the x value from the accelerometer sensor on the mobile device.
Y	Y is the y value from the accelerometer sensor on the mobile device.
Z	Z is the z value from the accelerometer sensor on the mobile device.
Timestamp	Timestamp is the timestamp when the mobile device sent the data to the server.
Longitude	Longitude is the longitude value from the GPS sensor on the mobile device.
Latitude	Latitude is the latitude value from

	the GPS sensor on the mobile device.
Speed	Speed is the speed value from the GPS sensor on the mobile device. It is stored as miles per hour.
Battery_level	Battery level is the current battery level, in percentage, that is left on the mobile device.
Heartrate	Heartrate is the current heart rate, in beats per minute, from the Zephyr Bioharness sensor.
Ecg_array	Ecg_array is an array of all the ecg values from the Zephyr Bioharness sensor that was reported since the last record that was sent to the server.
Rtor_array	Rtor_array is an array of all the R-to-R values from the Zephyr Bioharness sensor that was reported since the last record that

	was sent to the server.
Temperature	Temperature is the current skin temperature of the sensor wearer from the Zephyr Bioharness sensor.
Spo2	Spo2 is the percent of oxygen saturation in the blood of the sensor wearer that is reported by the Nonin pulse oximeter.
Pleths_array	Pleths_array is an array of the plethysmograph values from the Nonin pulse oximeter that was reported since the last record that was sent to the server.

5.4 SECURITY AND PRIVACY

There are some security concerns for a wireless BAN, especially for one that is made for a hospital/medical situation. Each component of the system will need to be protected as well as their connections to other components. If the system is to be used in a health care setting, the system will have to be HIPAA compliant. HIPAA is the Health Insurance Portability and Accountability Act of 1996. One of the rules to be compliant is to protect the privacy of patient records, or Electronic Protected Health Information. "The goal of encryption is to protect EPHI from being accessed and viewed by unauthorized users [42].” In this project, data and access to the server should be password protected. Since this project isn’t in the medical environment, this security would be nice, but it is not necessary.

The data sent from the sensors to the phone will need to be encrypted. Encryption is supported by both ANT+ and Bluetooth. This project does not use an encrypted Bluetooth connection.

Data stored on the sensor can be protected by encryption, but it is also protected by requiring physical access to the device. Same protection applies with data on the phone. This project does not encrypt the data where it is stored. The MySQL database where the data is stored online does use user access controls. A login is required to access the database.

Data transfer from the phone to the server will need to be encrypted. This can be achieved through encrypting the actual message or encrypting the connection using the HTTPS protocol. The HTTPS protocol uses Secure Socket Layer (SSL) public key encryption. Public key encryption involves two parties, each with a public key known to the world and a private key that is kept secret. When one party wants to send an encrypted message, they encrypt the message with their private key. To decrypt the message, the receiving party will use the sender’s public key to decode the message [41].

6 System Testing

This system was tested to see if it provided accurate results. I have tested the system on myself. I attached the sensors to my body and rode on an indoor bicycle trainer. A bicycle trainer attaches to the rear wheel of a bicycle and allows the operator to bicycle in one place. I rode the bicycle at different intensities (low, medium, high) and took my blood pressure reading using an upper arm cuff blood pressure monitor during the bicycle ride. For the webserver, I used a shared hosting account that supported PHP and had a MySQL database.

There were some issues testing the system. The Nonin pulse oximeter is not made for vigorous activity as it slid around on the fingertip and provided a yellow or even red status symbol which indicates the quality of the readings.

Another issue that was encountered was that the original mobile phone, HTC EVO 4G, did not have enough processing power to handle both the ECG's and pulse oximeter's Bluetooth connection. The frames that came in from the pulse oximeter would frequently fail the CRC checks when parsing the byte data. Switching over to a more powerful phone, Samsung Epic 4g, these problems instantly went away.

I have also recorded the ECG, R-to-R, and plethysmograph data directly on to the memory card on the mobile device and compared those values to the data stored in the online database.

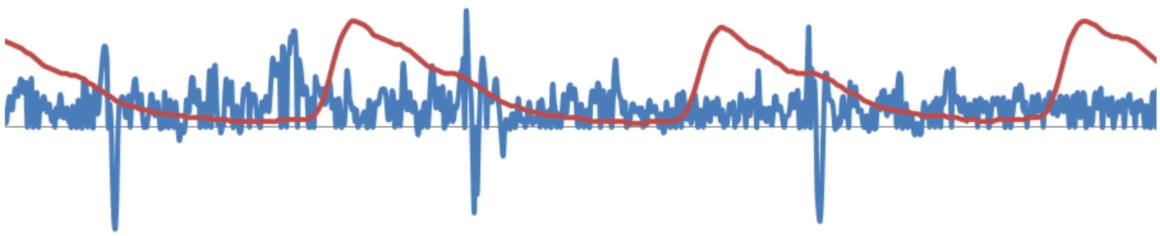

Figure 6.1 This is the graphed ECG data from the Bioharness overlayed with the plethysmograph trace from the pulse oximeter

Another issue is that the readings from the ECG are sometimes noisy. This happens in the provided sample application from Zephyr. Some readings are better than others when the strap is worn in an optimal position. So this leads me to believe that it is the actual design of their product.

7 CONCLUSION

The Remote Coach infrastructure was presented, along with its advantages for rapid health sensor prototype development. Additionally, its application to blood pressure measurement with the Wireless Cuff system was detailed. The system infrastructure and implementation details were discussed, along with data from a small case study.

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