Contactless Measurement of Electrocardiograms using Millimeter-Wave Systems

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Background

Cardiovascular disease is the leading cause of death in most developed countries and accounts for 1 in 5 deaths in the United States [1]. To diagnose heart conditions, doctors observe a patient's heart to ensure it is functioning correctly and has a proper sinus rhythm through an Electrocardiogram (ECG/EKG), which is a recording of the heart's electrical activity as a graph of voltage over time. During each heartbeat, there is a cycle of muscle polarization and depolarization that can be measured as a change in voltage, and the resultant waveform contains general P, Q, R, S, and T waves [2]. The P and Q/R/S waves correspond to the depolarization of the atria and ventricles, while the T wave corresponds to the polarization of the ventricles. Diagnosis of cardiovascular conditions from the ECG/EKG is typically done by pattern recognition, as most common conditions have very distinctive patterns. Deviations from the typical patterns are general indicators of an arrhythmia such as atrial fibrillation [2–4].

Typically, an ECG is performed using 4, 6, or 12 leads placed on the body to measure specific areas of the heart (see Fig. 1). Current ECG systems require adhesive electrode patches to be used for each lead. These patches can be very invasive, uncomfortable, and cumbersome for patients. They can also damage the skin upon removal. During cardiac stress testing, such as running on a treadmill, these wires can get in the way of the patient's range of motion. Newborns are especially susceptible to injury and can become entangled in the wires, including those in the Neonatal Intensive Care Unit (NICU), so placing these electrodes can be dangerous. Contactless monitoring solutions are necessary alternatives to improve patient safety while they are under care.

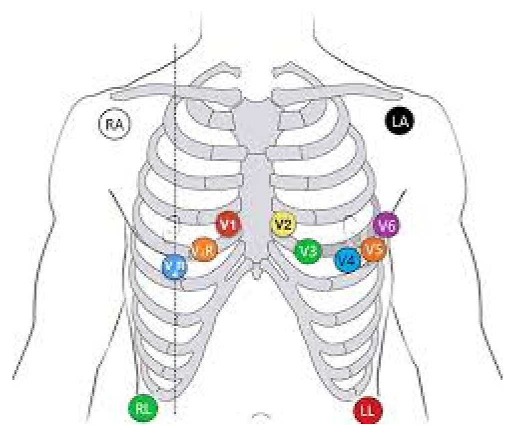

Figure 1: *12-Lead ECG Placement [5]*

Fortunately, millimeter-wave (mmWave) technology offers a safe and cost-effective solution. Millimeter-wave radars work by transmitting a Frequency Modulated Continuous Wave (FMCW) and then measuring how the reflected wave changes due to movement or material properties. As the atria and ventricles polarize/depolarize, they cause very small but unique vibrations signature in the skin that can be detected with mmWave radars [2]. Since the ECG readings directly correspond to the heart movement, we can build a deep learning model to correlate the reflected signals and output an ECG waveform [6] by learning several examples of time-synchronized ECG and mmWave reflections.

Research Question

How can we use a millimeter-wave system to provide contactless electrocardiograms?

Project Goals and Objectives

The goal of this project is to create a system to synchronously collect both mmWave signals and ECG data from volunteers. We will then use this data to train a deep learning model to predict a heart's electrical activity purely from mmWave signals without using the traditional lead-based ECG. Our objectives are as follows:

(1) Design a hardware setup for synchronously collecting mmWave and ECG data.
(2) Collect and analyze mmWave and ECG data from various volunteers.
(3) Identify patterns associated with the mmWave and ECG data and design a deep learning model for predicting an ECG waveform only from mmWave data.
(4) Test the model on its ability to generate accurate ECGs on various volunteers.

Project Significance

5G and beyond networks are changing the way people communicate and allowing for new innovations. These modern networks are designed at a much larger frequency spectrum than traditional networks, including the 77-81 GHz frequency range used by mmWave. This high frequency allows us to gain a much higher sensing resolution than many other sensors. Since we are sensing at the same frequency as mobile networks, this technology can be integrated with smartphones and home access points in the future. This opens up applications in many areas like at-home healthcare [7].

Project Design

This project will be divided into 4 phases:

In the ***first phase***, we will construct the setup for data collection. This setup will consist of a Spacelabs 91393 Xprezzon ECG monitor [8] and a TI mmWave device [9]. We have a preliminary setup that uses an Analog Devices AD5940BIOZ ECG board [10] and the mmWave device to act as a proof of concept. We will purchase the Spacelabs monitor to act as a more accurate ground truth. We will collect data by having volunteers place the traditional ECG leads on their body and then sit in front of the mmWave radar. We first configure the mmWave device to begin transmitting wireless signals and after the setup is complete, we will use a microcontroller to introduce an artificial spike in the ECG waveform and act as a hardware timer to synchronize the mmWave device. This synchronization is important as it will allow our model to better correlate the reflection data with the ECG waveform. We plan to collect data from 30 volunteers of different body types to ensure the setup will work across different types of people. We will also conduct 10 or more trials for each volunteer at rest, during, and after exercise. We plan to conduct trials on volunteers with known heart conditions as well.

In the ***second phase***, we will begin to analyze the data we collected. A basic component of this analysis is the preprocessing of the mmWave reflection data. This works by taking a Fast Fourier Transform (FFT) of the data and calculating the Doppler Shift to find the velocity of an object, which will allow us to find the micro-vibrations during each heartbeat. We can also use this to filter out the static elements of the scene such as furniture and walls. As the data is collected, we will assess the validity of the observed ECG waveform and the dynamic movement detected from the mmWave device. We will also ensure both devices are producing time-synchronized data to ensure our reflection to ECG waveform mapping will be correct. If we encounter issues, such as body micro-vibrations being filter out by the FFT, we will adjust our data collection as needed.

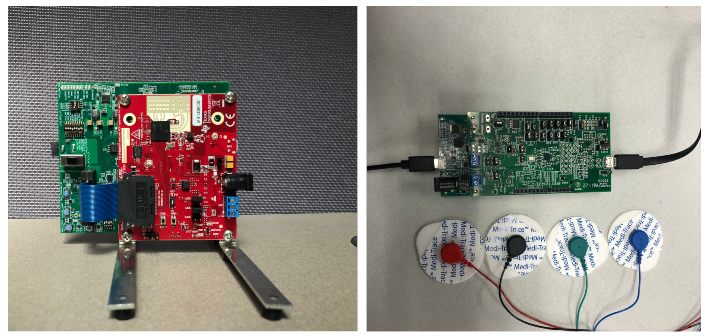

Figure 2: *(a) Millimeter-Wave Device [9] (b) AD5940BIOZ ECG Board [10]*

In the ***third phase***, we will design a deep learning model to correlate the mmWave reflection data with the recorded ECG waveforms. Specifically, the vibrations caused by the different heart valve movements will be correlated with the electrical P, Q, R, S, and T waves from the ECG. Since the electrical change in the heart is what causes the heart muscle movement, there will be a direct correlation between the movement and electrical signal data. This model will be trained with the collected reflection and ECG data.

In the ***final phase***, we will then test this model by feeding new volunteer reflection data and comparing the predicted ECG with ECG data from the ground truth device. We will ensure the model accurately predicts a person's ECG waveform regardless of their physical health or heart rate range. We will also ensure that the model will still produce accurate results even when the subject is moving. Since we intend to deploy this in medical environments such as hospitals or ambulances, the accuracy of this device is vital.

Project Timeline

The following table shows a tentative timeline for this project.

Task	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Complete Setup	X				
Collect Data	X	X			
Build and Test Model		X	X	X	
Prepare and Submit a Manuscript				X	X

Final Products and Dissemination

The end goal of this project is to develop a system that will be able to wirelessly measure ECGs using mmmWave. This system can be implemented in hospitals, emergency vehicles, and care facilities to continuously monitor patients without the need for physical contact. We hope to submit our findings as a paper to the ACM MobiSys conference [11] or the ACM IMWUT journal [12]. We will also present our research at Discover USC.

Personal Statement

I have been involved in research with Dr. Sur at the SyReX lab [13] since the Spring of 2023 during my freshman year. I joined the lab with an interest in autonomous vehicles, but the numerous projects the lab is engaged in have allowed me to explore other areas of research, including healthcare. I came into the lab with a limited understanding of wireless communication, signal processing, and machine learning, but I have learned a lot during my time here. Since joining the lab, I have had the opportunity to work on a variety of projects, including the MilliCar project [**?**], which aims to use millimeter-wave technology to detect the presence of pedestrians and other cars on the road. Ultimately, I hope to pursue a Ph.D. in Computer Engineering and continue to do research in the future.

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