Executive Summary

Wearable Cardiac Monitor

Design Document

Team 24

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Development Standards & Practices Used

- Circuit and Block Diagrams
- Agile practice & values
- Commenting on Code

Summary of Requirements

- Wearable
- 48+ hour battery
- Bluetooth phone connection
- Data storage
- Easy to use Android Application

Applicable Courses from Iowa State University Curriculum

1. CprE 185 - Introduction to C Programing
2. CprE 288 - Embedded Systems in C
3. CprE 388 - Android studios development
4. E E 224 - Signals & Systems I
5. E E 230 - Electronic Circuits & Systems
6. E E 303 - Energy Systems and Power Electronics
7. E E 324 - Signals & Systems II
8. E E 330 - Integrated Electronics
9. E E 475 - Automatic Control Systems
10. ComS 227 - Introduction to Java
11. ComS 228 - Java data structures
12. ComS 309 - Java app development

New Skills/Knowledge acquired that was not taught in courses

- Bluetooth Communication was something we hadn't really worked on in any of our classes so we need to learn how that worked in order to effectively finish the project.
- We also became better at communicating with a group and effectively managing our time while we are all meeting together.
- We got a better understanding of reading technical diagrams in order to understand how our devices work.
- We more efficiently learned to use existing libraries in order to reduce the amount of work needed and increase quality in development.

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1. INTRODUCTION

1.1 ACKNOWLEDGEMENT

Thank you to Dr. Cheng Huang, our client and advisor, for providing guidance throughout the project. He has been very helpful with providing us with a clear focus for the project as well as ensuring we have the resources we need to complete the project. Dr. Huang has lots of great recommendations and suggestions which have been greatly appreciated as we work to ensure our device works properly.

1.2 PROBLEM AND PROJECT STATEMENT

On the market right now, wearable heart monitors that last 48 hours are scarce and very expensive. Not to mention, in searching for one online, most of the products are watches. This form of monitoring is less useful than those with ECG electrodes.

With these issues in mind, we are making a heart monitor that will be cheap and easy to use for our client that may be used for future clients as well. This heart rate monitor will be smaller than a normal heart rate monitor in order to make it more portable. By making it smaller, the client will not be limited to sitting in a doctor's office all day and can still go about their day.

This heart rate monitor will be a compact, have low power consumption, and user friendly. We will still have the three typical ECG electrodes that will connect to the clients torso in order to get a signal which will be sent to the Android application. From there, the Android application will provide the client with their heart rate. Once the application has the data, it will store the data in order for someone (typically a professional) to read. We are hoping that it will help point out any irregularities that might occur in someone's heart such as a heart murmur or other irregularities.

1.3 OPERATIONAL ENVIRONMENT

Our product attaches to the human body, ideally, this should be worn all day long. Therefore, it will follow people's daily actions such as walking, running, showering, etcetera. Shaking and hitting against body could potentially happen. It may be exposed to water during a shower or rain.

1.4 REQUIREMENTS

- Wearable
- Smartphone (Android) connectivity
- 48+ hour battery life
- Motion calibration
- Data logging/storage

1.5 INTENDED USERS AND USES

The heart rate monitor will be intended for anybody that feels as though something is not working properly with their heart. Most of these clients will typically be coming from a doctor's office or a pharmacy. The client will wear this heart rate monitor for up to 48 hours with the gathered data being stored to a smartphone application via bluetooth connection.

1.6 ASSUMPTIONS AND LIMITATIONS

Assumptions

- 48+ hours battery duration
- 48+ hours worth of stored data
- Bluetooth connectivity - this is how data is sent
- Pocket size or smaller
- Wearable/comfortable
- Limit to one user per heart rate monitor
- The device will need to detect when it is not properly connected
- If the device is to lose power, it will not lose all currently collected data
- The system must operate at 3.3V

Limitations

- No larger than 5"x5"x3"
- Wires long enough to have the electrodes placed on the skin above the heart
- The electrodes that get attached to the body are limited where they can be placed so that they can pick up a reading
- The system must be safe to keep next to the body
- User must have a device to connect the heart monitor to via bluetooth

1.7 EXPECTED END PRODUCT AND DELIVERABLES

The client will be provided with a wearable heart rate monitor that will transmit the gathered data into an application on a smartphone. For this reason, the client will need to have a smartphone with access to the application.

The end product will be a device that is small enough to either be comfortable to wear somewhere around the body or fit into a pocket. The device will be able to monitor the heart and send the data to a smartphone, which will need an app that has been developed for the device to store and read the data. The user will need to have a smartphone with the app installed and the user will need to regularly get electrodes because they are a one time use.

There will be a user manual on how to set up the device and a power cord to recharge the device.The delivery date of our final product to our client will be during the last week of April 2020, April 26th - May 1st.

2. SPECIFICATIONS AND ANALYSIS

2.1 PROPOSED DESIGN

We will be using an AD8232 heart monitor, Arduino mini, and a Bluetooth Mate 4.0 to obtain, process, and send the data to the smartphone. The smartphone will either be graphing, or just storing the data sent out to be viewed by the client.

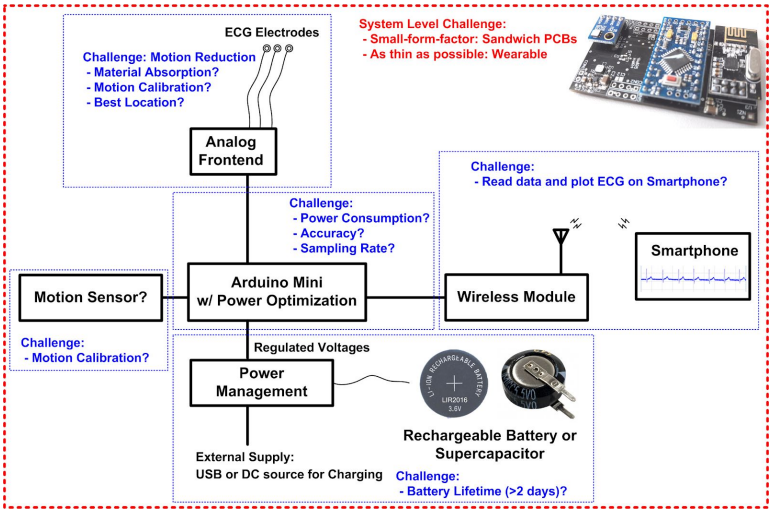

Figure 1 - General Overview of the Project Design

Figure 1 shows the general design of the project. It has been broken down into five specific areas which we will be working on to build an optimized product. Our initial focus is on establishing a reliable reading from the analog ECG electrodes and maintaining a bluetooth connection with the device. Upon successfully finishing these we will move into optimizing the power management of the device and work on potentially using motion sensors to eliminate any electrode noise.

2.2 DESIGN ANALYSIS

So far we have a general block diagram for our project. We are trying to create a system that has a small form factor and is easy to use for people. We are still deciding how we want our clients to wear the control box for the monitor. This will likely depend on how our testing of the bluetooth ECG pads work with our system.

We discovered that the original Arduino we were looking at is no longer made so we had to find another one. For the most part the design seems to be sufficient and shouldn't require many changes.

As we continue to work with the parts and better understand the capabilities and actual way the parts interact with each other we will gain a better understanding of what addition parts we may need. This method is fine for the time being, but it could slow down the roll out of this if we need to keep reordering parts that work better after we test them.

2.3 DEVELOPMENT PROCESS

We plan on following the Agile method. We think this will allow us to set short term goals and have an idea of where we are as a group on the tasks we need to complete. This will also allow us to have a way to look back at our project timeline and see ways that we can improve going forward

2.4 DESIGN PLAN

The design plan for the initial prototype is going to go through a heart rate monitor, with a signal sent out to an Arduino. The Arduino will then process this data, and sends the signal out to a bluetooth chip. Lastly, this will send the signal over bluetooth to a hooked up smartphone which will record the data, as well as show a live heart rate and, ideally, alert the user if there is some sort of anomaly.

The parts we have chosen are very small as to fill the size requirement. After we have a working prototype we plan to go back and limit power usage in all the places we can in order to meet the two day battery life requirement. After or during power management, we will attempt to design an algorithm to reduce false positives in the heart rate detector due to movement.

Lastly, we will perform final tests to make sure wearing the product over a long period of time remains consistent and that everything is up to the standards we have set. This will contain outside opinions of people who do not understand the technical aspect of the product, to get feedback on the user interface of the app and product itself. This will be key in figuring out if the product is user friendly and incentivising to use.

3. STATEMENT OF WORK

3.1 PREVIOUS WORK AND LITERATURE

We will be using many open sourced pieces for this project including Arduino libraries and the Android libraries. These libraries come with their own documentation and also have multiple examples available online to help us understand what we need to complete our final project. We have also looked at other existing versions of wearable cardiac monitors to find key similarities between them. We have specifically taken note of the layout, design, and features these other systems have implemented in their adjoining software to help make sure we can find ways to make our version equal to or better.

One product in particular which is similar to what we will be doing is the Qardio's Wearable ECG which can be seen in figure 2. This product has a nice application layout and is a sleek design which can be worn by the consumer during normal daily activities.

Figure 2 - Qardio Wearable ECG

3.2 TECHNOLOGY CONSIDERATIONS

Our biggest technology consideration for this project is our power consumption; we are wanting to keep it as low as we possibly can. Back when the technology was first starting to come out, everyone was just worried about getting products to work properly. Now since technology has grown, we are more focused on improving older products while still creating newer products that help make everyday tasks easier. Our group wants to make the typical heart rate monitor smaller and more user-friendly.

One of the biggest technological advances that we have today, which helps our project immensely, was the creation of Bluetooth. Our heart rate monitor will rely heavily on the Bluetooth module communicating between the physical monitor and the application. If we can get the hardware to properly send the data over to the application, it will allow us to reduce the size of the typical heart rate monitor. Once we can get a smaller heart rate monitor, it will make it easier to use on a daily basis if needed.

The downfall to creating a smaller heart rate monitor is that it may not work the way we plan. Our group has never made a heart rate monitor before so this is something that is new to each one of us. Another thing that will impact our project is learning new skills as we do this project; it will benefit our knowledge but it could affect our project negatively. An example of this is with the communication aspect of the project, we have two people working on this section and both are electrical engineers. There is some programming courses within the curriculum but a computer or software engineer would know more about the programming side of things.

3.3 TASK DECOMPOSITION

In developing our project we have separated our group into three groups; Hardware, Software, and Communications. Hardware is developing the ECG to monitor the hard and have the data sent to the Arduino. Communications is taking that data sending it from the Arduino to a phone through bluetooth. Software is working on creating an app for the phone to collect the data sent from the device's bluetooth and display a graph of the heart beating.

Hardware	Work with an ECG to monitor the heart and have the data sent to the Arduino.
Communication	Developing the code for our device to process the data and to send the data to a phone.
Software	Developing the app that will store the data from the device and do data processing to display the graph of the heartbeat.

Table 1 - Project Break down

3.4 POSSIBLE RISKS AND RISK MANAGEMENT

As it stands, there is a pretty big issue with the ECG monitor we are using. It is very sensitive to movement which is the exact opposite of what we would like for our product. We have thought of a few solutions as of right now, but they may not work as anticipated. We also have some research to do on the Software side involving the Bluetooth connectivity. None of us have much experience with this and we will be required to learn how it works before we can complete the project.

Another less pressing risk is in the user interface. We know from experience and research that if the UI is not user friendly enough or scuffed, the likelihood of the product being used decreases. To combat this we will be getting feedback, as mentioned, to provide the cleanest looking and most useful app possible.

3.5 PROJECT PROPOSED MILESTONES AND EVALUATION CRITERIA

There are three significant milestones currently with our project. The first is getting a working prototype that doesn't revolve on power and is somewhat accurate with minimum adjustment for noise. The second is getting the noise problem completely worked out without ruining the project. The third is getting our power consumption as low as possible as to not need to recharge the monitor every day. We have been not completely ignoring the third milestone, so we have picked low energy parts and have built in some features to reduce power in communication. We are just are putting that last because it will be a process to get it as low as we need it to be and we want everything else to be in place before hand.

Confirming it works will be testing it on all six of us with with given requirements. For the first test, we will just sit relatively still and get a reading sent out to our app that will ideally display the same as an oscilloscope would. Second would be the same, but with a much greater range of motion. Lastly, we will have someone wear over the course of a couple of days and see how long we can get the battery to last. If it lasts longer than some set amount at the beginning, with regular checking of the app, that will be classified as a success.

3.6 PROJECT TRACKING PROCEDURES

Project tracking has been done through weekly reports, which seems to be working most effectively. This can be continued into the upcoming semester, possibly with the addition of photos. As we complete certain aspects of the project we have been updating our client to ensure that they are pleased with the results and take any additional input they may have.

3.7 EXPECTED RESULTS AND VALIDATION

At the end of our project, we will have a working heart rate monitor. This heart rate monitor will be able to send a heart rate to a bluetooth module which will then send that data to an Android application. This application will be able to provide the user with their live heart rate and alert the user when something is irregular with their heart. Our group was able to borrow a bigger and older heart rate monitor which will be our verification that our monitor is working properly. We will compare the measured heart rate from our monitor to the one we borrowed.

4. PROJECT TIMELINE, ESTIMATED RESOURCES, AND CHALLENGES

4.1 PROJECT TIMELINE

Research on Product	T	09/15/2019	09/29/2019	10 days
Project Planning	T	09/30/2019	10/07/2019	6 days
Resource Gathering	T	10/08/2019	10/14/2019	5 days
Hardware, Communications, Software Definition/Work	T	10/15/2019	10/28/2019	10 days
Group Work	T	10/29/2019	11/08/2019	9 days
Arduino Sending/Receiving Data	M	11/09/2019	11/09/2019	-
Working to Connect Each Groups Work	T	11/09/2019	11/16/2019	5 days
Reduced Noise in Heart Monitor	M	11/17/2019	11/17/2019	-
Connect Pieces	M	11/18/2019	11/18/2019	-
Fix Current Project Issues	T	11/17/2019	11/24/2019	5 days
PowerPoint/Presentation Creation	T	12/02/2019	12/06/2019	5 days
Design Doc Redesign	T	11/25/2019	12/09/2019	11 days
Working Base App	M	12/05/2019	12/05/2019	-
Working Base Prototype	M	12/16/2019	12/16/2019	-
Break/Light Individual Work	T	12/21/2019	01/12/2020	15 days
Reassess Issue and Create a Plan of Attack	T	01/06/2020	01/13/2020	6 days
Fix App Latency/Laggy Issue	T	01/14/2020	01/28/2020	11 days
Work to Fix Motion Issue	T	01/14/2020	01/28/2020	11 days
Work on Packet Sending Problems	T	01/14/2020	01/28/2020	11 days
Bring Together With Second Working Prototype	T	01/30/2020	02/05/2020	5 days
Demonstrate New Better Working Prototype	M	02/06/2020	02/06/2020	-
Test Power Capabilities	T	02/14/2020	02/18/2020	3 days
Devise Plan to Fix Power Issues	T	02/19/2020	02/21/2020	3 days
Work As Group to Fix Power Consumption	T	02/19/2020	03/13/2020	18 days
Have Power Consumption Down to Where We Want it	M	03/13/2020	03/13/2020	-
Meeting to Discuss Project	M	03/13/2020	03/13/2020	-

Reassess Project on Feedback	T	03/14/2020	03/27/2020	10 days
Fix Final Issues Based on Feedback	T	03/28/2020	04/10/2020	10 days
Test Product/ Do Surveys	T	04/11/2020	04/19/2020	5 days
Final Changes/Revisions Based on Test Feedback	T	04/20/2020	04/29/2020	8 days
Finial Product Prototype	M	04/30/2020	04/30/2020	-

Table 2 - Project Timeline

The biggest part to getting our project done in two semesters is making sure we get some working prototype by the end of the first semester. It will be much easier than attempting to start from the very beginning second semester. That is why we have set it as a milestone on our chart. Also seen above, are the 2 different branches of work happening, with a third group helping with both: the software side, and the hardware side. The communication group gets a taste of both, but focuses on getting the data from one to the other. We then have a large section of time cut out for completing this document as well as preparing our presentation which will be on December 9th. Lastly, for this semester, we will try and get the base prototype working.

Once this is complete, our second semester will likely be split in half, one side working on getting the best data possible out of the heart rate monitor, and the other focussed on getting our power consumption lower. These may end up going hand in hand as reducing the noise from the monitor may take more power, but they are divisible in nature.

4.2 FEASIBILITY ASSESSMENT

Base functionality of reading an ECG by a small package device and transmitting to Android. Two-day battery life will pose significant challenges, but should be manageable before end of project. Motion noise cancellation will be worked on, but may not be implemented sufficiently.

4.3 PERSONNEL EFFORT REQUIREMENTS

Task	Hours	Explanation
Electrocardiogram hardware	80	Obtaining and maintaining a good reading
Arduino Communication	80	Connecting to the device with Bluetooth
Android Development	80	Creating an application for live readings and ECG data storage
Power Management	40	Finding ways to minimize power consumption
Noise Reduction	40	Using motion detection to eliminate ECG noise

Table 3 - Effort Requirements

4.4 OTHER RESOURCE REQUIREMENTS

Part	Ref./type of part	Cost	Quantity	Supplier	Supplier# / Part#
Single Lead Heart Rate Monitor	AD8232 PCB	$19.95	1	SparkFun	SEN-12650
Arduino Micro	Microcontroller	$20.63	1	Digikey	1050-1066-ND/ A000053
Single Lead Heart Rate Monitor	Sensor Cable	$4.95	1	SparkFun	CAB-12970
Bluetooth Mate 4.0 - HM - 13	Bluetooth Module	$19.95	1	SparkFun	SPX-14839

Table 4 - Components used in heart rate monitor

4.5 FINANCIAL REQUIREMENTS

Our client is a professor at Iowa State University and the funding to complete this project is solely based on the cost of the materials to build. These funds will be provided by the ECPE department.

5. TESTING AND IMPLEMENTATION

5.1 INTERFACE SPECIFICATIONS

Our project will use the Arduino Micro to interface between our hardware and software aspects of the project for the most part. The Arduino allows us to process the data from the electrodes and package it into a signal we can send using bluetooth. Once the bluetooth signal is in the air, the Android device will be able to receive that signal and process it into a graphical user interface to allow the user to view and interact with the data collected.

5.2 HARDWARE AND SOFTWARE

For hardware, we will have three biomedical sensor pads placed on user's chest based on Einthoven's triangle, which is the placement of sensors for electrocardiography, to detect bioelectricity and send to the monitor. Monitor will collect and process electrical signal, convert the analog signal to digital signal for Adurino. We will design the monitor with AD8233 chip as the core to achieve this goal.

For Communications, we initially started testing by setting up a voltage dividing circuit with a potentiometer and having the Arduino read the voltage and then send it to a phone. Then we used an app on the phone called Arduino Bluetooth Controller to read the data that was being set from the device. This test allowed us to see how we needed to set up our code to send data over to a phone. We are currently testing how reading the data from the ECG and figuring out how to processes the data to get rid of some noise in the system and to get a sampling rate that will be sufficient enough to give us an accurate reading of the heart beating.

For the software side we met up and tested our bluetooth connection with a simple LED circuit. The bluetooth device would broadcast a '1' when we wanted the Arduino to turn the light on otherwise it was off. Once we got that working it allowed us to see how to build off of that to get our signal transmitted instead.

5.3 FUNCTIONAL TESTING

Unit Testing	Putting all components together, hardware and software, to make sure everything works together properly.
ECG Testing	Understand how the ECG is picking up the signal; get an understanding of how to read the signal and process the data that is collected from the signal.
Bluetooth Testing	Understand how to send and receive data to and from the Arduino using the Bluetooth Mate 4.0.
App Testing	Stress test app by graphing data for long periods of time and compare the results with a live ekg reading. Have nontechnical users try app and get feedback on UI design.
Integration Testing	Connecting the ECG with the Arduino and having the data sent to app. Working on different ways to process the data that we are reading from the ECG to get out as much noise in our signal for when we try to plot our data points.
System Testing	Making sure that the bluetooth signal is being maintained through activities. Also making sure the user data is being saved under the proper account after the user logs into the application.

Table 5 - List of functional tests

5.4 NON-FUNCTIONAL TESTING

We have been working on different application layouts and designs to make sure that the application isn't confusing for the users. We will start working on more of the physical non-functional requirements next semester as we start to package our circuits up into its case.

5.5 PROCESS

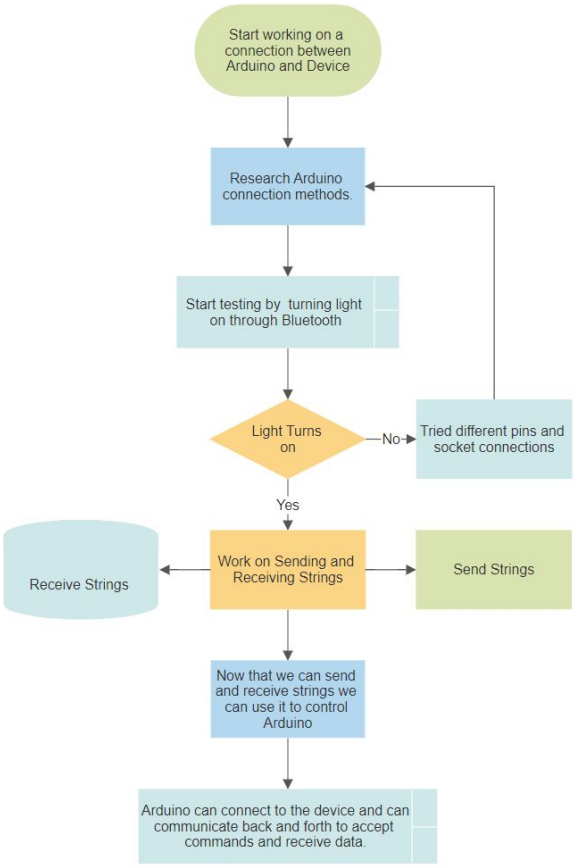

Figure 3 - Bluetooth Communication Testing

The testing we have done this semester from the communication and software side has revolved around the bluetooth connectivity. We started by establishing a connection and doing simple tasks to ensure it was working properly. The first test we did included using a potentiometer to send various voltage values over the bluetooth connection to ensure that the changes we were seeing had been caused by us. These various voltages were to simulate the effect we will receive from the heartbeat. After that, we used an LED light to ensure that we could send control signals between the device and the Arduino. Finally we hooked up the ECG and we were able to send commands to the Arduino from the device and the Arduino sent readings back to the device for it to graph.

5.6 RESULTS

From the software side, our biggest issue has been maintaining the bluetooth signal through various activities. We have tried creating app wide resources and passing data through activities but that can get messy. The next step for us is to take another look at using an app wide thread to handle the bluetooth connection. The local instance of the bluetooth activities have potential to work for now but after doing research many sources say this may not be the best practice as the connection can be dropped if the device enters a low power mode.

On the communication side, we were able to send the data over to the application where it was able to graph the results. Our biggest challenge is getting the Bluetooth Mate 4.0 programmed to the extent we need to get everything working properly with the application.

6. CLOSING MATERIAL

6.1 CONCLUSION

So far we have worked on determining the type of signal we are receiving and how to best turn that signal into usable data. There has been some noise issues while collecting a heart beat and we need to make sure we can eliminate that noise in our final data sample so that the user will have accurate values.

On the communication side we have had to work with the hardware and software sides to ensure that we are properly getting the data from the physical hardware to the software on the device without losing the data and ensuring it is not getting distorted in any way.

From the software side, we are developing an application which will be able to store the heart beat data at all times and also allow the user to view that data on their device for real time feedback. Since all of the data will need to be stored on the device, even while it is not being operated by the user we need to work with the communication team to make sure we are sending data as efficiently as possible. We will also hopefully be adding an option to upload the data to Google Firebase, a database which would allow the data to be more accessible. Firebase also allows for us to implement a more secure authenticated login by allowing users to use Google accounts, or other popular social media platforms to log into our app and verify it is truly them.

6.2 REFERENCES

"Documentation : Android Developers," *Android Developers*. [Online]. Available: https://developer.android.com/docs/. [Accessed: 08-Dec-2019].

6.3 APPENDICES

Bluetooth Mate 4.0 links:
Datasheet:
https://cdn.sparkfun.com/assets/c/5/2/7/8/bluetoothdual_en.pdf

Schematic:
https://cdn.sparkfun.com/assets/5/3/a/f/a/Bluetooth_Mate_4.0-x01-schematic.pdf