Bubz, a 12-lead Wire-free EKG

ECE 445 Project Proposal

Jack Rueth, Madhavan Nair, and Samhita Inampudi
TA: Josephine Melia

Section 1: Introduction

1.1 Overview

An electrocardiogram (ECG/EKG) is a graph of voltage versus time that measures the electrical impulses of the heart. This data is collected by strategically placing electrodes across the chest to determine the horizontal and vertical changes in electrical potential. The patterns that these impulses create gives doctors and other medical staff necessary insight on the functioning of a patient's heart. Deviations from the standard ECG pattern can mean a variety of cardiac issues, ranging from cardiac arrhythmias (abnormalities in heart rhythm) to compromised blood flow in the coronary artery to electrolyte disturbances.

The basic EKG measures the electrical signals of the heart to detect any medical anomalies and monitor the cardiovascular health of the patient. Essentially, the heart receives a series of electrical signals that are seen in the PQRST wave seen in Figure 1. The first P wave is the signal sent to the atria to contract, pushing oxygenated blood into the ventricles. This is called the Atrial Depolarization. The ensuing QRS complex, as it is called, is the electrical signal for the ventricles to constrict, sending the blood throughout the body, referred to as Ventricular Depolarization. The atrial repolarization also takes place at this time but is generally not seen due to the high electrical activity of the ventricle depolarization. Finally, the T wave contains the Ventricular Repolarization, where the ventricles reset and are ready to constrict once again.

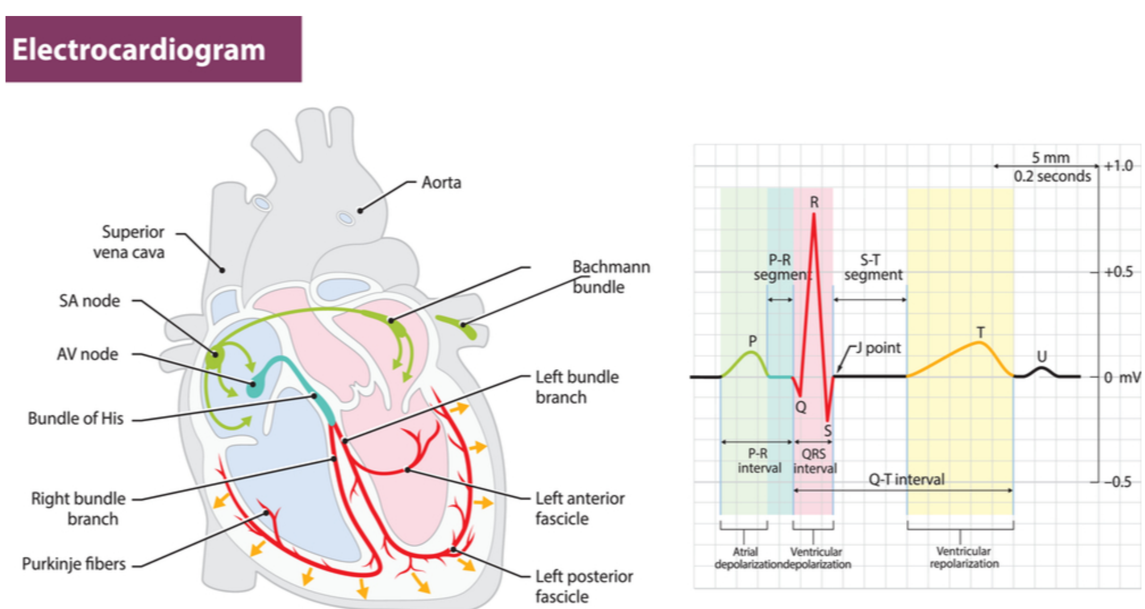


Figure 1. Diagram of electrical signals in the heart and how they translate to PQRST waves.

1.2 Problem

In a traditional 12-lead EKG, ten electrodes are placed on the chest and limbs of a patient as shown in Figure 2. As seen in the image, there are a lot of long, confusing wires along with heavy, bulky equipment. These wires frequently get tangled, and make it difficult for doctors to do their jobs quickly. According to Mayo Clinic, setting up an EKG can take between 10-20 minutes. While this may not seem like much of an issue on a relaxed day, in emergency cases, even a minute could be the matter of life or death. In addition to this, EKG equipment is generally bulky and hard to transport to underserved communities. This can mean decreased access to this test, which could mean compromised patient care in such regions.

Current attempts to address this problem include solutions like a product from KardiaMobile (shown in Figure 3). However, while this solution is incredibly user-friendly, it only provides a single lead capability, meaning that there is no way to see any of the data from the horizontal plane. In addition, other 12-lead solutions like AMD's still include wires to connect all of the electrodes together, and focus on transmitting data wirelessly over a long range for telemedicine applications.

Figure 2. Patient receives a traditional 12-lead EKG

Figure 3. KardiaMobile, single-lead wireless solution

1.3 Solution

Our goal is to build a 12-lead wire-free EKG that does not require any wires to transmit data from nodes to a computer. In our solution we want to create small suction bulbs to conveniently assess a patient's heart health. Each of these bulbs will contain a circuit board with wireless connectivity to transmit a PQRST wave in real-time to the data display along with a power supply (potentially rechargeable if time permits). Using Body Surface Potential Mapping, we can measure the electrical potential gradient at various points of the body to create a vector mapping including these 12 views from 2 different planes (vertical and horizontal). Each bulb would have to have some form of power supply and bluetooth/wireless transmission, in addition to the actual measurement mechanism/filtration process and data visualization. We hope that this solution would make the process of getting an EKG faster, easier, and more efficient.

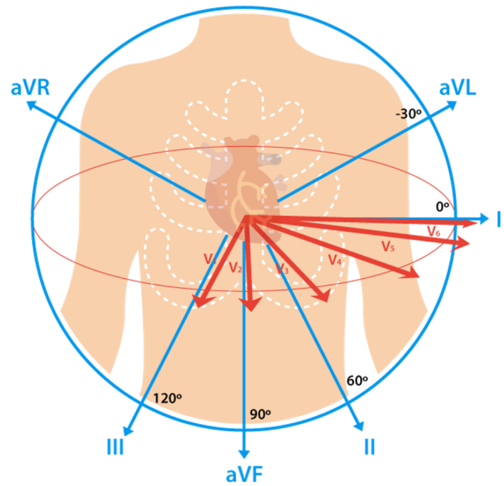


Figure 4. Vectors that show node placement in a 12-lead EKG

1.4 Visual Aid

While a whole 12-lead EKG would require a minimum of 9 bulbs, for the scope of our project, we want to focus on the creation of a single bulb that can accomplish the task of measuring the data and transmitting it wirelessly to create some data visualization with an associated timestamp. We hope that this project will be scaled up easily after the design of the bulb device itself.

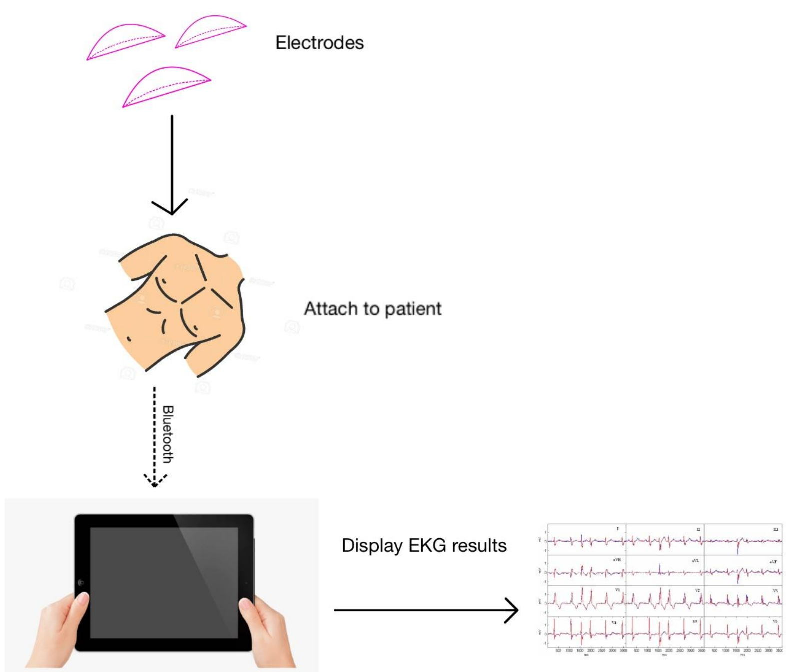


Figure 5. High-level visual representation of solution pipeline

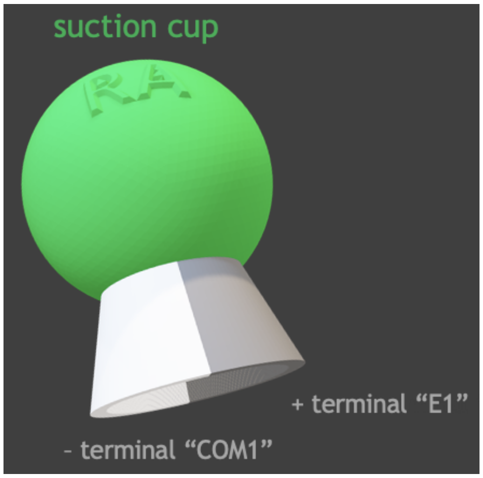


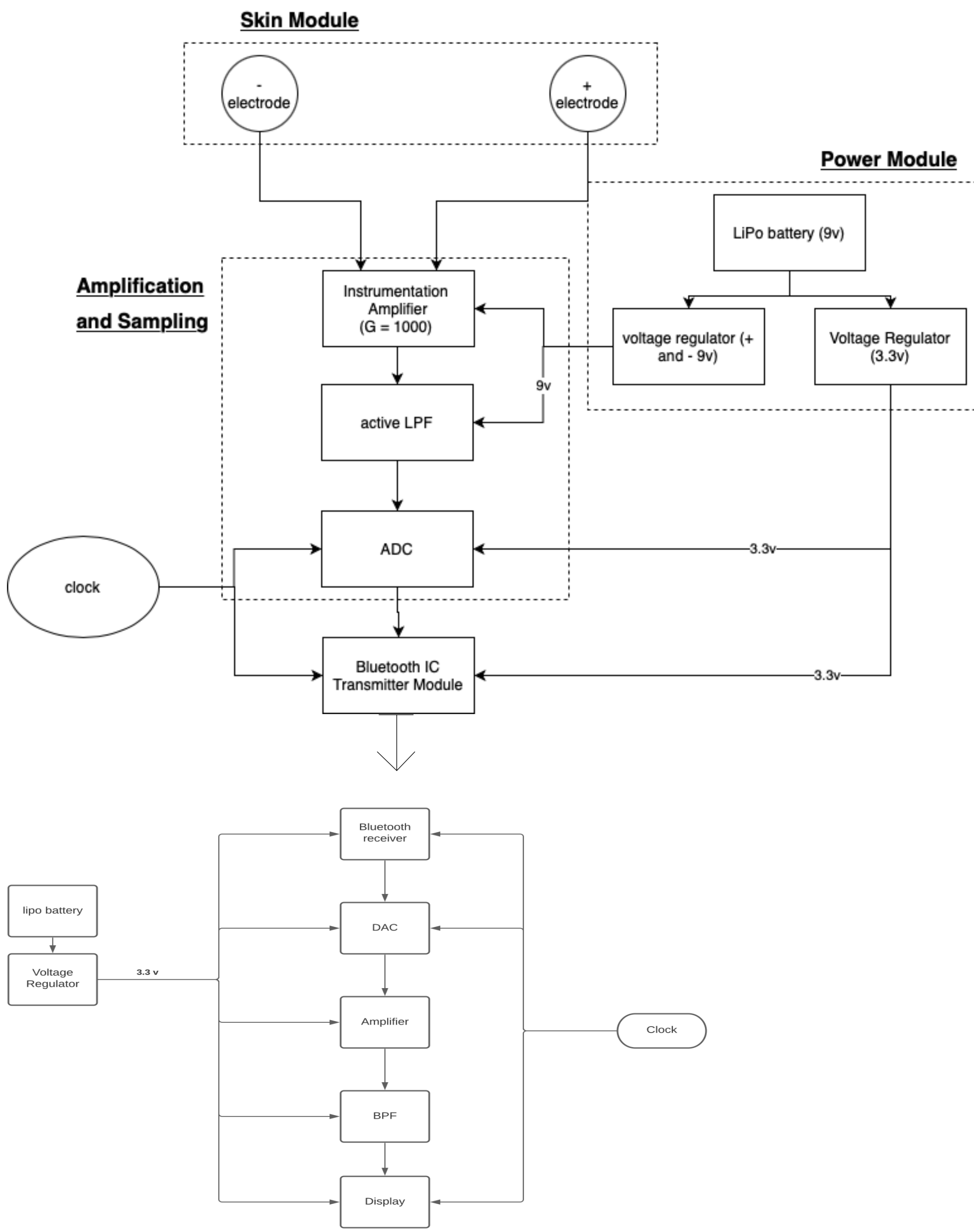
Figure 6. Potential design structure for individual bulb

1.5 High-Level Requirements

1. Accurately display PQRST waves in range between 0-0.5 mV for at least 5 seconds.
2. Bulb should measure electrical potential difference and sample at Nyquist frequency of 500Hz
3. Data transmission should include a minimum of 20 samples per ECG grid box.

Section 2: Design

2.1 Block Diagram



2.2 Subsystem Overview/ Requirements

2.2.1 Control Unit:

Microcontroller: Instrumentation Amplifiers will take the electrical signals measured from the electrodes. From here the signals will be sent through the low-pass filter to filter out the noise and clean up the signal. Next our signal will be sent from the low-pass filter to the analog to digital converter. This will convert our analog signal to digital so that we can view the PQRST wave on our display. One of the most important parts of this analog to digital converter is the speed at which it converts the signal.

Requirement: Signal will be sampled at a Nyquist frequency of 500Hz.

2.2.2 Bluetooth Module/RF Transmission;

From the Microcontroller, we need to send our digital signal to our display in order to view it. In order to achieve this our bluetooth module will receive the digital signal from the microcontroller and send it to the transceiver module. In the case that we can’t use bluetooth to transmit the data, our plan is to use RF transmission in order to send the signal. Once our signal is received from either the bluetooth or RF module, it must then be put through a digital-to-analog converter. From here the signal will be sent to an amplifier and a band pass filter to clean up the signal before we display it on our screen.

Requirement: Ensure proper and accurate data transmission by requiring no more than 5% of data packets dropped over an interval of one minute with physical distances of transmission being typically around 5 feet but up to 15 feet on occasion.

2.2.3 Power Supply:

The power supply module is essential to supplying power to the microcontroller in order to send the signal to our display. We expect our power supply to provide 9V of power in order to provide the sufficient power necessary for our control unit.

Requirement: Power Subsystem must be able to supply 9V to the rest of the system continuously during operation

2.2.5 Skin Module:

Our bulb will attach to the skin of the user. Through the use of suction, a vacuum will be created, holding the device to the skin tightly and ensuring a proper electrical connection between the mental contact pads and the skin. These electrodes will gather the potential difference and send this signal to our control unit.

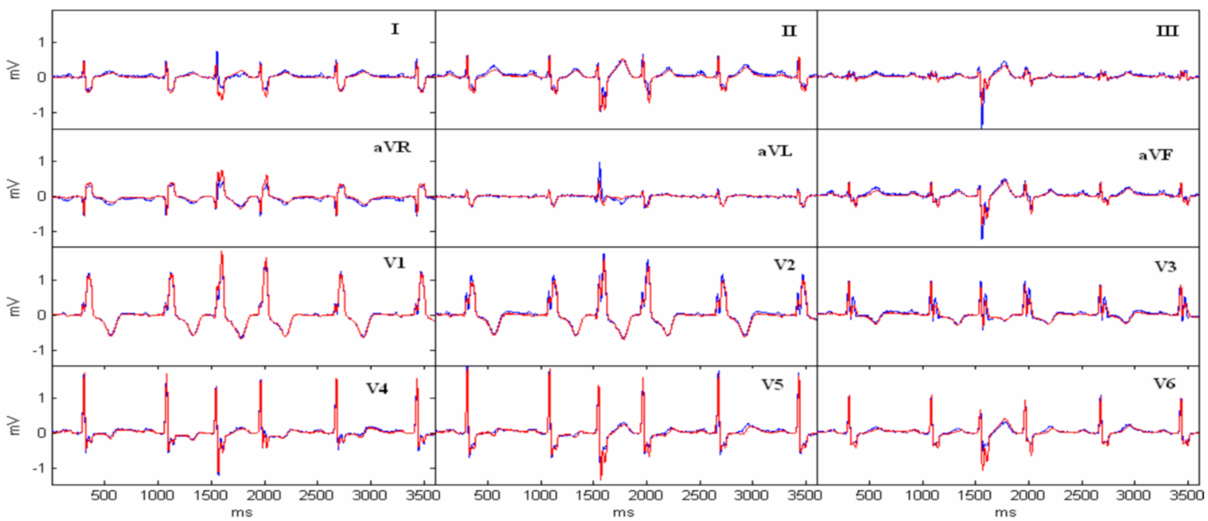
Requirement: Skin attachments should stay within 20-37 degrees C (between room temperature and body temperature)

Requirement: Bulb must constantly adhere to skin, specifically metal contacts that have strong electrical connection over the entire time interval of use.

2.2.6 Data Visualization Module:

Our display interface will have a graphical display of our signal in a PQRST wave form. An image of this wave is shown below. As the signal comes in from the receiver it will be put through an algorithm that will display the wave and the timestamp.

Requirement: PQRST wave will have 20 samples per EKG box



2.3 Risk Analysis

The biggest risk to the completion of this project will be the bluetooth/RF module and receiver. These units are responsible for sending and receiving the signal from the electrodes and to our display. While we think the general range of 1-2 Mbps will be sufficient for the needs of our project, we are concerned that the data transmission may not occur at a satisfactory level. On top of this, we have a very tight size constraint as the general size of an EKG bulb is a few centimeters wide. Since we are choosing to measure the electric potential across a slightly larger area to be able to reuse the bulbs, we don't have to follow the constraint of a few centimeters as strictly, but portability is a defining factor of our project and we have to be mindful of this success criteria while making design decisions. In addition, a big challenge for creating wireless EKGs is that there is no clock signal shared between all 9 or 10 electrodes, which makes time synchronization difficult across multiple electrodes. We hope to address this challenge by rearranging data as it appears to our data visualization subsystem, so that data associated with a certain timestamp will be reordered to appear before later time stamps.

Section 3: Ethics and Safety

When building our project, there are certain ethical issues and safety precautions that we have to consider. Since we are creating a product that will be used on the human body, we need to ensure the safety of all patients. Especially when handling electricity, we must make sure the voltage of our battery maintains safe levels of exposure to the human body so that it does not harm our user when they are getting an EKG. Specifically, we need to make sure that we follow Section 1.2 of ACM Code of Ethics: Avoid harm. We deeply understand the ramifications of injuring a patient, even unintentionally. We hope to exercise extra caution to ensure the safety of our users and follow all relevant regulatory standards. Since our product is being used on humans, it is imperative that we follow this code. In terms of ethics we must abide by 7.8 of the IEEE Code of Ethics. Thus we must uphold the highest standards of integrity, responsible behavior, and ethical conduct in professional activities. As we are working in a group it is critical that we treat all persons fairly and with respect, avoid injuring others, and to not engage in harassment or discrimination. Finally it is vital that we all support our co-workers.

Sources:

https://www.mayoclinic.org/tests-procedures/ekg/about/pac-20384983
https://amdtelemedicine.com/product/12-lead-digital-wireless-ecg/
https://store.kardia.com/products/
https://www.ieee.org/about/corporate/governance/p7-8.html
https://www.acm.org/code-of-ethics