HEAR DEVICE FOR ELECTRICAL ACTIVITY OF THE HEART: COMPUTATION TOWARDS CARDIOVASCULAR DISEASES USING NOVEL COMMA-Z CLASSIFIER AND GPU FOR AUTOMOTIVE

by

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Dedicated to my mother, father, and brother,

Mrs. Suvarna Sinnapolu
And
Mr. Sudhakar Sinnapolu B.COM D.J
And
Jagadish Sinnapolu M.S M.B.A

As a Family we shared everything from happiness to sadness from easygoing to hardworking along with affection, love, encouragement and prays of the day and night made me able to get such honor and success in life.

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Giribabu Sinnapolu

ABSTRACT

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Adviser: Shadi Alawneh, Ph.D.

The silent heart attack which is also known as silent myocardial infarction occurs in almost 45% of the heart attacks and strikes men more than women. Women have less tendency to get sudden heart attack or heart failure or arrhythmias due to the menstrual cycle hormone released by their bodies until certain age. However, studies also show that higher risk of cardiovascular events are found both in men and women. During the phase of myocardial infarction patients develop Ventricular Fibrillations or rapid Atrial Fibrillations which may lead to the risk of death in a short period of time [1]. Covid-19 also induces arrhythmias and myocardial injury and acute coronary syndrome [2]. The average time spent by a person behind the wheel is approximately 1 hour on an everyday basis for a 30 miles drive. The Driver and Vehicle agency promotes that a driver with heart arrhythmias require approval from medical professionals to drive and based on today's estimation most of the drivers are likely to get into an emergency or accident or collision due to Cardiac Stress, Hypertension, Cardiomyopathy, or complications after Angioplasty. There is a tremendous increase worldwide for wearables devices ranging from 325 million in 2016 to 929 million by 2021 and now 1 in every 6 Americans are

using a wearable device, automakers are trying methods that involve measuring heart data via seat sensors and steering wheel sensors. Finally, my contribution in this research comprises of inventing a circular earlobe device (HEAR) placed to the earlobe that sends enormous amount of heart related photoplethysmography (PPG) data to the in-vehicle GPU device and invented a method to observe, compute, analyze, predict, and study AF and VF arrhythmias along with NSR using novel COMMA-Z filter, Signal Differentiation and DFS filters while driving. Such a sensitive work requires thorough communication and discussion with medical professionals for correctness of final heart computed data so based on the various experiments and clinical trials conducted this research was extensively supported by well-known surgeons from Beaumont hospitals, Michigan. The HEAR device also helps in long term monitoring and study of AF and VF tachycardias and related heart conditions because it’s all about timing for heart conditions and diseases as these tachycardias may lead to occurrence of ischemic stroke and cardiac arrest and complete heart failure and other dangerous conditions.

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LIST OF ABBREVIATIONS

CUDA	Compute Unified Device Architecture
GPU	Graphical Processing Unit
CPU	Central Processing Unit
COMMA-Z	Continuous Median Moving Averaging-Zero crossing Detection
CNN	Convolutional Neural Network
CV	Computer Vision
NSR	Normal Sinus Rhythm
BPM	Beats Per Minute
VF	Ventricular Fibrillation
AF	Atrial Fibrillation
PPG	Photoplethysmography
ECG	Electrocardiogram
EEG	Electroencephalography
HEAR	Heart to EarLobe
IoT	Internet of Things
LED	Light Emitting Diode
I2C	Inter Integrated Circuit
STM32	ST Microcontroller 32 bit
ABP	Light Detection and Ranging
CDC	Center for Disease Control and Prevention
EEMD	Ensemble Empirical Mode Decomposition

LMS	Least Mean Square
SDK	Software Development Kit
CMOS	Complimentary Metal-oxide Semiconductor
IRED	Infrared Emitting Diode
DFS	Depth-First Search
OTA	Over the Air
LTE	Long Term Evolution

CHAPTER ONE

INTRODUCTION

The Population in the United States is majorly affected by the high rise of chronic diseases. However, US health care is facing a significant challenge in the increasing cost in managing the chronic diseases [3]. It is estimated that it costs US health care $315.4 billion in 2010 [4]. The cardiovascular disease is the most common disease affecting 611,105 Americans annually [5]. The cardiovascular disease may be due to high blood pressure, stressful environment, alcohol consumption [6]. Due to the tremendous increase in the technology, and using wearable sensors, the cost can be reduced by monitoring the patients remotely and assisting them with appropriate guidance [7]. The usage of wearables devices worldwide increased from 325 million in 2016 to 929 million by 2021 and now 1 in every 6 Americans use a wearables device [7].

In 2017 three American physicists Rainer Weiss, Barry Barish, and Kip Thorne won Nobel prize in physics for GPU powered Gravity Wave Detection [8]. GPUs are widely replacing CPUs for various applications that require heterogeneous computing capabilities in the field of Automotive, Medical, Industrial and Aerospace. Today the most widely used speech recognition algorithm is implemented with highly advanced computing level techniques using both CPUs and GPUs [9]. In recent years GPU computing platforms have emerged as a viable execution platform for throughput related applications [10] [11] [12].

Measuring of the blood volume circulation variations is one of the most challenging and important tasks and this kind of methodology is called photoplethysmography and this methodology due to technology and various potential sensing capabilities is widely used in the most recent times. Devices with PPG technology are used for early screening of various heart diseases and related conditions [13]. There are many heart diseases, but Ventricular Fibrillation and Atrial Fibrillation arrhythmias are one of the most dangerous diseases that require thorough screening on everyday basis for patients or users with the history of known heart conditions and diseases. This work here focuses on these two widely emerging and dangerous arrhythmias. There are methods out there that predict atrial fibrillation without pulse detection, but noise and vibrations and various environmental conditions will increase the uncertainty of screening or analyzing such diseases [14]. To implement this innovation in a better way the research work involves development from ground up as seen in Figure 1 i.e from the sensor implementation and placement on the surface of the skin to the GPU computing using averaging filters. The research work comprises of a HEAR device also called as circular earlobe device, as observed in Figure 1 it is placed at the earlobe that outputs highly potential heart related PPG data to the GPU device to compute, analyze, predict and study heart data activity comparing normal sinus rhythm and arrhythmias such as AF and VF that may have occurred due to myocardial infarction or cardiomyopathy or any related health history or complications in heart surgeries, in real-time on an everyday basis. The overall proposed system design is introduced in this section to understand briefly about the overview of the entire system pipeline as shown in Figure 1. The classifier COMMA-Z is a filtering technique applied to the highly sensitive industry certified bio PPG sensor part of the HEAR device placed at the earlobe and computed using Graphics processor unit (GPU) while the patient or the user is resting, standing, walking, and driving. In Figure 1 we can observe the overall proposed system design. In Figure 1 the raw heart data is sent to the HEAR device of the driver wherein the data is sent via wi-fi to the GPU to compute using the novel COMMA-Z, Signal Differentiation and DFS Filters. The final Output from the GPU shows the AF/VF signals and NSR signals.

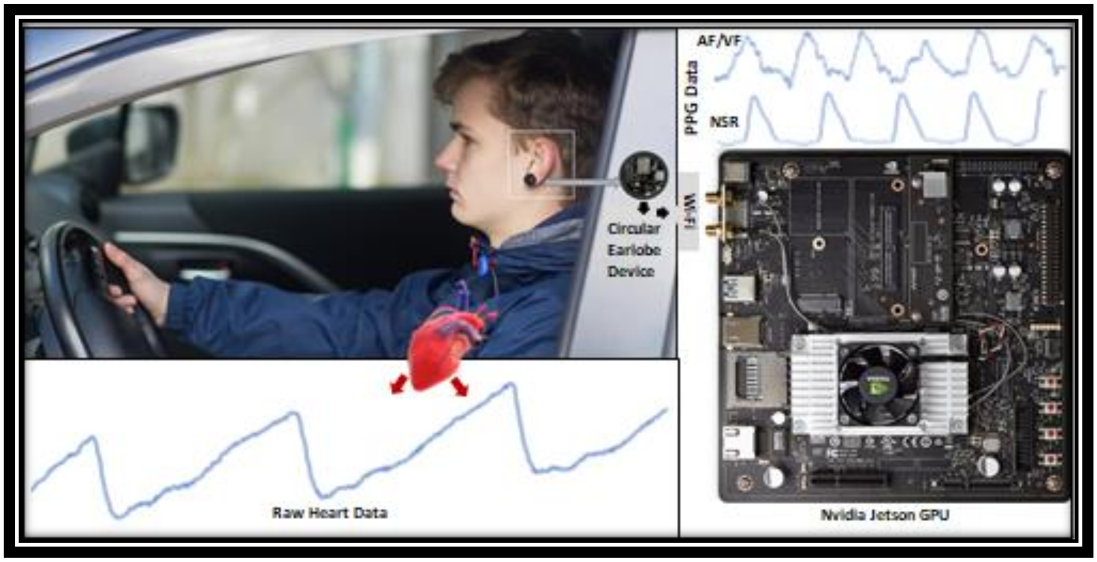

Figure 1 Overall Proposed System Design using Earlobe(HEAR) Device

1.1 <u>Research Topic</u>

Based on today's estimation most of the older drivers are likely to get into an accident or collision based on their varying health and heart conditions or diseases while driving. Nowadays, middle-age and younger drivers are also facing similar issues. Timing is everything when the symptoms are predicted and the faster its diagnosed better the survival. Myocardial arrhythmias have led to various occurrences and once such widely occurred are the atrial and ventricular fibrillation conditions. Hence, this current work developed the study for cardiac rhythms and the electrical activity of the heart and for few of the most critical cardiac arrhythmias occurred due to myocardial infarction or cardiomyopathy that may have developed over the time. This current work is for patients or users who are non-drivers and can be used in clinics and hospitals. This work implies to incorporate driving scenario as the main theory because today's cars are IoT on wheels and these machines or robots can easily be designed to understand the patient or user's medical conditions in a better way. It's good to have a machine or a device monitoring us on an everyday basis because on an average humans spend not less than an hour behind the wheel every day [15] and a lot can be done while driving. Studies show that drivers who had crashes that have been precipitated by medical emergencies are not related to vehicle design or roadway integrity as indicated by the type of crashes and manner of collisions. Six in ten Americans live with at least one chronic disease like heart diseases, heart surgeries and dangerous health conditions. While driving most of these conditions may arise for drivers who are precipitated by chronic conditions, especially the stroke like ischemic stroke and intracerebral hemorrhage stroke. Automakers are trying methods that involve measuring heart data via seat sensors and steering wheel sensors, but for measuring sensor data also requires better region for placement of sensors on the surface of the skin. The research is also developed to be focused towards comparing, measuring, observing, predicting, and analyzing heart data for most critical cardiac arrhythmias along with related history of heart complications before and after heart surgery using invented COMMA-Z filtering method. The work comprises of implementing a high-resolution HEAR device with programmable LED current at the earlobe for raw heart data. Apple watch is one of the most accurate heart rate sensing devices in the market with less than 2% error rate, Apple watch is in fact better than seat and steering wheel measurements designed by vehicle OEMs, but Apple watches are still not medically certified and approved to measure full potential heart related conditions and diseases [16]. Hence, the current research work invented a device called circular earlobe or HEAR(Heart data from EarLobe) device to show better computing of heart data using GPU than an Apple watch or any other devices in the market because the HEAR device is integrated to in-vehicle infotainment section of the vehicle that consists of high computing processors(GPU Processors). The standalone cloud-based GPU board can also be stationed in the servers for clinics and hospitals, this data is sent to medical professionals to monitor the patient accordingly on a daily basis due to his/her history of heart conditions or to observe any arising heart conditions or in case of any surgeries. The HEAR device can also be used outside of the transportation segment such as in clinics and hospitals but require a high computing GPU. The GPU is designed to compute the novel filters in this research. The GPU processors are always part of today's vehicles that are driven on an everyday basis and is not an added cost to develop this work. Today GPUs are widely used for sequencing the novel coronavirus and the genomes of people who are affected with COVID-19. The post infectious Myocardial Infarction caused by any viral diseases that occur after certain period of time after any infection have led to ventricular fibrillation due to blood clot formations in the heart. Part of this research and development contains implementation to collect raw heart rate data samples from fingertip, earlobe and process those results using CPUs and GPUs. In this research for comparisons the raw heart rate data is collected using a photoplethysmography method both for earlobe and fingertip. The HEAR device shows its potential capabilities when placed at earlobe than fingertip. Finally, of all the cardiac arrhythmias and after thorough research and discussion with medical professionals this study concluded to address atrial fibrillation and ventricular fibrillation conditions that fall under tachycardias part of arrhythmias. The development work includes some extensive clinical trials and computations. To conclude, this research comprises of two inventions one is the HEAR device for the earlobe and the other is the novel COMMA-Z filter implementation using GPU.

1.2 Motivation

Driver & Vehicle Agency is promoting that road safety has been established for drivers who have medical conditions, these drivers require to satisfy medical standards of fitness for safe driving while seeking doctor’s approval to start driving after major heart condition or surgery or to observe for any complications after angioplasty [17].

The road is always dangerous for people who are texting, eating, changing stations, but there is not much attention on the growing number of people having heart attacks or cardiac arrests while driving [18]. Considering the coronary heart disease as the biggest killer in the heart disease family it is estimated that there is still a very high number of heart attacks but if it happens on road while driving or travelling it is nearly impossible to assist a patient or user and gain control in case of emergency [19]. One of the most common manifestations of coronary heart disease is the silent myocardial infarction. Coronavirus disease and hypertension along with coronary artery diseases are associated with high mortality rate [2]. Heart failure was one of the most observed complications of COVID-19, with a reported incidence of 24% in all patients and 49% in patients who died [20].

However, while driving monitoring the patients or user's condition after heart related surgeries and predicting and analyzing their heart related conditions in case of emergency can be solved by Photoplethysmography concept using HEAR wearable device along with the help of medical professionals. In Figure 2 the temporary pacemaker is used and is widely used nowadays to generate the electrical pulses when needed for the heart. The pacemaker is used to understand all the heart related signals and is used only as a reference in this work. HEAR device can observe and analyze these scenarios and provide studies for the betterment for heart data computing using a GPU.

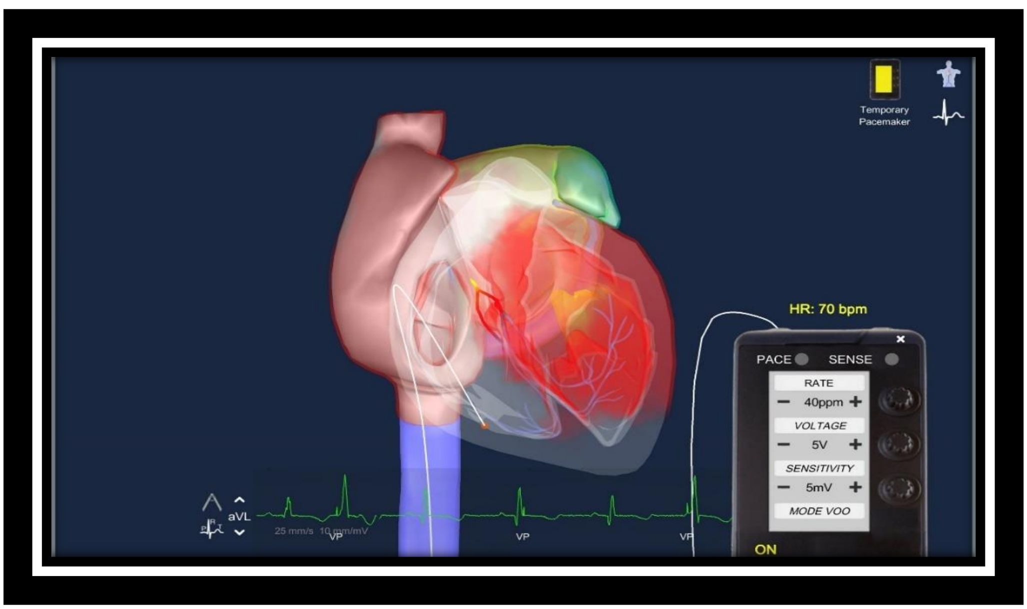

Figure 2 Heart and Temporary Pacemaker Simulation [21]

A patient with silent myocardial infarction and who has undergone angioplasty [22] is required to be monitored on everyday basis for certain number of days because conditions and emergencies do occur even after they are treated. In Today's technology advancements we know that vehicles are one such machines that comprises of powerful processor such as a GPUs. To investigate the symptoms for arrhythmias the trigger points for such conditions would be depression, anxiety, cardiac stress, medication and other related health conditions and monitoring heart data daily while driving will help understand the rise of heart diseases and conditions. High performance computing requires intensely challenging method and tasks to compute. In the recent days, researchers and physicians have come a long way in inventing various types of wearable devices for health monitoring which makes it easier for medical professionals for monitoring patients. Considering a situation, when a patient or user is mainly driving, his/her health cannot be monitored on daily basis in real-time or assisted immediately in case of emergency due to enormous drawbacks in the communication or the reporting system which is of today's prime issue. If a patient had a heart disease history and had a major surgery such as angioplasty or shunt replacement, they required to be monitored daily for betterment to observe for any complications which is also part of the prime issue, apart from monitoring VF and AF. Apple watch and third-party sensors may help monitoring and solve the issue to some extent but inventing a solution from ground up using high performance real-time GPUs and computing along with highly sensitive HEAR device while considering portability and robustness will solve the prime issue. Research in any field of study requires analysis and comparisons or real-time prediction to extract useful information which are one of the challenges of the prime issue. There are various heart related diseases and conditions which require in depth study and understanding. Consider if invented a network of heart related data and maintaining the history of the driver or passenger heart related data throughout his lifetime while driving, this concept does lead to various health related studies, outcomes, and predictions and such a concept with enormous amount of data may also be used for GPU computing for betterment. This current work focus is to develop the system for a user, patient, driver, or passenger while resting, walking, standing, or driving but this work mainly considers only while driving because in today's vehicles the GPUs are inbuilt and can easily compute enormous amount of heart data on daily basis in real- time with no extra development cost except for the HEAR device. Most of the third-party devices and apple watches have high computing capability too but to perform computing using advanced algorithms on daily basis in real time consumes enormous amount of power and resources. The HEAR device can be used to perform all the data computation activities at home, clinics, and hospitals too but require a standalone GPU hosted on a server, the reason behind choosing vehicles is because it's the only robot on wheels that consists of existing powerful computing processors that we live around and travel with on an everyday basis. If the computation requires to be done in clinics, hospitals, and homes then a dedicated GPU needs to be hosted and integrated to the cloud or to any handheld GPU device for computation. It's just not the GPU but also design and development of novel averaging filter from ground up called the COMMA-Z filter. There are various heart related conditions that prevent a driver or passenger from driving [23]. In this extremely busy world various health related factors will always play a major role and this work invents solution to solve one such occurring problem by continuously monitoring it.

Based on the American driving survey an average person spends nearly an hour behind the wheel every day [15]. Hence, considering all the scenarios and situations, this research is about developing a system from ground up as mentioned earlier as HEAR device which is a circular earlobe device that is placed at the earlobe to input highly potential raw heart related data to the GPU device to compute, analyze, predict and study certain chosen heart related arrhythmias and conditions on a daily basis in real-time, based on research studies it is known that myocardial infarction over 5 years of observation consisted signs of ventricular fibrillation and atrial fibrillation arrhythmias. During the phase of myocardial infarction patients develop ventricular fibrillations or rapid atrial tachycardia which may lead to the risk of sudden death in a short period of time [1]. Hence working towards these two dangerous arrhythmias is a motivation and it would not be possible to study these diseases without the HEAR device, novel COMMA-Z filter and the GPU.

Developing the HEAR device from ground up and integrating the heart data to the GPU to compute novel COMMA-Z filter classification to observe, predict and analyze these two dangerous arrhythmias while driving was the most challenging task in this research work.

1.3 Methodology

In this research work, the sensor abstraction and its capabilities when placed at the fingertip and earlobe region are shown in Figure 3. To prove that the results have practical potential, outstanding filtering techniques and methodologies are applied using the GPUs. Filters being a class of signal processing always helps innovate newer technologies with unpredictable outcomes, using filtering techniques there are always various ways to solve a problem. The moving average filtering technique is the most commonly used for averaging an array of sampled data but here the development work reconstructed the traditional moving average filter with a slightly different averaging filter method called the continuous median-moving average filter where the system design and experiments will prove that the novel filter technique is better than the traditional moving average filter. In addition to this theoretical analysis of filters combinations such as Kalman filter, Gaussian filter, LMS algorithm and exponential smoothing's were applied but seems like none of these filters helped build a promising and solid study. After tremendous amount of research work, the zero-crossing detection, signal differentiation and DFS methods were concluded to be used [24] which helped predict, study and analyze arrhythmias better than other filters mentioned earlier. These filtering techniques using heart related data is implemented and compared using both GPUs and CPUs.

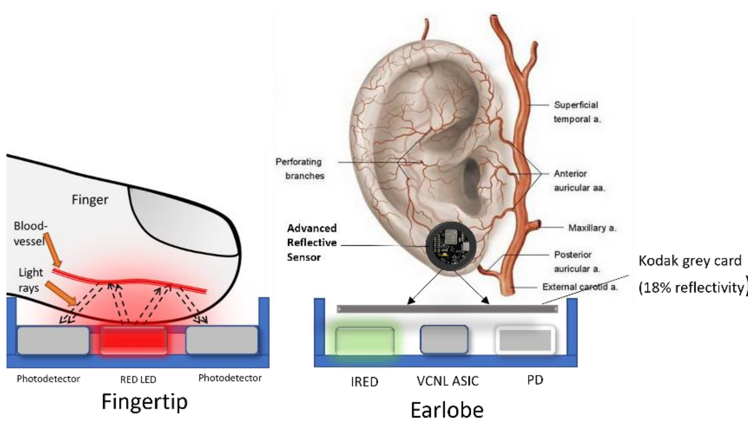

Figure 3 Fingertip and Earlobe Sensor Placement [25] [26]

However, the filters using GPUs are slightly altered as per the GPU framework and CUDA programming techniques to optimize and output tremendous results. The experiment sections conduct Human trial scenarios while a patient or user is walking, resting, and driving considering other environmental conditions and scenarios. In this section the sensor methods are used to compute raw heart data for atrial and ventricular fibrillation arrhythmias and discusses about sensor implementation. The methodology used to collect heart data is via earlobe, but fingertip is also used in hospitals widely now a days. However, the varying signals and noise corrections can be applied widely in earlobe as well than compared to the fingertip due to enormous blood vessels in the earlobe region because the red light penetration is much deeper into the skin allowing multi-spectroscopy approach for better sensor accuracy [27].The fingertip measuring waveform and the earlobe measuring waveform vary slightly, both represent waveforms with R-peak, systolic and diastolic states. The HEAR device to the earlobe consists of PPG sensor and a particle photon IoT microcontroller, the PPG sensor is a combination of photodetector, VCNL ASIC and IRED, the IRED is a combination of both red and green light and the current work comprises of red LED to perform experiments, the kodak grey card reflective material is 18 percent better than the traditional reflective devices that will help improve and enhance the light throughput deeper to the skin and absorb it back more efficiently as shown in Figure 3. In Figure 3 observe the earlobe with Arteries and Veins. Here, the External Carotid is connected directly to the heart valves, but the earlobe is one of the strongest pressure points with very less artifacts when compared to the Fingertip. The External Carotid as shown in Figure 4 branches to two branches of common carotid artery that has many branches extending towards the neck, face, and head region. Observe how the external carotid is connected to the earlobe from the Figure 4. This shows clearly why the head, and the ears are always warmer than anywhere in the body. Such branches are also proof to enormous amount of blood vessels existence at the earlobe.

Figure 4 Heart and Ear region connected via External Carotid Artery [21]

As shown in Figure 5 the wave form clearly explains how and what the PPG signal consists of. The signal waveform is a final output after applying the COMMA-Z algorithm from the HEAR device. The systolic peak, dicrotic notch and diastolic peak are the most important occurrences of a PPG heart signal. All these occurrences on a signal are at an earlobe and fingertip, the signal appearances on both these regions look almost similar with slight changes at the signal peak, this also depends on patients and users and the related current settings from the sensor for heart data extraction.

This below generated heart rate sample from Figure 5 is from a subject who is a 32-year-old male participant, the signal is computed using a GPU. The computed data here represents 5-point median-moving averaging filter with zero crossing filter that is perfectly aligned like a traditional PPG signal as shown in Figure 9. Figure 5 signal was obtained at 40ma current with 16.625 measurements/sec. Figure 5 signal is called NSR (Normal sinus rhythm) which is widely used in this research to compare with other arrhythmia conditions [28]. The x-axis in the Figure 5 is the time in seconds and y-axis is the amplitude.

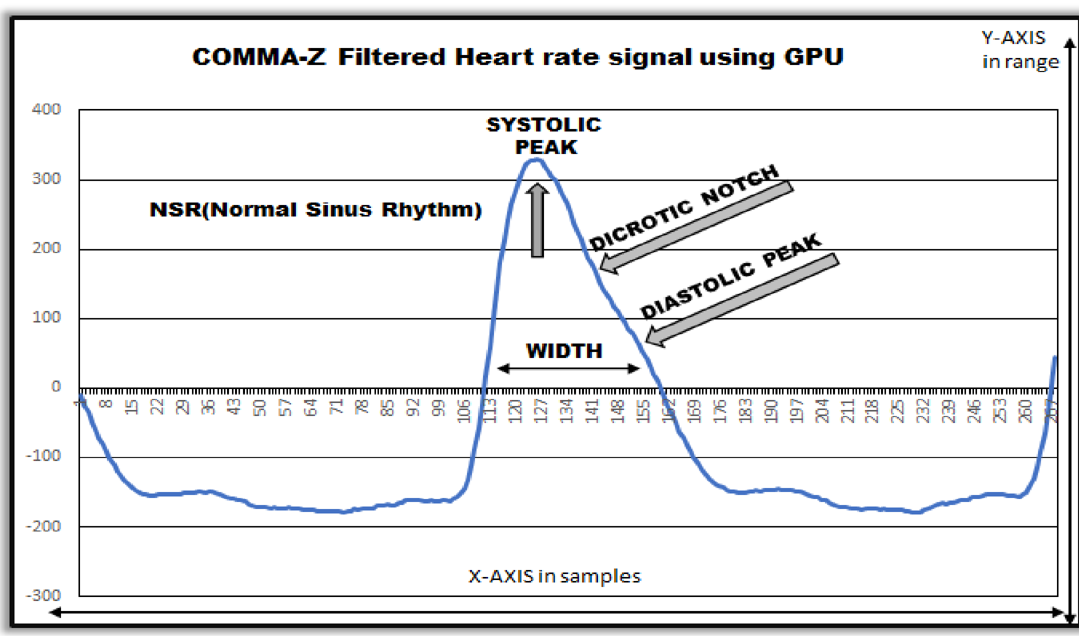

Figure 5 Generated Normal Sinus Rhythm Overview

To keep up with preliminary testing the patient or the user wears the HEAR device to the earlobe, the sensor data is collected based on the novel COMMA-Z classifier applied to GPU and the concept will be discussed in detail in the software system design section, the GPU computed data is sent to the medical professionals to monitor, predict and analyze and understand heart related arrhythmias due to occurrence of myocardial infarction and history of heart conditions [28]. The Figure 5 shows the generated normal sinus rhythm for earlobe using the HEAR device, but the signal classification compared to the ECG device is almost similar as shown in Figure 9.

1.4 Heart Rhythms and Arrhythmias

Silent Heart attacks lacks the symptoms of classic heart attack, with extreme pain, sweating, higher body temperature, stabbing in the arm, dizziness. It's also sudden shortness of breath and irregular chest pains.

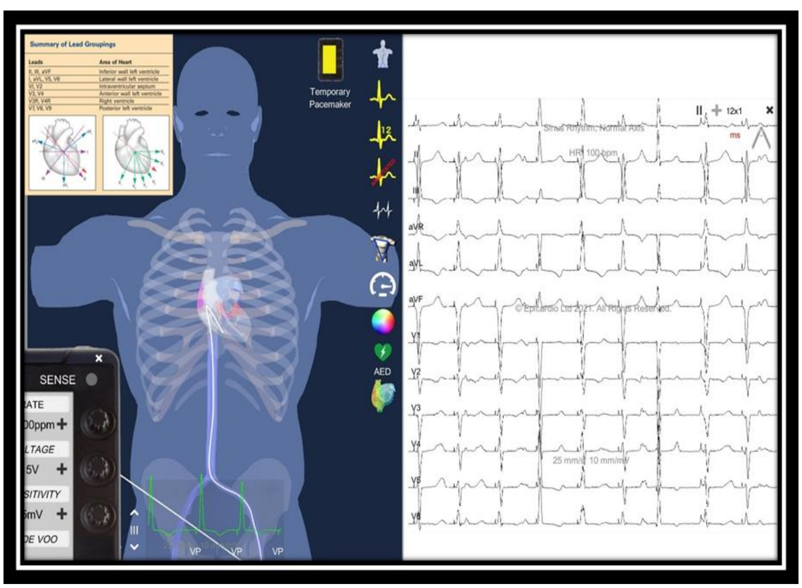

Figure 6 Theoretically Simulated Heart signals using Pacemaker [21]

Monitoring the continuous heart activity and changes in heart signals may help study the occurrences of silent heart attacks [29]. This work indulges more towards the myocardial infarction and how dangerous it is [28]. To understand heart conditions, it's required to first understand the heart rhythms and electrical activity of the heart. In Figure 6 the pacemaker is connected to the heart to understand the signals related, these signals require thorough understanding. The electrical impulses are sent from the pacemaker device to contract and produce heartbeat. Some pacemakers send signals all the time at a fixed rate. The signals I, II, III, aVr, aVL, v1, v2, v3, v4, v5, v6 are unipolar leads measuring from area of the heart as shown in the summary for the lead groupings in Figure 6.

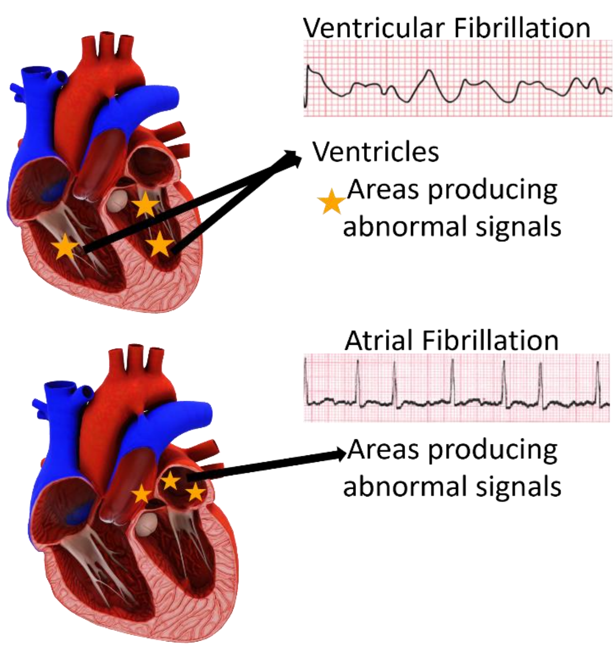

Figure 7 Ventricular and Atrial Signals of the Heart [30]

As Shown in Figure 7 the conditions in ventricles and atrial region areas in the heart for ventricular and atrial fibrillation occurrences. Both these conditions are considered dangerous and troublesome. These conditions should be well understood and treated. Medically there are various methods to diagnoise these diseases, but early detections and long-term detections are challenging. Hence, HEAR device is designed to solve such a problems in this research. To do this kind of work thorough understanding of the heart and its electrical activity is very important and related cardiology courses were required for this study and the one that widely helped was the EKG Guy online cardiology course conducted by surgeons and PubMed cardiovascular training group [31]. Hence, before developing this excellent work as a main author and researcher I have attended classes and courses from The EKG Guy [31] which is a famous online medical course designed to train students to understand the heart and its activity and its related condition helping engineers to easily develop algorithm and apply filters for diseases such as atrial and ventricular fibrillation arrhythmias.

1.5 Introduction to HEAR Device

The product Hear is a Primary heart rate monitoring device for both self-driving and gasoline driven cars, considering the gasoline driven cars, this product is designed to the earlobe for drivers as shown in Figure 8. These vehicles have an inbuilt GPU device that is capable of reading heart data from the HEAR sensor via UDP. This device in self driving cars will only be used by passengers. However, the proposed idea is to use the GPU located at the headrest or center stack to connect via UDP communication protocol to the HEAR device for computation, which is the prime concept of proposed system currently in this work using vehicles, the Figure 8, 17 and 20 provide in detail explanation on this. This work is bench marked with CPUs as well. The HEAR device also consists of a particle photon IoT microcontroller used to control the registers of the inbuilt PPG sensor. The microcontroller simultaneously connects to the GPU via UDP or wi-fi for heart data computing. Figure 8 demonstrates the concept of how a HEAR device is placed at the earlobe. This heart data monitoring system is a combination of measuring heart data, body temperature along with gyroscope and accelerometer.

Figure 8 Portable HEAR Device to the Earlobe [32]

The body Temperature sensor, Accelerometer and Gyroscope sensors do not require computing from the GPU because sensor registers output values for skin temperature, moisture and fall detection accordingly and these sensors data is directly fed to the CPU. The current work does not focus much on these sensors because our novelty is based on the heart data and how the COMMA-Z filters with other filtering techniques compute arrhythmias and heart conditions using a GPU and HEAR device sensor .The goal here is also mainly to provide highly computed GPU data for analysis to medical professionals while driving. The HEAR device data will be sent to both CPU and GPU to perform computation for data analytics and observations for heart related data. The HEAR device is placed to the earlobe of the driver for Gasoline cars and Passenger for self-driving cars. Consider this computed history of heart data of a patient or user from gasoline to fully self-driving cars being stored in a cloud server because today's driver will always be tomorrow's passenger. This data can be stored in the cloud servers and this concept can be further elaborated to be used to observe, analyze, predict, and study the upcoming generations of human heart data for any arising heart conditions and diseases in real-time but the current work does not include such innovation because this requires storing final computed novel COMMA-Z filter data on to a server to perform AI challenging computations. Hence, to also maintain the history we as drivers, patients and users need to begin with today's gasoline cars and then prepare the system from ground up for tomorrow's self-driving cars. There are various methods of measuring the heart data. Few of the commonly used methods are Electro-Cardiography, Blood Test, Photoplethysmography and Oscillometer; these quantitative methods except the photoplethysmography require patients to be at the clinic for the tests [33] [34]. To monitor and assist a patient remotely would require a Photoplethysmography method. This remote-patient monitoring technology using Photoplethysmography method and wearable devices can be used by patients or users to measure the heart data in real-time. The HEAR device is a portable device which requires basic processors to compute the data using GPUs that are chosen to be a part of the gasoline or electric cars and now the cost is only for the HEAR device but if we have to use this device outside of the vehicle while at home, clinics or hospitals it is required to be integrated to the cloud system or your cellphone to perform computing using GPUs that are part of cloud or phone device. The heart rate responds to increase in physical activity and the emotion such as fear, chronic stress, and anxiety require to be monitored [35]. These are few of the main factors that initiate heart conditions and diseases over the time [36] [35]. On a day-to-day basis currently, everybody uses various types of wearables, but iOS and android based are the most widely used wearables; these wearable devices use Photoplethysmography to monitor heart data, but all these devices have too many limitation and they are not medically certified [37]. The Photoplethysmography consists of an infrared light emitter and adjacent photodetector, to the amount of blood flow the amount of light reflected is measured in terms of R-R interval for calculating BPM and also develop studies [38] as shown in Figure 9. The heart rate target zones define a percentage of maximum heart rate, there are algorithms to calculate heart rate but a simple one is HRmax = 220 – age in years [39]. Photoplethysmography should be placed in either at the fingertip, head region, or earlobe for most accurate results. The optical sensor measures the blood volume, the periodic fluctuations is reflected light back by the sensor to measure heart rate [40]. A patient or a user while driving is nearly impossible to assist in case of any emergency condition. However, while driving real time monitoring such patients or users for arrhythmias or after a heart surgery or for various other heart related conditions and assisting them on a regular basis and in case of emergency can be solved by using wearable sensors such as the HEAR device. This device data was fully accessible to medical professionals in this work for studies, and they will always have access to current and accurate heart related data along with history of heart related data to observe, predict and analyze for any existing or arising arrhythmias and conditions. While testing the HEAR device along with the apple watch results showed some tensions in the wrist and comparing along with existing environment while driving and at clinics the best possible way for measurements using photoplethysmography method was at the earlobe. In this method the HEAR device is placed at the earlobe, and here in this section also explains why earlobe was chosen for bodily measurements. So, where *is* the best place to track heart rate? An expert advice from Valencell - maker of heart rate sensors - [41] and First beat mentioned that measuring heart rate at the wrist has certain limits which may be very difficult to push beyond a certain level, because the motion artifacts are so major in the hand when you are using it for doing something, Having the proximity sensors further up the arm or legs or chest strap might have a lot of tension [42], but there is one region that is the earlobe which is the proposed region in this research. The reason being earlobe because there's a lot of blood perfusion, in which we're referring to the density of blood flow in the outer layers of the skin. There's a lot in that region. Ever cut your ear and found that it *just won't stop bleeding*? In fact, in the ear there's a bank of arterioles, between the antitragus and concha, which expand with heart beats as seen in Figure 3. Therefore, angled right, a sensor can get a fantastic reading of our heart rate as seen in Figure 3. While measuring the proximity data using PPG from the earlobe one can enable access to measure the respiratory rate which is an additional factor for further health prediction and analysis, respiratory rate and heart rate variability play a major role while stressed out or while any medical condition or other related factors. The respiration rate is the number of breaths a person takes per minute. The rate is usually measured when a person is at rest and simply involves counting the number of breaths for one minute by counting how many times the chest rises. Respiration rates may increase with fever, illness, and with other medical conditions. When checking respiration, it is important to also note whether a person has any difficulty breathing. Normal respiration rates for an adult person at rest range from 12 to 16 breaths per minute. All these vitals are measured after the filtering portion of the innovation is completed. Gyroscope and accelerometer play a major role to detect the drivers or passenger's position in the vehicle, if there is any serious condition that arises to the patient such as sudden fall detection and or irregular motion, these sensors will help with information based on his position. These sensors will help with various health-related conditions, one of the most dangerous one would be predicting seizures and fall detection at the time of stroke or cardiac arrest and this problem can be solved with just HEAR product as well because this part of silent myocardial infarction was discussed earlier, but these gyroscope, accelerometer and skin temperature sensing capabilities are to support and strengthen the prediction and analysis for any heart conditions and arrhythmias or emergencies. This current work does not focus much towards other sensing capabilities but the motivation of this research was to observe such occurrences eventually over the time using HEAR device and GPU. These occurrences and heart conditions were shared with medical professionals to see how our system is helping observe, predict, and analyze arrhythmias such as atrial fibrillation and ventricular fibrillation that may have occurred due to myocardial infarction or any other history of heart disease while the person is behind the wheel. The project here is also a combination of various algorithms and filters being developed lately using a heterogeneous system bringing together all the features for better analysis and prediction.

1.6 Thesis Contributions and Publications

Based on the proposal the thesis contributions and the novelty of this research work can be summarized in the following:

- Developed a Portable HEAR device that is suitable for Driving and for hospitals wherein it establishes communication to the GPU for heart data computation.
- Visited surgeons from Beaumont hospitals eventually to understand electrical activity of the heart and various arrhythmias such as tachycardia, bradycardia, and common heart surgeries such as shunt placement and angioplasty which are later used in this research work.
- Integrated High performance VCNL Bio proximity sensor from Vishay and a particle photon IoT STM32 microcontroller together as HEAR device.
- Developed studies using gyroscope, skin temperature and accelerometer sensors to strengthen the research work, these sensors are not part of HEAR device as they were developed and tested separately.
- Developed heart data studies and comparisons for both earlobe and fingertip using the HEAR device and Jetson GPU.
- Thoroughly designed and developed I2C and UDP protocols for the HEAR device and the Jetson hardware for raw heart data extraction and parallel computation.
- Implemented CPU functions and GPU kernels to compute the traditional median-moving average filter and novel COMMA-Z filter along with signal differentiation and DFS.
- Developed an optimized and fully functional C++ code for the HEAR device and

CUDA C++ code for the GPU, the novelty lies within the CUDA C++ code.

- Implemented Novel COMMA-Z Filter using CUDA C++ for GPU which is a combination of 4 kernels along with signal differentiation and DFS to study Atrial and Ventricular Fibrillation tachycardias.
- Also observed and computed road conditions and various unknown noise, vibrations while driving using GPU and COMMA-Z filter for betterment.
- Conducted various experiments and discussed outcomes with medical professionals to understand the correctness of the NSR, AF and VF heart data signal.
- Conducted clinical trials and demonstrated studies and experiments while a patient or user is driving, resting, walking, and performing various other intense activities in real time using HEAR device, GPU, and Novel COMMA-Z Filter.

Finally based on the contributions the research work was developed to observe, predict, analyze, and monitor Normal sinus rhythm, Atrial and Ventricular Fibrillation while driving or while at clinics or at hospitals that may have occurred during the phase of myocardial infarction or cardiomyopathy or due to complications in angioplasty or shunt replacement or conditions in his/her health history.

Sections of this thesis includes material from different Journals and publications for the author. The publications present original works of which the author is the main contributor:

- G. Sinnapolu, S. Alawneh, S.R. Dixon, “A Method to Compute Electrical Activity of the Heart: Prediction and Analysis of Heart Diseases using Novel COMMA-Z classifier and GPU Framework”, IEEE Sensors Journal.

- G. Sinnapolu, S. Alawneh, “Intelligent wearable heart rate sensor implementation for in-vehicle infotainment and assistance”, Internet of Things, Science Direct, ISSN 2542-6605, https://doi.org/10.1016/j.iot.2020.100277.
- G. Sinnapolu, S. Alawneh, “Integrating wearables with cloud-based communication for health monitoring and emergency assistance”, Internet of Things, Science Direct, ISSN 2542-6605, https://doi.org/10.1016/j.iot.2018.08.004.
- Sinnapolu, G. and Alawneh, S., "A Method of Filter Implementation Using Heterogeneous Computing System for Driver Health Monitoring," SAE Technical Paper 2021-01-0103, 2021, https://doi.org/10.4271/2021-01-0103.
- G. Sinnapolu and S. Alawneh, "GPU Accelerated Implementation for Sunday String Pattern Matching Algorithm," *2018 IEEE International Conference on Electro/Information Technology (EIT)*, 2018, pp. 0007-0011, doi: 10.1109/EIT.2018.8500261.

1.7 Thesis Organization

This dissertation consists of seven chapters. The introduction chapter tries to present the research problem, methodology to develop the work from Ground up. Chapter two presents literature work that is thoroughly done for this research work. The chapter third is the related scope and purpose of this research work. The chapter Four represents the heterogeneous system development and capabilities. Moving to the Fifth chapter the novel and related work techniques developed in this research is explained in detail. Chapter sixth and seventh discuss the progress of the research work done that is starting from initial basic work untill the full proposed working system along with experiments of valid studies, use cases and outcomes.

CHAPTER TWO

LITERATURE REVIEW

This section is devoted to literature review work developed. Since the system is a combination of multiple modules this chapter showcases the sensor technology, heart related diseases, conditions, and related datasets.

2.1 PPG and ECG

In Figure 9 the ECG and PPG RR Intervals are clearly showcased such that the signals reference each other with a red dot to represent the combination and related differences. In Figure 9 on top right corner an ECG wave form represents segments and QRS complex.

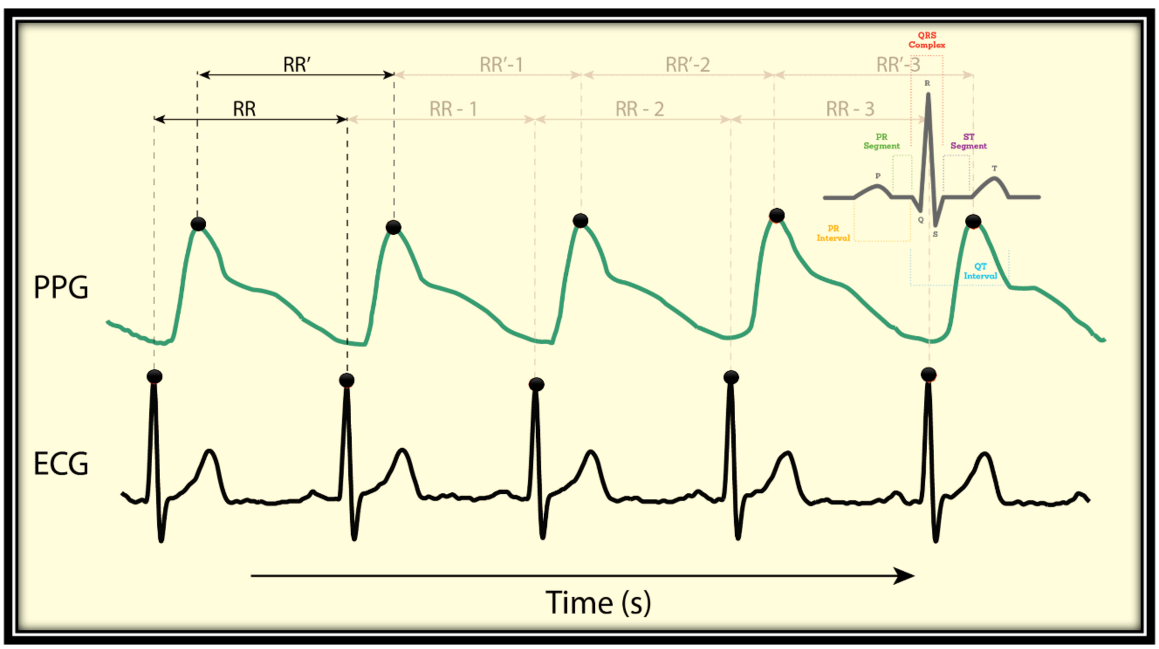

Figure 9 ECG and PPG Signal Study and Comparison [43]

To understand the normal sinus rhythm for an ECG the heart rate between 60-100BPM is calculated by time interval between RR signal occurrences. The P,Q, R, S, T segments and intervals refer to as one rhythm. The RR intervals remain the same for both ECG and PPG, but studies showed that PPG devices are widely used than ECGs. The PPG signal in Figure 9 represents the similar generated signal from COMMA-Z filter using a GPU as observed in Figure 5. By convention the signal representation in Figure 9 is important to understand, lets understand the ECG signal in Figure 9 because Figure 5.represents the original signal computed from a user. The first upward deflection from the baseline is termed the P wave, and it reflects atrial depolarization wave. The P wave should not exceed 2.5 mm in height nor 0.11 second in width for any signal. Ventricular depolarization is represented by the QRS complex. The Q wave is the first negative deflection from the baseline after the P wave but preceding an upward deflection. Normally, the Q wave reflects ventricular septal depolarization, and its duration does not exceed 0.03 second. The R wave is the first positive deflection after the P wave, reflecting depolarization of the ventricular mass. The S wave is the negative deflection following the positive R wave representing later ventricular depolarization. The T wave reflects repolarization of the ventricle and may be represented as either a positive or negative deflection following the QRS complex. The area incorporated within the T wave approximates that within the QRS complex, and its polarity is roughly the same as the principal QRS polarity. Occasionally, another wave, the U wave, may follow the T wave, the mechanism of the U wave is unknown, though it may reflect repolarization of papillary muscles, or an afterpotential. The PR interval is the time from the beginning of the P wave to the beginning of the QRS, whether initiated by a Q or an R, the QRS interval is an interval from the beginning of the Q wave to the end of the S wave, incorporating ventricular depolarization. The QT interval is the time from the beginning of the Q wave to the end of the T wave, incorporating both ventricular depolarization and repolarization. The PR segment is that portion of the recording between the end of the P wave and the beginning of the QRS. The ST segment is that portion of the recording, generally represented by a horizontal line, from the end of ventricular depolarization, whether represented by an R wave or an S wave, to the beginning of the T wave [44] Figure 5 represents the normal sinus rhythm for the PPG signal and has similar systolic, diastolic and dicrotic notch from a clinical trial and from Figure 6 the conventional signal representation looks similar.

In Figure 9 the PPG and ECG waveforms are clearly represented based on the literature review Electroencephalography(EEG), photoplethysmography(PPG) and Electrocardiography (ECG) methodologies are very much prone to internal and external artifacts and require smoothing filtering algorithms to prove their usefulness [45]. The traditional moving and novel continuous median-moving average filters are implemented to collect the raw heart data from the HEAR device placed at the earlobe. Firstly, the novel continuous median-moving average filter is far more advanced than the traditional moving average filter due to its immense filtering methodology. Research in this project also compares the traditional and newly developed continuous median-moving average filters. These filters are designed and developed using both CPU and GPU and the results are demonstrated accordingly. However, the newly developed state-of-the-art algorithm using a GPU has design changes based on the architecture. This newly developed state-of-the-art algorithm of the novel continuous median-moving averaging filter helps physicians and medical teams widely compare and understand in detail the arrhythmias such as the tachycardia mainly and thoroughly when compared to the traditional methods. The novelty is the algorithm that is currently focused only on two heart arrhythmias those are the atrial fibrillation and ventricular fibrillation part of tachycardia that may have originated from myocardial infarction or cardiomyopathy or history of heart diseases, which are the most dangerous and actively occurring ones. Photoplethysmography (PPG) is an inexpensive optical data measurement method often used for heart rate monitoring. It is a technology where light source and a photodiode measure the volumetric changes of blood circulation [46]. In this project based on various studies and sensor placement we found that the blood volumetric level is high at the head section region especially near the ear. Magnetic ear clips and earphones have been used in the past to obtain PPG signals. Swenson and pho proposed various methods of magnetic ear clip sensor placed to the earlobe [47]. Researchers also looked up to design sensor earbud sensors that could be positioned against the targus to be able to reflect light from the blood vessels [48]. Considering these scenarios, the most powerful HEAR device sensor was designed to the earlobe and the data was parsed to the Jetson hardware using the traditional and the novel continuous median-moving average filter techniques and methods. Silent myocardial infarction is one of the dangerous and most common heart attacks in men. Researchers are providing abilities and methods to predict and seek medical attention to provide reperfusion therapy [49]. Diagnosis and study of such conditions using GPU will fasten the process to predict these tachycardias well in advance. Based on the estimation, 43% of the life-threatening Electrocardiogram (ECG) alarms issued by bedside monitors are false [50]. Some Research works have used Photoplethysmography (PPG) and Atrial blood pressure (ABP) for predicting these diseases [51]. These predictions are better and contain less ECG-related artifacts [51].

2.2 VCNL PPG Sensor for Earlobe and Fingertip

Vishay VCNL 4020 is the sensor used to interact and collect data from earlobe and fingertip in this research. The sensor in the Figure 10 is designed and developed as HEAR device as shown in Figure 17. The hardware design explains more about the HEAR device but the sensor VCNL4020C is a fully integrated 16-bit sensor with built in infrared emitter for red and green light to work with and has excellent light modulation and programmable LED with varying current from 10MA to 200MA [52]. The reference to the sensor PDF provides in-depth access to sensor development and integration.

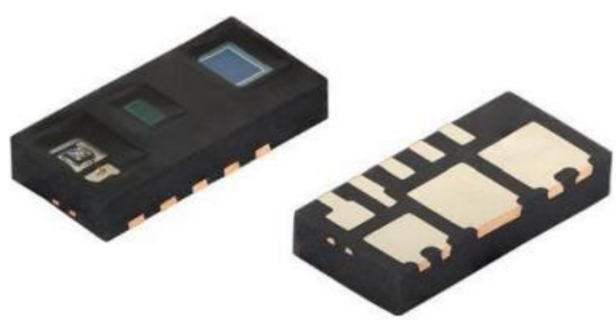

Figure 10 VCNL 4020C PPG sensor [52]

There are various methods out there to detect PPG pulse and one such method is to detect quality pulse index from every pulse and then the highest quality portion of the signal is later used for detection and this method also proves that PPG provides better results and shows viable alternative for traditional ECG detection methods [50]. Any heart rhythms different from a normal sinus rhythm is called arrhythmia. This rhythm difference may be due to lower or faster heart rate which may be due to atrial and ventricular fibrillation that are the most common ones [53]. Therefore, continuous monitoring is critical for patients with these conditions who are at a very high risk of cardiac events and the bedside ECG based monitors that are commonly used for monitoring such conditions, but ECG devices require electrodes and limbs for recording at the chest region and the chest related ones are very much uncomfortable for continuous monitoring over the time. Therefore, PPG devices are becoming more popular because they can be used at any comfortable pressure points and in this research after thorough consideration and research it was found that the earlobe is the highly recommended skin surface, but experiments are conducted for fingertip as well for benchmarking and PPGs don’t require an adhesive gel similar to the ECGs [53].

2.2.1 Fingertip and Earlobe Computation

The Current research work estimates various cycles of data being computed both via fingertip and earlobe and those results are compared in the experiment chapter. The fingertip computation would be challenging due to more artifacts and tensions and cannot be a viable option while driving, since earlobe has enormous amount of blood vessels it’s easier to compute data better than the Fingertip. Top automakers are designing fingertip sensor implementation to steering and body measurements via seats and this work proves that such system will fail if implemented based on the studies that are being developed in this project. The prediction via PPG is more advance due to the limitation of the ECG as well due to the electrodes that may feel uncomfortable while driving.

2.3 Apple and Third-Party Sensors

The Skin temperature sensor, gyroscope and accelerometer are used to measure body temperature, body position for any arising heart related symptoms such a fall detection and seizures. The HEAR device is a combination of high performance VCNL proximity sensor and the microcontroller to send data via UDP to the Nvidia GPU for computation. These skin temperature, gyroscope and accelerometer sensors support and strengthen the analysis and prediction states of the arrhythmias, but the work here is to closely focus on the novel COMMA-Z filter implementation using a GPU, VCNL PPG sensor and the particle IoT microcontroller part of the HEAR device. Wearable devices consist of sensors which can monitor the physiological vital signs, these sensors are placed on the surface of the skin which are tested and designed to provide most accurate results, when these wearable devices are combined using transmission via Bluetooth, zigbee, GSM, or through cloud-based will help monitor and assist the patients remotely as well in case of medical emergencies. Wearable sensors are a combination of hardware and software which play a major role in helping to detect medical condition prior to serious symptoms [54]. Wearable devices like Apple watch, Fitbit, Samsung gear and Garmin devices are the most widely used devices in the market but are not medically certified [55]. According to Gartner study, 98.1 million wearable fitness trackers are expected to sell in 2016 [56]. The Innovation of internet has led to many possible techniques in the cloud platform which runs high performance computing in no time [57]. The cloud implementation platform is also a solution to store heart data and access it, by storing and monitoring all the heart sensor data in the cloud would make it easier for health professionals in the long run to access and retrieve data anywhere in the world [57]. Top automakers like ford have worked on implementing heart rate monitoring to their seats. Toyota also has research on implementing the sensors to the steering wheel to monitor heart rate, but these companies have put an end to their research as they think there are wearables out there which are more powerful like the apple watch and Fitbit [58]. Recently in 2020, Ford did introduce the heart monitoring via seats but seems like it's just not monitoring and there was much more to be done [59]. Sensors to the seat and steering wheel don't help achieve the goal. Based on this work in comparison to our previous published work [60]using apple watch, as discussed this work implemented a design to monitor heart data using intelligent CUDA techniques in the HEAR device but seems like the watch doesn't do everything that is required to predict and understand the emergency situation of the heart attack and cardiac arrest. It is slightly difficult for the doctor to monitor the patient as the watch at the hand is more prone to muscular tensions while gripping or hand movements or cold weather. The optical sensors in the watch always depend on the blood flow and the muscular tensions that restrict the blood flow and lead to inaccurate readings [61].

2.4 Heart Conditions while Driving

Heart Attack occurs approximately every 43seconds in united states [62]. Timing is everything when it comes to heart conditions and symptoms on the road and it's better to get diagnosed as quickly as it is recognized. The faster we predict the faster the side effects can be treated according to American heart association the symptoms typically last for several minutes with discomfort at certain areas of the body such as arms, back, jaw and stomach and difficulty breathing and sweating [62]. Driver and Vehicle Agency is also promoting safety methods for safe driving and the disease are heart attack (acute coronary syndrome to include myocardial infarction), coronary artery by-pass surgery (CABG), coronary angioplasty (also known as percutaneous coronary intervention), heart valve disease/surgery and the patient cannot drive for 1 month after seeing these conditions. These conditions can be troublesome even after few months of surgery and require monitoring as proposed in this work [17]. Cardiac arrest and heart attack are two different terminologies, and they are often not the same. Cardiac arrest is when the heart beats unexpectedly malfunction, this irregular heartbeat (arrhythmia) requires immediate assistance and treatment. Cardiac arrest is an “electrical” problem here the pumping action is disrupted and cannot pump blood to other organs of the body [63]. Cardiac arrest requires fast action to save lives. However, a heart attack occurs when the blood flow through the arteries is blocked and if this block is not reopened quickly then heart attack occurs if not treated within days or weeks. Here the symptoms include shortness of breath, cold sweats, and vomiting. Here, unlike cardiac arrest the heart does not stop beating [64] and physicians based on the PubMed publications need to advice patients and monitor their heart data while driving to understand, observe and prevent the occurring condition of heart attack and cardiac arrest. Cardiovascular diseases are ones that makes the driver lose control while driving, there are certain symptoms when it is related to cardiac arrest and the driver will experience sudden fall, no pulse, no breathing, and loss of consciousness [65]. Everyday most of the truck drivers undergo heart attacks and in every 5 of 1000 people behind the wheel undergo coronary heart attack [65]. According to top German study 0.4% of road deaths of people who die behind the wheel are due to coronary heart disease [65]. In Japan, based on the study between 2000-2006, there were 200 cases of sudden accident out of which 28.4% where due to heart attacks and cardiac arrest [66]. In Finland, over the age of 65 years 20 to 30 percent have undergone fatal accident, as in most cases 70 percent is cardiovascular disease [66]. Also, in Canada studies show that age 60 plays an important role in road accidents, people in this age group who die behind the wheel are approximately 86% who had significant heart disease and out of these 40% is caused due to acute myocardial ischemia [65]. Sudden death while driving also leads to danger to other motor vehicles drivers, passengers, pedestrians, and property. Medical condition due to coronary heart disease occurs also due to alcohol and other illness when behind the wheel [67] [68].Physical and mental stress leads to heart attack, cardiac arrest and arrhythmia which sometimes also runs in families and this tendency is inherited. These families have increased risk of sudden cardiac arrest which may happen even behind the wheel or at home or at work or anywhere [69]. In united states 610,000 people die every year due to heart disease and 1 in every 4 die behind the wheel due to mental or physical stress [70]. Coronary heart disease is the most common type of heart disease killing 370,000 people annually out of which 7,037 are children, 347,322 are adults and 356,461 is any age [70] [71] [72]. Study chart shows that 1358 unexpected deaths in Florida in the USA over 65 years of age and in 100 people 52 people underwent heart attacks and cardiac arrest while driving [71] [68].

There is research based on monitoring heart rate while driving and there are some automakers who are involved in bringing this work of monitoring heart rate. In 1958 Saab invented seatbelts [73]. As the technology changes similarly Toyota and ford are now working on health sensors for measuring heart rate via steering and seats. These companies also reference to national highway traffic safety administration study for driver related medical emergencies and out of the 100 percent 11 percent is due to heart attacks. Diabetic condition might also lead to cardiac arrest and heart attack due to the drop of blood sugar levels that occurs in any time maybe 1.00am Sunday morning or 11.00pm afternoon [74]. GM is also working on these technologies and most of these automakers using steering wheel to monitor heart rate [75].

2.5 Heart Related Datasets

As seen in Figure 11 the Current data set for the state of Michigan between 2017-2019, it's the heart diseases and stroke map representation with number range per 100,000 from CDC.

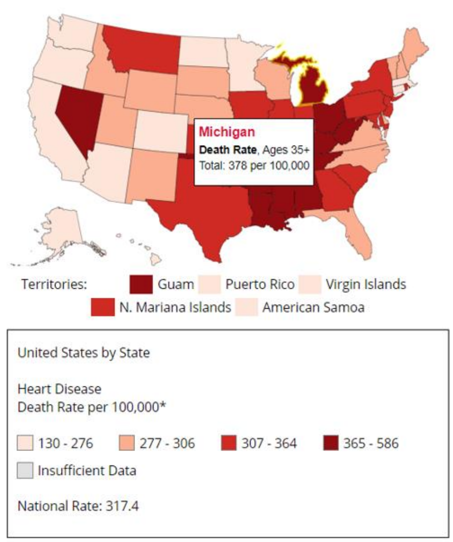

Figure 11 Stroke and heart diseases in Michigan state 2017-2019 [76]

2.6 Summary

Based on literature the heart date measuring methods such as PPG, ECG and EEG are considered to be fingertip and earlobe. Building such system estimates risk and various error factors and the thorough literature work was addressed to see if there was any previous or existing work similar to the novel COMMA-Z filter development implemented. Based on the driver and vehicle agency and required medical approvals the easy method to analyze and observe heart condition can be possible using the HEAR device while driving. The literature work on the silent myocardial infarction or cardiomyopathy explains more about such occurrences that lead to various heart conditions. The CPU and GPU would fasten the process of understating atrial and ventricular fibrillation and computing such diseases long term would help to understand and analyze other related arrhythmias such as bradycardia. The HEAR device was developed from ground up and is also discussed comparing with Apple watch, as it’s the most widely used device in the market which is not medically approved. As discussed, automakers, scientists and researchers are dealing with this current situation of developing some intense work to understand and analyze occurrences of heart related arrhythmias and diseases while driving, or in any normal condition.

CHAPTER THREE

SCOPE AND PURPOSE

This chapter aims to introduce the main technical concepts for the main building blocks used in this thesis, the Atrial and Ventricular Fibrillation, the heart and other filtering concepts. The following sections will discuss in detail concepts and theory for each.

3.1 Introduction of Theory Background

In the United States 610,000 people die every year due to heart disease and 1 in every 4 die behind the wheel due to mental or physical stress [77]. Measuring of the blood volume circulation variations is one of the most challenging and important tasks and this kind of methodology is called Photoplethysmography and this methodology due to technology and various sensing capabilities is widely used in the most recent times.

World’s no. 1Killer - the heart disease is taken a closer look by the Stanford university team to detect heart abnormality using EKG and this historical EKG data of 30,000 patients are modeled on a cluster of GPUs which in turn gives cardiologists a clearer picture of what's happening with a patient's heart [78]. Irregular heartbeat arrhythmia requires assistance and treatment based on the patient’s health condition, age, daily activities [79]. Heart condition should be treated within days and weeks, the symptoms include shortness of breath, cold sweats, and vomiting [60]. Heart disease and diagnosing heart related disease is very important for daily drivers due to immense stress, illness and other health related symptoms, German study shows that 0.4% of road deaths of people who die behind the wheel undergo coronary heart attack [60]. Studies show that high heart rate was associated with higher risk of cardiovascular events, which was found stronger in men than among women [80]. If the heart rate is increased to 10 beats per minute, then there is always an increased risk of heart rate of 20% [80] [81].

Research in any field of study requires analysis and comparisons or real-time predictions to extract useful information. To prove that the results have practical potential, various filtering techniques and methodologies should be designed and implemented. Filters being a class of signal processing helps innovate new technologies with various kinds of outcomes, using filters there are always various methods to solve a problem. Considering the current COVID-19 situation, researchers are working on sequencing the novel coronavirus and the genomes of people affected with COVID-19 using CPUs and GPUs along with various filtering techniques. The research work in this project involves a method of filter implementation to collect raw heart data samples from fingertip and earlobe and process those results using CPUs and GPUs. Here, the implementation to collect raw heart rate data is using a photoplethysmography method. The traditional moving average filtering technique is the most widely used for averaging an array of sampled data, but this research aims to reconstruct the entire moving average filter with a slightly different averaging method parallely for a GPU where this work proves how the novel filtering technique is better than the traditional moving average filter. This novel filtering technique is implemented and compared on both GPUs and CPUs. However, the filters on GPUs are slightly altered as per the GPUs framework and CUDA programming techniques to optimize and output challenging results. Human trials are conducted to understand how the heart rate changes while driving using traditional and novel averaging filter for a CPU and GPU considering environmental conditions and scenarios. The findings of this work are also compared with apple watch heart rate data as it is the most accurate heart rate sensing device in the market with less than 2% error rate [82].

3.2 Heart Diseases and Related Symptoms

Not only there is a higher risk factor of cardiovascular disease but diseases like tachycardia also show a stronger risk factor of sudden death that should be thoroughly researched. Heart rate is also associated with the high insulin, excess weight, dyslipidemia, and high hematocrit [83]. While driving the heart rate is close to resting heart rate with environmental noise including stress and strain but studies show that resting heart rate is an independent predictor of cardiovascular disease, and all cause of mortality and high heart rate that also has detrimental effects on coronary atherosclerosis on left ventricular function [84]. In general, let’s list out and understand the heart related diseases like the congenital heart disease and arrhythmias. Arrhythmias have several ways of irregular intervals, and they are tachycardia, bradycardia, premature ventricular contractions, and fibrillation. This current research work is only to study tachycardias. The coronary artery disease is caused by plaque deposits of cholesterol. The dilated cardiomyopathy is caused due to the heart muscle weakness and less pumping capabilities followed by myocardial infarction, heart failure hypertrophic cardiomyopathy, mitral regurgitation, mitral valve prolapses and pulmonary stenosis where in all these diseases are one of its kind with common symptoms of chest pain, breathlessness, and heart palpitations [85]. Patients with dyspnea, seizures, respiratory disease such as the lungs disease, chronic renal disease such as the kidney disease, psychotic disorders such as mood and anxiety should also be monitored by the medical practitioner and all these diseases also show changes and variations in heart rate [86]. There are many heart diseases, but ventricular fibrillation and atrial fibrillation are one of the most dangerous tachycardias that require thorough screening. This work here aims to focus on these two widely emerging and dangerous diseases. There are methods out there that predict atrial fibrillation without pulse detection, but noise and vibrations and various environmental conditions will increase the uncertainty of screening or analyzing such diseases [14]. Echocardiography was used for a patient with myocardial infarction but sometimes there are no evidence of the shunt detection during doppler echocardiography or during left ventriculography [87] In 2005 France has proposed based on the studies in 3670n patients to implant the implantable cardioverter-defibrillator in such patients even with low level of evidence [1]. Kaplan Meier estimation was one of the precisions used to develop a survival curve and one of the most famous methods used for prediction of survival curves over a period [88]. Sudden cardiac death may occur due to Myocardial Infarction along with Ventricular Fibrillation [89]. Left Ventriculography was performed for close to 2000 patients who underwent angioplasty for acute myocardial infarction, but the survival rate was significantly lower for baseline left ventricular ejection fraction and the conclusion was that the baseline left ventricular function measured during the procedure is a strong predictor of early and late survival angioplasty [90]. Women have less tendency to get sudden heart attack or heart failure or Atrial Fibrillation due to the menstrual cycle hormone released by their bodies until certain age [91]. Ventricular fibrillation prediction can be done using some tests and medicine such as the prophylactic lidocaine based on the recommendation by American Heart Association in 1996 [92].

Photoplethysmography method was used to analyze and research using ensemble empirical mode decomposition (EEMD). EEMD results in decomposition of a signal into intrinsic mode functions. These intrinsic mode functions together with their power spectral densities (PSDs) of Photoplethysmogram (PPG) signals were used to analyze for ventricular fibrillation conditions [93].

Cardiac arrhythmias contribute to large number of casualties around the world every year. The monitors in hospitals also provide too many false alarms and bedside care ECGs are not very suitable for use in wearable device due their requirement in using electrodes [50]. Physionet datasets are widely used to detect different types of arrhythmias from patients such as Tachycardia, Bradycardia, Ventricular Tachycardia, Ventricular Fibrillation and Atrial Fibrillation [50].

3.1.1 Ventricular Fibrillation and Atrial Fibrillation

Atrial and Ventricular Fibrillations are part of the tachycardia in arrhythmias. Let's understand the theory and study behind the atrial fibrillation. Here, the pacemaker is used to study the heart signals and diseases. Atrial Fibrillation is an irregular rhythm and it's a chaotic firing of multiple atrial pacemaker cells in a totally disorganized fashion. Considering there are various mechanisms, but the two most widely proposed ones are the focal activation and multiple wavelets In Figure 12 the Fig 1 is the focal activation with green dot with green markings and is often said that it's originated from those PV(pulmonary vein) and it sets of the rhythm that leads to atrial fibrillation. The second one proposed mechanism is the wavelets rhythms as seen in Figure 12 where the Fig 2 represents the multiple wavelets and is often said that the wavelet with green circular markings go in and out causing micro wavelets and develop AF. The atrial fibrillation is caused by heart diseases that are untreated cardiomyopathy and drug toxicity. In Figure 12 the graph explain that the p wave is not observed, and the intervals are random and can be slow or fast paced. The QRS complexes is between 70-100ms. The red circle marking in the Figure 12 for the graph is the P wave disappearance.

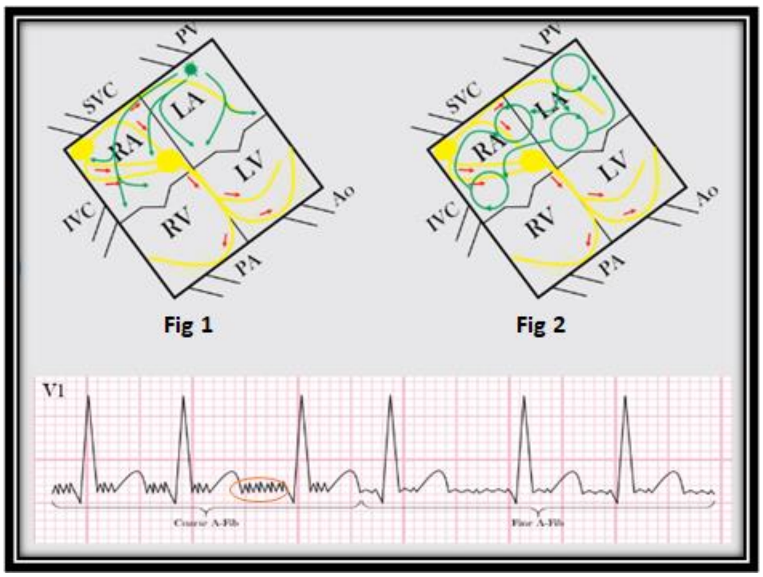

Figure 12 Atrial Fibrillation mechanism of focal activation and multiple wavelet [94]

Figure 13 shows the atrial fibrillation data being observed from a Physionet clinical data set that compute both ECG and PPG signal. The P wave occurrence in ECG and PPG signal and the irregular intervals with varying data can conclude the effect of atrial fibrillation.

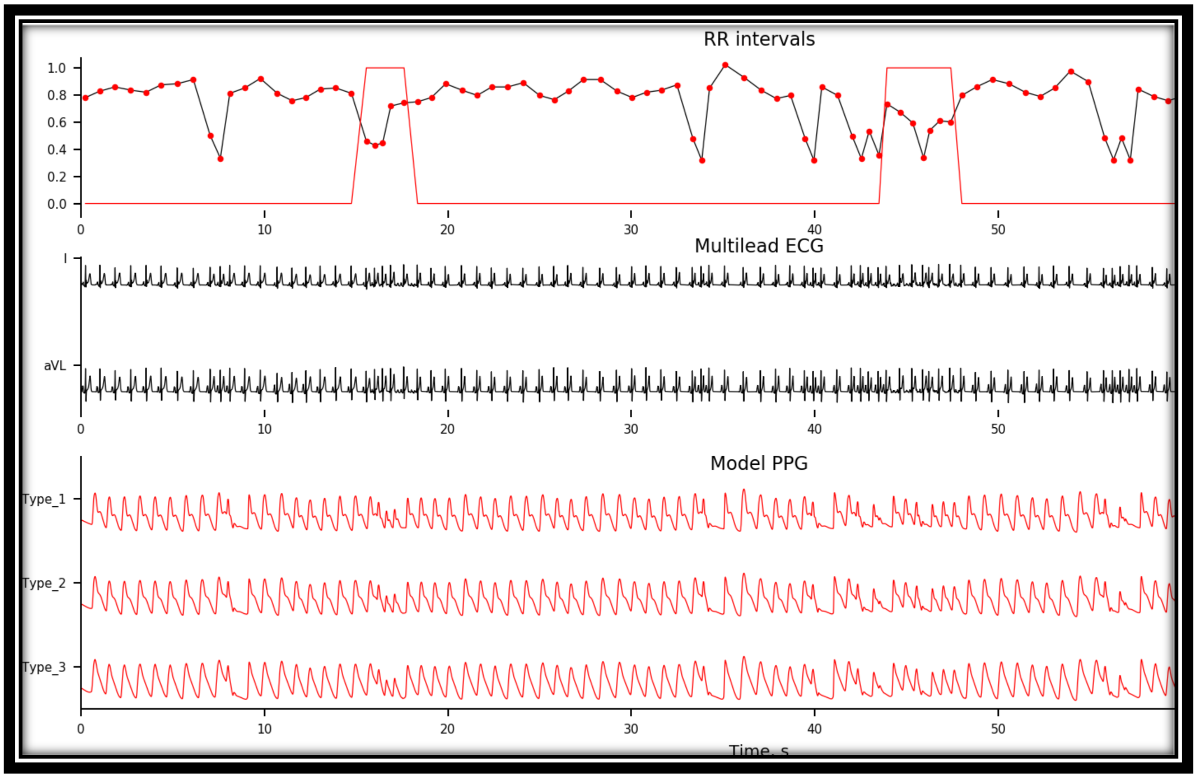

Figure 13 Atrial Fibrillation data using ECG and PPG – No Noise or Artifacts

Ventricular Fibrillation is a chaotic depolarization and loss of synchronization of ventricular contractions, and this results in circulatory arrest in seconds and loss of cardiac output, and this could lead to fatal without immediate advance life support. As observed in Figure 14 the Fig 1 represents the firing chaotically so we cannot have any cardiac output and the patient can die. In the Figure 14 the graph shows that the course ventricular fibrillation to fine ventricular fibrillation eventually leads to asystole also called as flat line. There are various instances that can cause Ventricular Fibrillation and the base rate is between 150-500BPM.

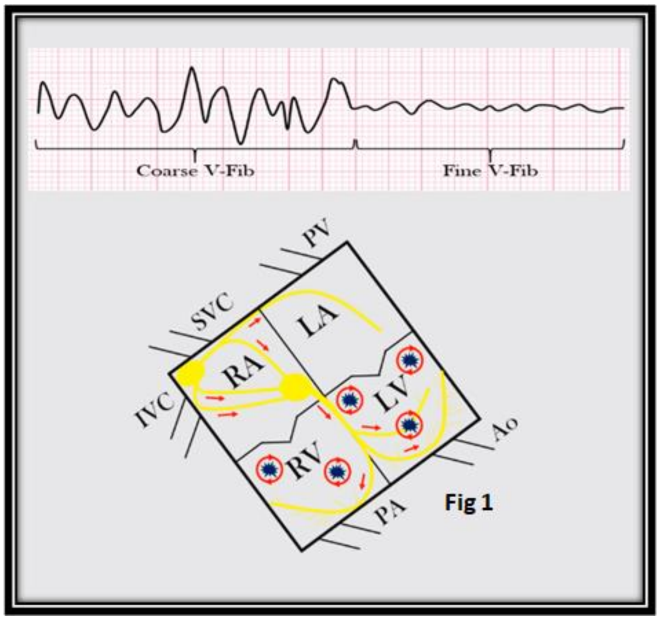

Figure 14 Ventricular Fibrillation study [94]

There are various sensors that can be used to measure heart conditions passively and one such method was to use a KardiaBand, which records a rhythm strip from an Apple watch and when paired the app detects atrial fibrillation. These are one of the first studies to examine using a smartwatch to discriminate between sinus rhythm and atrial fibrillation [95]. Most of the predictions using PPG's will always have an annotated ground truth and comparison using ECG's and these annotations are made using various rhythms such as normal sinus rhythm, atrial fibrillation and ventricular fibrillation and prediction of these diseases in PPG and then applying pre-processing and removal of segments corresponding to motion artifacts is one of the common and challenging tasks used in methods of comparison. The methods of PPG signals predicted using inter-beat interval-based features and wave-based features included complexity measures that were computed using power spectral density [95]. Ventricular Fibrillation is the most identified arrhythmia in cardiac arrest patients and the patients usually die within minutes if urgent treatment is not done [51].

3.3 Filters

The ability to use filters is increasing on a day-to-day basis. To move and interact with our surrounding is an effective way to implement the most related ones. We can estimate relatively the changes of heart data from person to person based on various factors which will be baselined for filters.

3.3.1 Filtering Concepts

One of the most widely used filtering techniques in the world, the moving average filter is an averaging filter that helps provide solutions to many mathematical problems occurring in real life scenarios, to name a few they are used in sports for predictions and analysis, stock market analytics, astronomical data computation, weather analytics. Moving average filters are also used in UV communication systems by implementing noise reduction algorithms [96]. This filtering method is also used to remove high frequency noise in ECG data [97]but most of these are traditional moving average filters. As discussed, the current work implements a novel COMMA-Z filter which is a method that is used to compute heart data using an HEAR device. COMMA-Z means continuous Median-Moving averaging filter and zero crossing detection algorithm applied to the high-performance proximity sensor’s raw heart rate data which is extracted from earlobe and fingertip. Here, based on the CUDA architecture implemented signal differentiation algorithm and depth first search algorithms for atrial and ventricular fibrillation predictions and analysis for physicians based on previous recurring health or heart related conditions. Initially proposed using Kalman, LMS and Gaussian filters but after through study and research these filters did not satisfy the problem solving in this research work.

3.4 Summary

As the study and research highlights the worlds no 1 killer and it aims to discuss occurrences and symptoms that are required to be monitored and treated well in advance, the heart data should be extracted in real time and based on the scope and purpose the motivation was to develop research work for atrial fibrillation and ventricular fibrillation arrhythmias which may occur during the phase of myocardial infarction and such instance of myocardial infarction could be due to Cardiac stress, history of heart conditions or any health conditions and surgeries or illness. Training on various EKG and ECG medical courses was required to understand heart and related arrhythmias such as AF and VF. As discussed, studies show that Covid -19 itself will also induce arrhythmias and myocardial infarction. The research work scope is also towards understanding irregular intervals such as tachycardia, bradycardia, premature ventricular contractions, and fibrillations. The scope is not limited to heart only and can be applied to seizures, lung disease, kidney disease and other health conditions. Hence, the purpose was to develop the entire system from ground up and innovate filtering concepts such as the COMMA-Z filter using the HEAR device and GPU.

CHAPTER FOUR

HETROGENEOUS COMPUTING SYSTEMS

The proximity sensor is placed to the earlobe which communicates raw heart rate data to the Jetson Tx2 hardware for heterogenous computing. In this approach the raw heart data is applied to both CPU and GPU to compute traditional and the novel continuous median-moving average filter techniques. The traditional and recursive moving average filters are widely used by researchers and engineers for reducing white noise and keeping the sharpest step response. There is a recursive moving average filter method which can be designed with N points to achieve a desired fastest and more efficient output [98].

4.1 GPUs and CPUs

The CPU loads data to the memory of the GPU via PCI bus to perform high-performance parallel computation, the final output is later loaded back to the CPU for further processing [99]. Understanding the GPU architecture is very important to motivate the need and use of a GPU [100].

4.1.1 CUDA and Related Architecture

Today Nvidia's widely used Jetson products have high performance computing capabilities, the Jetson TX2 has 256 CUDA cores with most powerful processor for AI and edge computing while Nano is small yet a powerful computer with 128 CUDA cores but Xavier is the most powerful of all with 512 CUDA cores and 64 Tensor Cores used for AI/ML and is widely used in autonomous machines [101]. All these products run Jetpack SDK's that install various software's for development. The most important toolkit is the CUDA Toolkit. The Compute unified device architecture (CUDA) toolkit provides a high-performance environment for GPU accelerated applications. CUDA is a parallel computing platform and programming model that enables developers to compute intensive applications using GPUs. CUDA is also widely used for signal processing software along with a GPU to process large amounts of astronomical data [102]. CUDA performance led to the new era of drug discovery with specific illustrations and methodologies that were applied to atomic and molecular scales and how harnessing CUDA also led to their discovery [103]. Research based on medical imaging, diagnosis and treatment play a crucial role as they are computationally demanding, hence GPUs emerged as a competitive parallel computing platform for computationally expensive and demanding tasks [104] [105].

4.1.2 GPU and CPU Estimation in Technology

GPUs are widely replacing CPUs for various applications that require heterogeneous computing capabilities in the field of Automotive, Medical, Industrial, and Aerospace. Today the most widely used speech recognition algorithm is implemented with highly advanced computing level techniques using both CPUs and GPUs [9]. Today Nvidia's widely used Jetson products have high performance computing capabilities, the Jetson TX2 has 256 CUDA cores with the most powerful processor for AI and edge computing while Nano is a small yet a powerful computer with 128 CUDA cores but Xavier is most powerful of all with 512 CUDA cores and 64 Tensor Cores used for AI/ML and is widely used in autonomous machines [106].

The Compute unified device architecture (CUDA) toolkit provides a high-performance environment for GPU accelerated applications. CUDA is a parallel computing platform and programming model that enables developers to compute intensive applications using GPUs. CUDA is also widely used for Signal processing software along with a GPU to process large amounts of astronomical data [107]. CUDA performance led to the new era of drug discovery with specific illustrations and methodologies that were applied to atomic and molecular scales and how harnessing CUDA also led to their discovery [108]. Studies show that high heart rate was associated with higher risk of cardiovascular events, which was found stronger in men than among women [109]. One of the most widely used filtering techniques in the world, the moving average filter is an averaging filter that helps solve many problems, to name a few they are used in sports, stock market analytics, astronomical data computation, weather analytics.

4.2 Summary

Based on the motivation and purpose of this research heterogenous computing also plays a major role and to summarize here the GPUs and CPUs are widely used in various fields in automotive, medical and aerospace to solve enormous problems but once such application being developed here in this research requires enormous amount of heart data to be computed in real time, this data is not only computed while driving but also in various other scenarios, one needs to understand the environment and design the work accordingly. To achieve the techniques such as CUDA programming the GPU architecture and optimization methods need to be thoroughly understood to be applied, failure to do so will also increase the error conditions and may indulge scenarios that fail to satisfy the study here. In one such example GPUs are used by researchers to sequence the novel COVID -19 virus to develop medicine, failure to understand the disease and its related variants and occurrences would lead to wrong information.

CHAPTER FIVE

NOVELITY AND RELATED WORK

5.1 Novel Contributions and Related Work

Team of scientists from Stanford university are integrating AI to predict heart abnormalities to increase the accuracy of diagnosis, but these scientists are depending on the Kardiaband embedded into an Apple watch band [110]. Apple watch by far is the most accurate device for EKG or ECG sensor readings, the error rate is less than 2%, but Apple watch sometimes is also more prone to muscular tension and other occurring artifacts [111]. This apple device is not medically approved to measure full potential heart related conditions but has certain potentials. The optical sensors in the apple watch always depend on the blood flow and the muscular tensions will restrict the blood flow which will lead to inaccurate readings [112]. Hence using an apple watch or any wrist related sensors might not make justice to the predictions of heart abnormalities and diagnosis.

The approach aims towards implementation of the proximity sensor to the earlobe, the approach to the ear section is because the heart always tries to maintain warm temperature at the head region [113]. Hence, the ear receives more blood to keep it warm [114]. There are more blood vessels in the head and the ear region [114]. More the blood vessels more and enormous amount of heart data that is available for computing. Some of the work also defines to compare heart data results with the apple watch while observing behavior when compared with the GPU but this prediction is not the novel idea, the novelty is to develop and implement a system and an associated algorithm with a method to predict, analyze and observe occurrences of ventricular and atrial fibrillation that can be occurred from various diseases and conditions. The novelty section details this study, but the related work explains the research study associated with this work. There are various proximity sensors that are tested for this work that have high power IRED and incorporate powerful photodiodes, amplifiers in one single CMOS process, one such high performance bio sensor has been carefully selected for this work, it’s a 16-bit high resolution sensor with excellent sensing capabilities [115].

The approach here was also to implement the optical sensor close to the neck, chest, or the ear region but finally ended up choosing earlobe. The research is involved in these three areas because the heart always tries to maintain the blood flow to the head very often and makes sure it’s warm based on the temperature [116]. The ears in this scenario receive tremendous amount of blood to keep it warm [116]. There are various blood vessels in the head and the ear has a direct connection from the heart from one of the main arteries. When the ear is cut, the blood will not stop flowing until immediate medical attention.

The heart attack and cardiac arrest are two different scenarios, and they need to be addressed and monitored based on the most accurate sensors. The arteries are also the ones that deliver blood to the other parts of the body [116]. Medical professional will observe and analyze any occurring heart conditions and disease eventually with this proposed system in this work. The heart data is a raw data received from the HEAR device and the data is filtered using moving average concept, but the novel filter implementation plays a major role and is further discussed in the novelty section, there are 4 cascaded novel filter implementations in this current work.

The moving average filter is the most widely used filter in digital signal processing because it's the easiest digital filter to understand and use on a CPU for various applications but while on GPU this filter needs to be carefully implemented due to the factor of parallel computing. The heart data from the HEAR device is applied to both CPU and GPU, both CPU and GPU consists of an algorithm that explains how GPU will help clearly understand the detection and analysis of arising conditions using novel continuous median-moving averaging filter when compared to the CPU, but in initial stage of research when novel continuous median-moving averaging filter was applied to the CPU only the results show that CPU has better performance than apple watch. Practically the results and performance varied when applied on a GPU along with CUDA programming techniques.

To dive deep into the concepts, superior vena cava and inferior vena cava play a major role in the blood circulation in the body and arteries deliver blood to the body [117]. Nowadays researchers are developing work to understand the “silent heart attack” [117]. The silent heart attack is also named as silent myocardial infarction which eventually is developed due to various existing heart symptoms, conditions, and diseases over the time in a patient or user and leads to atrial and ventricular fibrillation, this is the research work that was conducted and demonstrated and discussed in this thesis. Various algorithms and methods were used to observe, predict, and analyze ventricular fibrillation and atrial fibrillation but to outperform such work a well-designed and advanced sensor is required to collect precise sampling heart data. As discussed, earlier Stanford university study of heart abnormality was detected and modeled on a cluster of GPUs, and these scientists were depending on the KardiaBand embedded into an Apple watch and for such predictions for scientists modeling data from a HEAR device at the earlobe would provide better results and outcomes. Hence using apple watch or any third-party devices might not make justice to predict heart abnormalities and diagnosis.

This novel state-of-the-art algorithm, the continuous median-moving average filter is designed keeping in mind various environmental conditions and surroundings not only while driving but also for hospitals and clinics for better performance and noise reductions. The novel COMMA-Z filter when applied to both CPU and GPU using CUDA programming techniques can help medical professionals understand and analyze the early detection and diagnosis of certain chosen cardiovascular arrhythmias such as atrial and ventricular fibrillation, eventually these filter techniques can also be applied to other similar cardiovascular illnesses such as tachycardias and bradycardia to study and make assumptions for any high risk of stroke and changing heart rhythms. Diseases such as seizure occurrences while driving is a dangerous condition that needs to be addressed as well and compute observations to medical professionals to develop some potential medical solutions, prediction of such arising condition using the HEAR device is definitely possible and lifesaving, but this area of work will not currently focus towards this direction. This work focuses only on VF and AF tachycardia arrhythmia occurrences and related conditions after any surgery. Early recognition and analysis and prediction of any condition require real time monitoring of data. Hence, in this work as discussed, the HEAR device is placed at the earlobe and the novel COMMA-Z filter is applied to the GPU to outperform and produce better computed heart data signal in real-time.

The COMMA-Z classifier filter is a combination of continuous median-moving average filter and the zero-crossing detection, the signal differentiation and DFS algorithms are also used to further compute arrhythmias while comparing those with normal sinus rhythm, the concept design will be thoroughly discussed in upcoming sections. The HEAR device's PPG sensor signal along with COMMA-Z and other related filters are implemented to show the fastest and closest estimation of heart data using the normal sinus rhythm for any arising arrhythmias, the CPU and GPU show better results when compared to the apple watch or any other third party devices in market due to the GPUs and the enormous amount of heart data collected by the high performance Bio sensor which is part of the HEAR device placed at the earlobe while computing real-time data on everyday basis.

Researchers and engineers use moving average filters for reducing white noise and keeping the sharpest step response. The recursive moving average filter method is designed with N points to achieve a desired fastest and more efficient output. Based on this similar concept to increase efficiency and faster filter response, the current research was to completely redesigned to develop a novel filter called the continuous median-moving average filter with 5 point median average calculation, the 5 point is used to find median between the N samples, consider every 100 samples while the first GPU kernel executes median first and then subtract median with N samples to find an average and apply continuous moving-average to get rid of the drift-off or excessive noise or environmental changes while driving or in any fitness center, this concept was applied and divided into thread/blocks and carefully implemented on a GPU while also increasing the samples from 100 to 10,000 at certain time considering only integer values. This heterogeneous computing methodology using both CPU and GPU to compute continuous median-moving average filter, zero crossing detection, signal differentiation and DFS filters for various heart related arrhythmias caused due to untreated heart conditions, cardiomyopathy or myocardial infarction while driving in real-time using the HEAR device is the novelty of this work . The HEAR device can also be used in hospitals and clinics but require a standalone GPU to compute the raw data. GPU from Nvidia provide compute unified device architecture (CUDA) toolkit that helps with high-performance parallel computing capabilities and these GPU architectures are widely and majorly used in medical and automotive application to perform enormous real-time computing providing tremendous and unbelievable results. The most recent drug discovery also included CUDA performance architecture for COVID-19 that was applied to molecular and atomic scales [118]. Myocardial Infarction phase consists of atrial fibrillation but also leads to ventricular fibrillation [1] but there can be instances of predicting it in early stages using sensors when placed at a certain position on the body where there are high blood vessels. Based on the prediction and analysis COVID-19 itself induces Myocardial Infarction and coronary syndrome leads to ventricular fibrillation which requires monitoring using sensor-based system. Recent studies also highlight that Covid-19 omicron variant has led to post infectious myocardial infarction causing blood clots in the body, but one such blood clots occurring in the heart leads to sudden death, when any viral infections occur the immune system is highly active in the body and once the infection is cured between 1 week or 30 days the patient may observe blood clot occurrences anywhere inside the body leading to dangerous conditions [119]. Any viral infection in that case will lead to post infectious myocardial infarction similar to Covid-19 situation but there are ways to avoid this using blood thinners and one of our proposed solution would be to monitor the heart conditions before and after any viral disease because myocardial infarction leads to ventricular fibrillation and sudden death, here high risk patients who are prone to diabetes, HIV, liver and kidney infections, high blood pressure and other related diseases are widely targeted who may possibly undergo post infection myocardial infarction. As per surgeons a patient with stent and without stent after angioplasty show variations in heart signal and studying such variations requires more heart data and high computing processors. Based on the previous research papers [51] photoplethysmography was used for prediction of various heart diseases because certain percentage of ECG alarming are false. Based on the situation looking for best earlier prediction and computed data requires innovative sensor implementation and better computing. There are methods and mathematical implementation that show better results for PPG than ECG, but we still need to make sure the PPG sensors are carefully designed and developed using advanced filtering techniques. Photoplethysmography (PPG) optical data measurement method is a technology of a light source and a photodiode measure volumetric blood circulation change [46].

Based on this similar concept to increase efficiency and faster filter response we designed a completely different filter called the novel continuous median-moving average filter. The novel contribution is the novel continuous median-moving averaging filter design. Firstly, this novel continuous median-moving average filter reads raw heart data from the earlobe sensor and stores it into the shared memory on the GPU. Later, this data is assigned to each block/threads for computing the moving average of the recurring raw data to output as Fx but while doing this parallelly the work computes median values for every first 5 raw values and next occurring 5 values using window size in real-time and then apply moving average to output as Fy. The median value prediction is performed and applied using moving average similarly for a set of 1st 64 raw values with a window size of 3-point to 12-point values accordingly which will output more Fy values. Now subtract and divide values Fx, Fy and original raw values from sensor with a total set of N raw values in each thread/block. CUDA techniques were applied for optimization and synchronization of threads within the blocks. This thread/block provides final filtered output and to this final output we will apply zero crossing algorithm to eliminate excessive noise and vibrations occurred while driving due to environmental conditions and related errors.

The novel COMMA-Z is a continuous median-moving averaging filter with zero cross detection algorithm, it’s a parallel computing method implemented using thread blocks to provide optimized and excellent results and this method of implementation showed low performance on a CPU than GPU.

5.2 Novel COMMA-Z Classifier

Photoplethysmography biosensor MAX30102 pulse oximetry is also used to detect heart rate and related conditions along with KardiaBand mobile data to compare readings, these readings were also compared with FDA approved Single-led ECG monitoring Device [53] but there is no existing work out there that is using GPU computation being performed at the earlobe to collect heart data along with invented novel COMMA-Z filter and related high performance proximity sensors that are used to showcase heart diseases such as ventricular or atrial fibrillation for analysis and prediction using Photoplethysmography technology. Considering the traditional moving average filter this research will focus towards discussing more about the novel COMMA filter, zero crossing detection, signal differentiation and DFS. Here, COMMA-Z classifier is a combination of continuous median-moving average filter and zero crossing detection. To perform the novel contribution a sensor with immense capabilities is required and one such implementation was to use the most advanced proximity sensor from vishay industries, this sensor is a part of the HEAR device along with microcontroller. This vishay VCNL is a highly advanced proximity sensor with best light reflections using kodak grey card which is placed to the earlobe, the approach in ear section is because the heart always keep the head section warmer in temperature when compared to other parts of the body and also at the ear region there are more blood vessels than anywhere in the body which will help provide enormous amount of heart data required to predict and analyze any heart related conditions and arrhythmias in no time [120] [121]. Based on the literature work discussed scientists and researchers are using methods for heart data extraction and sensor placement but in this research and development approach enormous amount of time was spent with medical professionals to analyze and understand these arrhythmias and electrical activity of the heart. Based on the outcomes the research was finalized to use and implement vishay PPG sensor part of the HEAR device to the earlobe for enormous amount of heart rate data collection and compute that data using a GPU to predict and analyze the dangerous and deadly cardiac arrhythmias such as ventricular fibrillation and atrial fibrillation using novel COMMA-Z filter along with signal differentiation method and DFS(Depth-First Search Algorithm) [122].

5.2.1 COMMA-Z , Signal Differentiation and DFS Classification

Based on the baseline left ventricular function, predictions for survival can also be observed using Photoplethysmography. This method can be used to detect variation of blood volume circulation after angioplasty that has been performed for a patient who has undergone acute myocardial infarction which helps to predict and analyze the heart data outcome using a GPU to compare and observe for any further medical diagnosis. The experiment section will discuss more about how well the GPU along with a COMMA-Z filter can compute heart data for these situations better than a CPU or any other device [90].

Data computing and specially enormous amount of data computing is really important to make any decision and to do so a GPU should definitely be considered because in one such example the right coronary artery occlusion with reperfusion, bradycardia and hypertension occur commonly in patients with proximal occlusion and there is a chance that it might be arising from the right ventricle as well and computing heart data using powerful processing, advanced sensors and filters would help understand situations like these as well [123].

The novel COMMA-Z filter is implemented and designed in the GPU to perform prediction and analysis studies, and this cannot be possible without the vishay VCNL high power IRED that incorporates powerful photodiodes and amplifiers in one single CMOS process which has very high sensing capabilities using green and red LED light reflection's [115]. This entire method used here is from ground up untill prediction and analysis of heart disease which will be thoroughly discussed and experimented. The reason for choosing the GPU was to fasten the process with no errors to predict well in advance an arising heart condition. An overall true positive rate (TPR) of 98.95% was achieved with true negative rate (TNR) of 2% -14.78% suggesting that PPG is a viable option for arrhythmia detection than ECG at Earlobe than Fingertip, the TNR rate from

2% to 14% is the maximum negative rate depending on a worst signal or a tremendously bad or dangerous signal situation even if the PPG sensor is placed at the Earlobe, this overall rate is also due to the GPU parallel computing using novel COMMA-Z and related filtering techniques and this rate would not be possible if we have used CPU only. Understanding the atrial and ventricular condition occurrences was not possible without the medical course work and top cardiologists from Beaumont hospitals as they always supported this work. Let’s briefly compare atrial and ventricular conditions once again, Atrial Fibrillation has chaotic signals with irregular RR intervals with varying rhythm and the signal has no pattern to it with a lot of jitters as shown in Figure 15 [124]. Atrial rate varies between 300-700 beats per minute and ventricular is typically between 80-18 beats per minute. Ventricular Fibrillation leads to death and the person is given very less time if this condition occurs, this condition shows a high heart rate of 150-500 beats per minute on the ventricular side and the rhythms are not organized and the patient dies due to stroke or cardiac arrest as shown in Figure 15 [125]. The atrial and ventricular fibrillation represented in Figure 15 are one of the most dangerous and similar occurrences for any patient, the atrial fibrillation when diagnosed immediately with an advance life support can be prevented and treated for any future occurrences but for ventricular fibrillation that’s not the case the advance life support does not help because of the chaotic firing within the heart and this condition will eventually lead to sudden death within minutes.

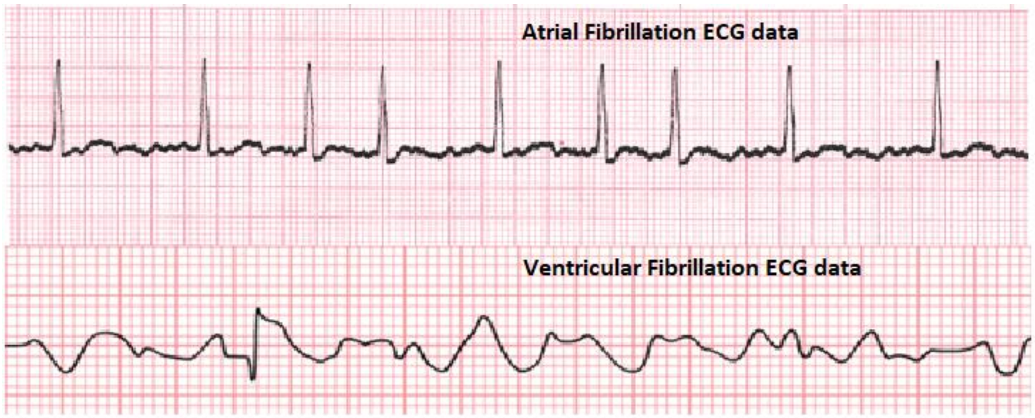

Figure 15 Atrial and Ventricular ECG Signal Lookup

This novel state-of-the-art algorithm is also designed keeping in mind various environmental conditions and surroundings for better performance and noise reductions. This works demonstrates the experiments applying Novel COMMA-Z filter for both CPU and GPU using CUDA programming techniques while Resting, Standing, Dancing and Driving both for a Fingertip and Earlobe and also the compute heart data to medical professionals to understand and assist in early detection and diagnosis of few major cardiovascular conditions and occurrences such as ventricular fibrillation and atrial fibrillation and simultaneously help make assumptions for medical professionals. Let’s briefly discuss about how the novel COMMA-Z filter was applied along with other filters to predict and analyze atrial fibrillation as shown in Figure 16 which also applies similarly to ventricular fibrillation prediction and analysis as well. Figure 16 shows real time atrial fibrillation data from a male patient marked in red, but also compared with another patient data of similar age who is showing normal sinus rhythm (NSR) marked in blue, both these subjects are 48-year-old Male individuals.

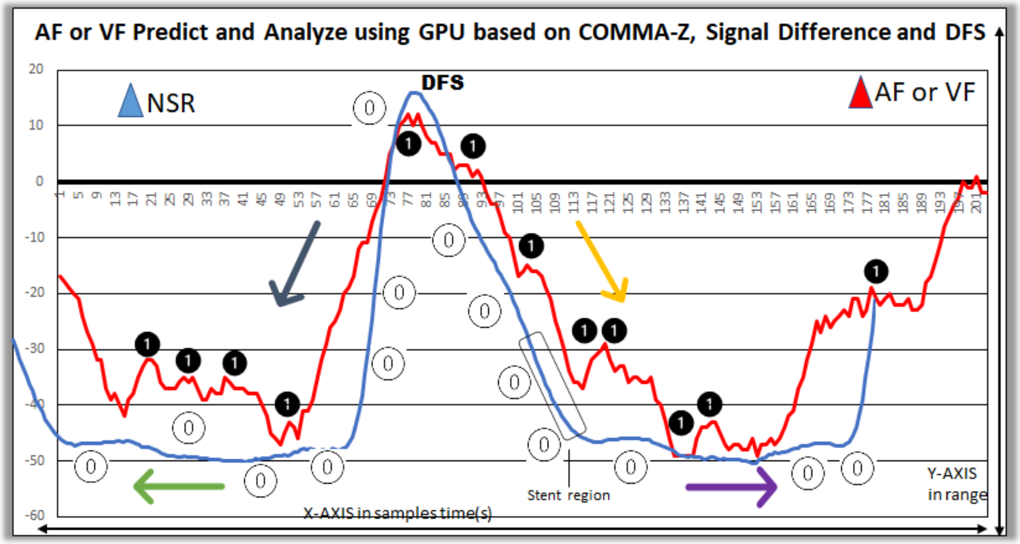

Figure 16 AF or VF computation using COMMA-Z, Signal Difference and DFS methods

As shown in Figure 16 observation shows two signals, and both these signals are final filtered output after applying the novel COMMA-Z filter on a GPU using PPG sensor data from earlobe. while the subjects are in resting condition the signal which is in red is the Atrial Fibrillation data and the signal in blue is the computed Normal sinus rhythm data. Here observe how well the GPU computed the Atrial Fibrillation and Normal sinus rhythm. In this experiment method it was found that both the waveform are exactly similar with two different scenarios which helped baseline and solve the atrial fibrillation prediction and study using signal differentiation and DFS algorithm. COMMA-Z is a continuous median-moving averaging filter applied with varying thread blocks on a GPU using 5-point average calculation and zero cross detection algorithm initially using CUDA techniques. Hence, Figure 16 shows outstanding result from the novel filter, but few more filter implementations were required to develop that analysis and prediction work to satisfy the true positive values for ventricular fibrillation and atrial fibrillation on a GPU and they are the signal differentiation method and DFS method. The signal differentiation method is used to find difference between the previous occurring data point to the next occurring data point. These differences are shown as number 1 in Figure 16 for red signal and number 0 in Figure 16 for blue signal. The atrial fibrillation red signal contains chaotic signal with varying amplitude and highly irregular RR-intervals with no P-wave that are marked as the number 1 based on filters output, but in the GPU kernel algorithm if any occurring data point differences are more than certain set threshold when compared to the normal sinus rhythm signal then that data point is marked as number 1 to show that there are various irregular jitters and unknown signals and there could be a tendency that the signal has Atrial Fibrillation condition. Here, the signal difference was introduced because it differentiates the data points in both the red and blue signal and then compare those signals for medical professionals for thorough analysis and after the signal differences the current work proposed to further apply depth first search algorithm as a kernel on the GPU for both the signals, the colored arrow marks show how the left, right, bottom traversals data are fed to the DFS kernel which is a node as shown in Fig. 5 from there the traversals predicts at least number 1 in any direction in any part of the signal then there is a percentage prediction that starts from 45% to 98% based on the occurrences of number 1 for atrial fibrillation prediction in red signal while number 0 is always considered normal sinus rhythm as shown in Figure 16.This signal difference and DFS algorithm helps predict, analyze and understand the heart signal thoroughly not only for arrhythmias but also for a patient who has undergone surgeries such as stent and angioplasty because based on the discussion with surgeons the signal waveform varies at the stent region for normal sinus rhythm as well as shown in Fig. 5.

5.3 Summary

Scientists are developing research work for accuracy and diagnosis of heart data using available wearable devices but to perform such work requires enormous amount of data and computing power. Apple watch and KardiaBand devices are not medical approved but still they tend to be using these devices for developing work. As discussed about arrhythmias and other related prediction methods and studies based on the literature review there was no work out there that was similar to the system being developed as represented in this research work. The work here is from ground up using HEAR device and GPUs to predict, analyze and study Atrial and Ventricular Fibrillation. In this research studies were conducted for filters such as Kalman, gaussian and LMS but ended up designing signal differentiation and DFS for AF and VF studies, Normal Sinus Rhythm (NSR) was used as a base signal for VF and AF studies. The novel COMMA-Z is the groundbreaking methodology developed in the research work, but this filter will not be that effective if the work is not being developed using right sensors placement region on the body. Finally, HEAR device to the earlobe was developed for enormous amount of heart rate data collection and then compute that data on a GPU to predict, analyze and study the dangerous and deadly cardiac arrhythmias such as Ventricular Fibrillation and Atrial Fibrillation using novel COMMA-Z filter along with signal differentiation method and DFS(Depth-First Search Algorithm) [126] to understand not only the deadly conditions but also the patient’s heart data and electrical activity of the heart.

CHAPTER SIX

SPECIALIZED SYSTEM DESIGN

Having the HEAR device placed at the Earlobe is very important for the driver who is a user or a patient. The Normal sinus rhythm and related heart data changes for arrhythmias such as VF and AF are computed in real-time on ever-day basis while driving but in hospitals and clinics similar observations are provided for medical professionals as shown in Figure 17.

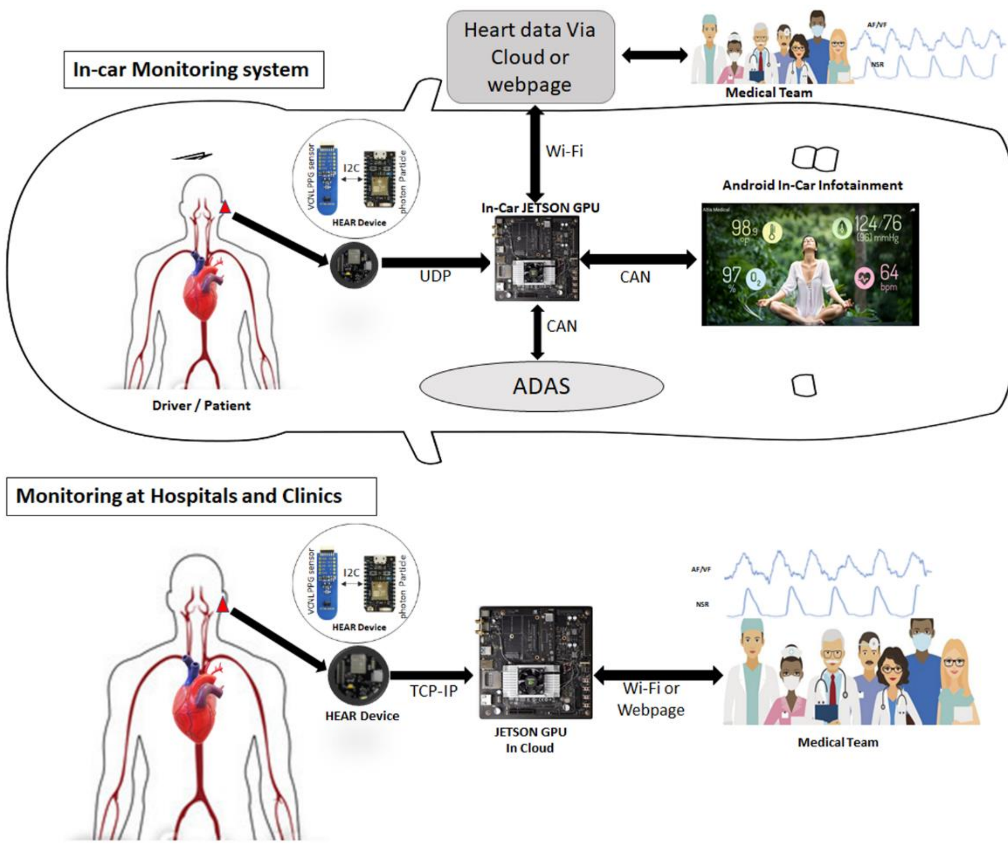

Figure 17 Complete system pipeline : In-car and Hospitals

Previous chapters discussed about the different building blocks required to build a system to observe, predict and analyze the occurrences of atrial and ventricular fibrillation while comparing with Normal sinus rhythm. Figure 17 shows how well the system is designed for both In-car and Hospital monitoring. As discussed earlier the research focuses only for In-car monitoring only. The system pipeline clearly explains the protocols and components used to develop the system from ground up. The HEAR device software hardware and the parallel code for the GPU play a major role in this system.

This Chapter will showcase the completed system pipeline for monitoring in-car and in hospitals as shown in Figure 17.

6.1 Proposed System Design

There are two different frameworks designed one for traditional moving average filter and other is the novel continuous median-moving average filter. Both these filters are applied using CPUs and GPUs. Here CPU and GPU are both part of the Jetson hardware only. Based on concepts we know that GPU is a combination of CPU, CPU receives data and loads them onto the memory via PCI bus for GPU to perform computations, to design the system for best performance CUDA programming related techniques and approach should be thoroughly understood, followed, and implemented, any failure to do this will lead to critical real-time system design and functionality failure. This work contributes to make use of a standalone CPU irrespective of the GPU to compare results. The Figure 18 explains basic framework designed on a standalone CPU initially. The pipeline of the system defined in Figure 18 is a combination of simple moving average filter and traditional median-moving average filter on a standalone CPU. When the raw sensors data is received on the CPU both these filters are applied. Firstly, the proximity and current settings of the HEAR device are addressed and designed for a potential environmental vibrations, conditions and noise obstructions, the initial filter algorithm in the HEAR device is designed for the filters to first adapt to these conditions and automate the Particle Photon IoT device (STM32 Microcontroller) to programmatically set and reset certain parameters of the Vishay VCNL PPG sensor register.

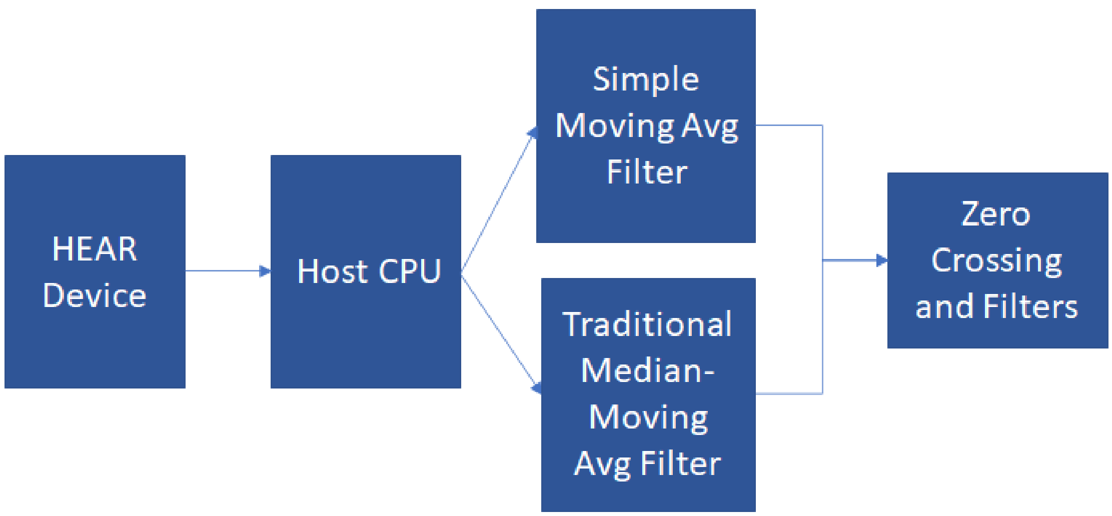

Figure 18 CPU System Operation Pipeline for Traditional filtering without the GPU

The traditional moving average filter algorithm for a CPU reads an input signal of certain set samples to average the filter with total number of samples in real-time. The algorithm loops to the next set of samples to perform similar operation. while this operation is performed the current and the proximity values are set to default by HEAR device PPG sensor registers, when the traditional median-moving average filter output is not stable with set threshold level then the final output does not satisfy the noise and vibration corrections and rules to apply zero crossing algorithm, the CPU writes back the required current and proximity values to the HEAR device PPG sensor, the traditional median-moving filter is a 3 point to 12 point recurring method of averaging to find every possible median within a set of 100 - 200 raw samples of data and these samples range may increase to 500 samples, this filter also is a combination algorithm designed to predict unknown spike occurrences due to sudden environmental changes and conditions which may have occurred while driving but we found errors computing this scenario using CPU due to less computing power and was fixed with enormous amount of data using GPU and CUDA which is part of the COMMA-Z filter implementation, the sudden occurrences of various heart conditions and normal rhythms changes along with unknown driving or road conditions, noise and vibrations that occur frequently while driving so methods were implemented with combinations to solve such use cases. Confined to the research the traditional median-moving filter shows better results than the apple watch placed on a wrist while driving when compared with HEAR device placed at the earlobe.

GPU and CUDA related techniques were designed and researched to develop a better system for heart arrhythmias and conditions and its occurrences and one such was to modify the traditional median-moving average filter as continuous median-moving average filter because the latter does not provide better result on a GPU and hence required to compute enormous amount of data parallely considering the past and present heart data of a patient or user while comparing and computing the next occurring data simultaneously, this continuous real-time process consists of 5-point window size computing in real-time to find media, moving average and zero crossing and this implementation is named the novel COMMA-Z filtering for best results. The real-time data is varying due to the combination of various environment, road conditions and patient's history of surgeries or arrhythmias hence, an additional filtering block was constructed along with COMMA-Z filter as shown in Figure 15 and those are the signal differentiation and DFS methods .It is made sure that the experiment results are compared for both CPU and GPU.

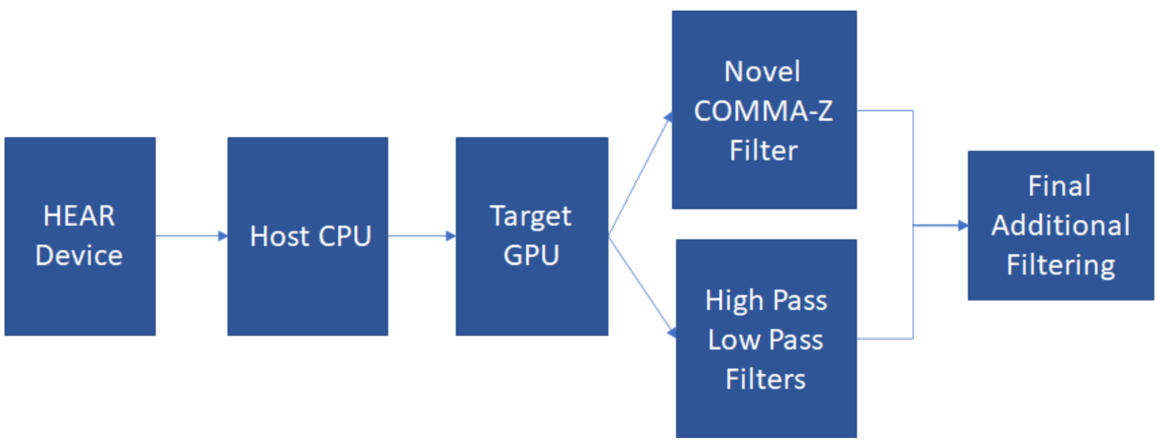

Figure 19 GPU System Design Pipeline using Novel COMMA-Z Filters

The GPU system design pipeline is defined in Figure 19, the Hear device PPG sensor is placed at the earlobe and placement of this sensor at the wrist is more prone to artifacts and enormous unknown activity. For experimental results and comparison, the HEAR device is also placed at the fingertip. Here the CPU on the Jetson reads all the HEAR sensor-based data and then loads all the data to the GPU, the raw heart sample data was divided into N number of thread/blocks for parallel processing and once the computation is done the GPU offloads the results back to the CPU for any further computation. The further computation as seen in Figure 19 would be to make sure the medical professionals have access to this data, various methods can be used to make computed heart data available to them but in the current work the focus is limited to only the novel idea and the method of computation. The target GPU comprises of the novel COMMA-Z implementation and related signal differentiation filter along with DFS algorithm for prediction of ventricular and atrial fibrillation diseases. In detail design and algorithm structure will be discussed in the software and hardware section of this thesis. The traditional moving average filtering techniques were demonstrated and implemented in our previous sections and chapters while comparing those with apple watch, but this novel COMMA-Z filter is to showcase how the continuous median-moving average filtering technique along with zero crossing algorithm executed parallelly on a GPU was better than traditional median-moving average filter on a CPU and apple watch [120], kardiamobile app or any other third-party devices.

The HEAR device PPG sensor current and measurements/sec settings are automated based on the patient or user skin thickness using software for the GPU based on the collection of initial data, one of the algorithms applied for Jetson TX2 initiates register commands to the HEAR device PPG sensor for best raw heart data collection based on initial sample collection. Hence, the particle photon’s STM32 microcontroller sets the registers of the PPG sensor via I2C protocol, this initially presets to default values and later sets values accordingly based on the thickness of the skin and sends commands from Jetson if required for best optimized GPU computing. ECG and PPG waveforms measured are totally different, PPG in fingertip/wrist and earlobe measures are discussed in the methodology section in chapter 1. The blood vessels in the earlobe are high compared to any place in the body and is ideal and the considered R-peaks for PPG at the fingertip/wrist require more current setting than at the ear and measuring raw heart data using green and red LED. our skin color is melanin and melanin is a very good absorber of green light [127] meaning the darker skin can absorb more light but red light is also widely used in hospitals especially the finger pulse oximetry devices the red light is not a good absorber by the skin hence it can travel deeper into the body and see multiple bed tissue in which multiple signals variations and noise can help prioritize noise reduction and signal purification for more sensor accuracy [120]. Considering these scenarios currently the HEAR device PPG sensors produces red light at the earlobe to demonstrate the work. Hence to conclude the COMMA-Z filters along with signal differentiation filter and DFS algorithm is applied on a GPU using extremely accurate raw sensor data from the HEAR device placed at the earlobe to output real-time computed heart data for medical professionals to compare, understand, predict and analyze any arising or existing heart related conditions such as ventricular and atrial fibrillation arrhythmias, and make assumptions for any emergencies and medical diagnosis after surgeries or arising serious heart conditions. The experiments are conducted while a patient or user is resting, standing walking, and driving.

6.2 System Design

In Figure 20 shows the ear with veins and arteries, one of the main arteries is connected to the heart valves directly and hence the blood flow to the head region is very high and constant. Figure 20 also shows the heart connected directly to the arteries to pump blood to the ear region. Many theories and surgeons and doctors and as per our research work show that the head is always warmer in the body and the heart pumps blood accordingly and our ears are the warmest. As Shown in Figure 20 the HEAR device sensor package placed to the earlobe is a combination of VCNL high resolution sensor and a standalone particle photon IoT STM32 microcontroller for establishing I2C and wi-fi communication. This device communicates to the Jetson board via UDP. The sensor consists of 3.3V rechargeable coin cell battery which is inbuilt. The Circular HEAR device mounting is a proprietary design, and the initial development was done using devkits. The IoT STM32 microcontroller sends register settings, commands, and wakeup signal to the vishay PPG sensor within the HEAR device initially on wakeup and the sensor capabilities are already discussed in Chapter 1 methodology section.

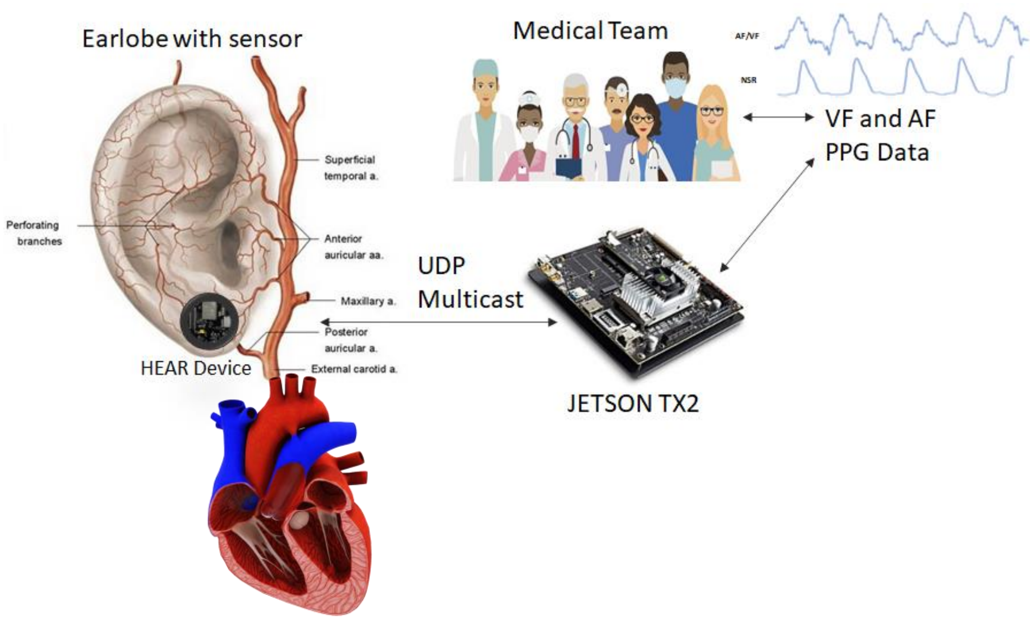

Figure 20 HEAR Device to the Heart : System Design [26]

In Figure 20 the HEAR device measures photoplethysmography signal when placed at the earlobe, the heart blood volume circulation and reflected heart data based on the HEAR device settings are preset to default by the microcontroller such as the current and the measurements/sec and this raw heart blood volume circulation and reflected data is sent to the Jetson Tx2 via UDP. Once this data is received at the Jetson hardware via UDP multicast the CPU collects the data and loads the data to the GPU memory via PCI Bus. Now the GPU applies the COMMA-Z filters accordingly based on the algorithm developed. Here, the raw values range from 0-65535 and based on the current and measurements/sec every patient and user will have the raw data values range within 0-65535 if the CPU within the GPU collecting raw heart data for some reason predicts 0 or out of range then most of the time the sensor current settings will be automatically requested to be decreased or increased based on the default settings and the photon's STM32 IoT microcontroller on the circular HEAR device sensor resets the register values accordingly. This technique is applied because of the skin thickness of the patient or user varies for every human body and environmental conditions and require current and other measurements to be set and automated accordingly, now the measurement values from 0-65535 continues and the GPU executes the COMMA-Z filter while applying signal differentiation and then finally DFS for arrhythmias and conditions occurrences for providing prediction and analysis to medical professionals. Detailed Software development for COMMA-Z filters and other related filters are discussed in the software section in this chapter. The circular HEAR device has an inbuilt charging circuitry as well. The GPU related thread/blocks are calculated based on incoming real time raw heart data and the kernels that are applied accordingly for computation. Majorly using CUDA techniques optimizing the kernels was designed using warps and shared memory. Heterogenous computing is a combination of host and the device integration of data via PCI bus, currently the host is the CPU, and the device will be the GPU. We have applied the raw data for both the CPU and GPU and compared these signals. The CPU always receives the data first and then packs it to its functions and simultaneously loads the data to the GPU kernels for computing, the COMMA-Z filter is designed as functions for CPU to pack data and then initiate kernels for a GPU for parallel computing, the experimental section discusses the final output results. Various experiments were conducted along with many use cases to understand the filter capabilities based on the environmental conditions for both CPU and GPU, as we know the circular HEAR device behaves and adapts to set changing current and measurements/sec values while resting, walking, dancing, and driving based on the thickness of the skin of the user. The COMMA-Z filter applied using CUDA technique is a challenging task that led to outstanding results when applied using a GPU to observe, predict, and analyze arrhythmias and conditions better and faster than any existing method or sensor out in the market. The medical team reviewed the data for some scenarios, and they will have access to the GPU computed data, this data is compared with previous history of the heart data and analyzed as well for any existing conditions or any occurring conditions or for general comparisons for arising heart arrhythmias such as tachycardia, bradycardia, sudden cardiac arrest and high risk of stroke but the current work will focus only on atrial and ventricular fibrillation arrhythmias. The doctors can request for different proximity and change current if required via cloud to the circular earlobe device of the patient or the user via wi-fi, this feature is implemented here as well but we will not be demonstrating this feature due to some limitations on development and scope of work.

6.2.1 Hardware Design Model

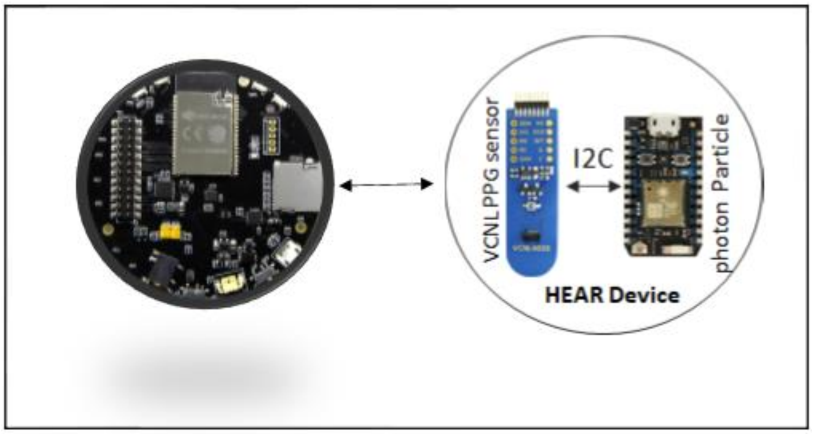

Figure 21 HEAR Device components

The circular HEAR device as shown in Figure 21 is a combination of both VCNL high-precision proximity sensor and ST Microcontroller. The power required is 3.3v and approximately 100ma–200ma from both these devices. The circular HEAR device consists of a USB slot to recharge the in-built battery and at the same time debug the STM32 microcontroller. The particle Photon IoT STM32 Microcontroller device can also be programmed and controlled using OTA using Wi-fi. The VCNL PPG sensor shown in Figure 17 is an Evaluation board of the VCNL 4020C sensor for development and testing. The PPG sensor used to build the circuit for the HEAR device is surface mount

SMD package of Dimensions (L x W x H in mm): 4.90 x 2.40 x 0.83 as seen in Figure 21.

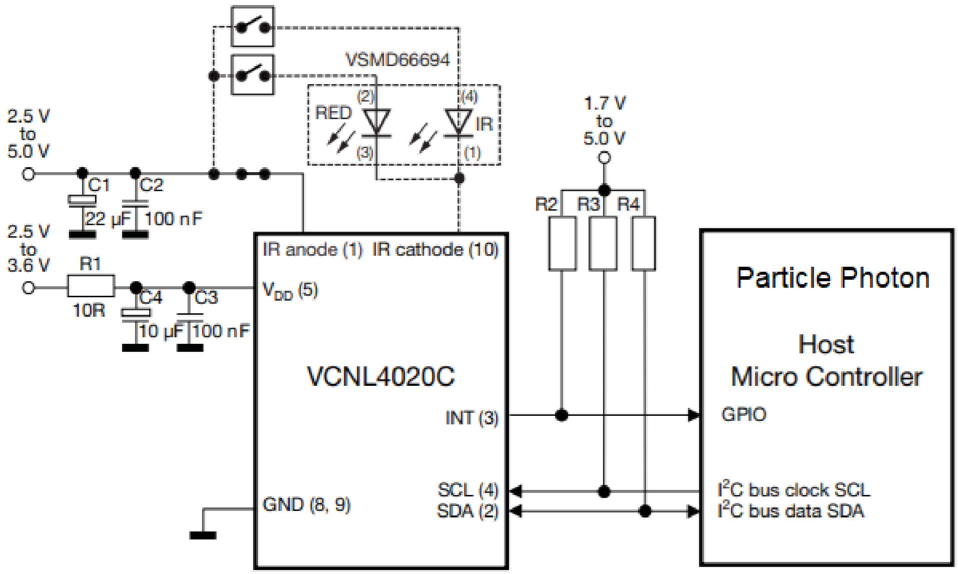

Figure 22 Circuit Diagram for HEAR device [128]

The ST Microcontroller is connected to the PPG VCNL 4020C proximity sensor via I2C bus, and the microcontroller sets up the registers for the current and measurement/sec for the PPG sensor as shown in Figure 22. The HEAR devices particle photon IoT microcontroller activates the UDP connection for the Jetson TX2 hardware to send the raw heart data for computing. The HEAR device and the Jetson TX2 model diagram and connection is shown in Figure 13 and Figure 16.The Circular HEAR device also has a feature to update the software via OTA. Currently this feature is also available and fully functional. Medical professionals can push some software updates or changes to the HEAR device via cloud because the particle device IoT also support cellular 3G. The power circuit for the VCNL 4020C sensor and the particle photon is connected to rechargeable battery circuit.

6.2.2 Software Design Model

The software section explains algorithm developed to interact between the HEAR Device and Jetson Tx2 GPU. Firstly, as discussed in the previous sections the algorithm explains the method of continuous median-moving average filters for a GPU. The first method implementation is for the particle Photon IoT STM32 microcontroller part of the HEAR device that initiates raw heart data by setting current and measurements/sec and next is the COMMA-Z filter implementation along with signal differentiation filter and DFS algorithm for the Jetson hardware to observe, predict and analyze ventricular and atrial fibrillation. As shown in Figure 18 the first method of development is implemented for the STM32 microcontroller to initialize the PPG sensor while setting registers for current and measurements. The second step is where the connection is established between the HEAR device and the Jetson Tx2 via UDP and once the Jetson board CPU host receives the first set of samples, the samples are fed to the GPU device kernels using thread/blocks for computing and optimized using shared memory, warps, preventing control divergence technique and coalesce all memory accesses. The Novel COMMA-Z filter is implemented along with signal differentiation and DFS. This Novel implementation consists of 4 kernels to achieve the results. To begin with a detailed implementation of the COMMA-Z algorithm the 5-point window size median filtering was designed as a first kernel of the GPU the first kernel reads the raw heart values from the HEAR device continuously in real-time to find a median recursively for a set of previous and next occurring set of values. This median filtering was designed from 3-point window size prediction untill 12-point window size prediction but more the points the smoother the signal becomes but the current and other HEAR device PPG sensor settings need to be perfectly synchronized with the thickness of the skin if not the diastolic peak will not be visible sometimes. The windows size is also dependent on the HEAR device sensor settings. Refer to the Figure 5 for the diastolic peak curve, all occurring raw values need to be carefully designed accordingly. Hence, based on research the 5-point median was the best prediction point range for a set of 100 - 200 samples of raw heart, noise, vibration and other driving related error signals and unknown data. In this kernel majority of noise and vibrations and unknown signals occurred are removed. This was only possible because the 5-point window size is constantly and continuously shifting to parallely compute to produce the original signal. Now, implementing the second kernel which is the moving average to the existing 5-point window size median kernel output. This particular process can also be achieved using 5-point on a CPU only serially but it doesn't compute well when compared to the GPU even with such enormous amount of data on a CPU because on a CPU a lot of resources and techniques are required to handle such data to compute and store some values in global memory and always recurring through that array of data in the memory to compute but in a GPU it's just thread/blocks and computing happens parallely using shared memory and applying thread synchronization to make sure all the thread are computed, along with other CUDA related techniques, the GPU when compared with the CPU the bench marking results showed that the GPU is approximately 132.20 times faster and better computed compared to the CPU and the figures in the experiment section show the benchmarked outcome, along with some outstanding results in the experiment section. The third kernel is the zero-crossing detection algorithm where the threshold presets values between positive and negative values at zero for the final signal which is from the second kernel. Finally, in the fourth kernel the data point difference for a signal is generated considering high pass and low pass filter application to the zero cross detection followed by DFS (Depth first search algorithm) to observe, predict, and analyze the occurrences of atrial fibrillation and ventricular fibrillation comparing with Normal sinus rhythm. To conclude, the COMMA-Z along with signal differentiation and DFS on a GPU is approximately 132.20 times faster and better computed when compared with the CPU or other existing devices in the market such as Apple watch and Kardia mobile or any other third-party sensors. The experiments are conducted using all the 4 kernels on a GPU while resting, standing walking, dancing, and driving and in this work, Figure 23 shows algorithm flowchart that includes all the 4 kernels of the GPU.

Once all these kernels are implemented as shown in Figure 23, the data point signal differentiation and DFS perform similarly as explained in the methodology section in chapter 1 as shown in Figure 16. Later, all the VF and AF computed data is sent to the medical professionals for any future study to observe and predict and analyze, the results include metrics and studies based on the COMMA-Z, signal differentiation and DFS filters, the GPU computing better than a CPU could not be possible without the GPU, Averaging filter technique and CUDA techniques. The Figure 18 explains the novel implementation of 4 kernels for a GPU, Now let’s discuss about these methods and techniques developed using CUDA programming. To implement CUDA programming techniques one needs to be aware of CUDA architecture design and GPU framework.

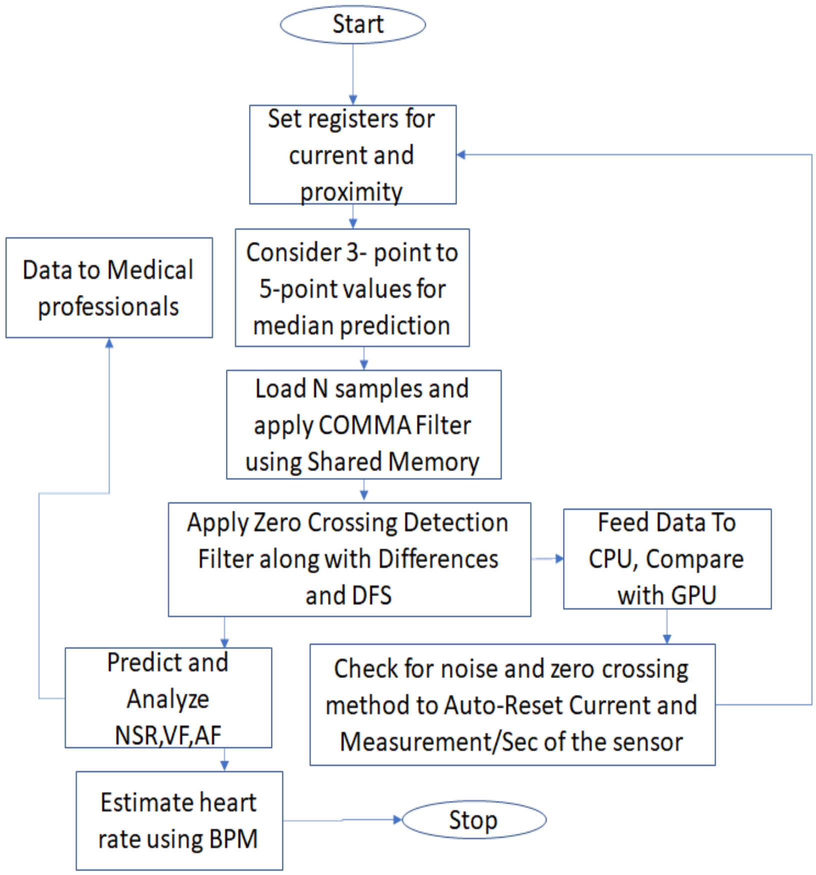

Figure 23 Software Algorithm Flowchart

Heterogeneous computing system consists of the host and the device memory, the host CPU loads the input data from the HEAR sensor to the device GPU to compute results parallely using kernels. In CUDA programming the host will launch the device code aka kernel code through CUDA API's. The kernel is a parallel code launched by the host on the device. Considering only 1or 2-dimension method the kernel will be launched with grid, and thread/blocks parameters, so the syntax is kernelfunctionname <<< Grid, ThreadsperBlock>>> (arg1,arg2…, arg n) here in the syntax the grid is composed of blocks and it can be either 1,2,3, dimension and block is composed of group of threads in 1,2,3 dimension and executes the kernel code in parallel, the 5-point windows size shifting continuously in every 5 threads in a block. The threads have been defined for each block to perform computation parallelly, the COMMA-Z parallel computation within defined threads per block for all the 4 kernels applied shows outstanding results. There are various types of memory, one is local memory and another one is global memory but for high - performance optimization techniques shared memory methodology of implementation is followed because shared memory is faster than local and global memory and the threads can access the shared memory within the same thread block. Each thread is indexed to one value of raw heart date, the first 32 values(warps), keeping in mind the number of warps assigned to a streaming multiprocessor in threads per block, each block consists of 32 values i.e., each thread is indexed with real time raw heart value to be computed using shared memory to perform averaging. The entire software design should be thoroughly understood and developed keeping in mind the EKG course concepts to understand arrhythmias along with CUDA techniques if not we might not observe better performance and occurrences in the final computed signal which may lead to increasing the error percentage to maximum potentially leading to failures in GPU computation.

CHAPTER SEVEN

EXPERIMENTS PREDICTION AND ANALYSIS

As discussed in previous sections, the HEAR device is placed to the earlobe that collects raw heart data. The Particle IOT microcontroller understands its surroundings and builds register settings to the VCNL vishay PPG sensor which is part of the HEAR device. These register settings can also be controlled manually using OTA. The experiments are conducted with varying currents and measurement and related positions of the patient or user.

In these experiments the GPU compute the raw heart data using the COMMA-Z filter along with signal differentiation and DFS for NSR, VF and AF and all these occurrences are compared using a CPU and demonstrated accordingly in this chapter.

7.1 Experiment Setup

Most of the Experiments are performed indoor and outdoor. The Experiment setup is a bench setup that is portable which can be used in any environment. The Bench setup includes HEAR device and Jetson GPU Hardware with portable power supply. In Figure 24 the experiment setup is a bench setup, and the similar setup is designed for car except the HEAR device is compact and fits the earlobe region as observed in Figure 8 and Figure 17. The portal setup shown in Figure 24 consists of HEAR device with a combination of VCNL4020C Evaluation Kit and Particle Photon IoT STM32 Microcontroller, 4G LTE hotspot for UDP communication and Jetson TX2 GPU.

The HEAR device components communicate via I2C internally setting registers and memory and initiates UDP client. The 4G LTE supports communication between the

HEAR device and Jetson GPU. The Jetson GPU is designed as UDP Server, and this experimental setup helps sending raw heart data from the HEAR device to the Jetson GPU via UDP for computation and the Jetson GPU will request back any change in milliamps current and measurements/sec settings based on the skin thickness and environmental conditions as discussed in earlier chapters. In the vehicle the Jetson GPU is inbuilt along with 4G LTE Wi-Fi and the only device that requires to be used by the patient or by the user while driving is the HEAR device. At clinics and at hospitals the 4G LTE will replace the existing Wi-Fi and the Jetson GPU is a standalone hardware placed in the cloud to compute and receive results on everyday basis.

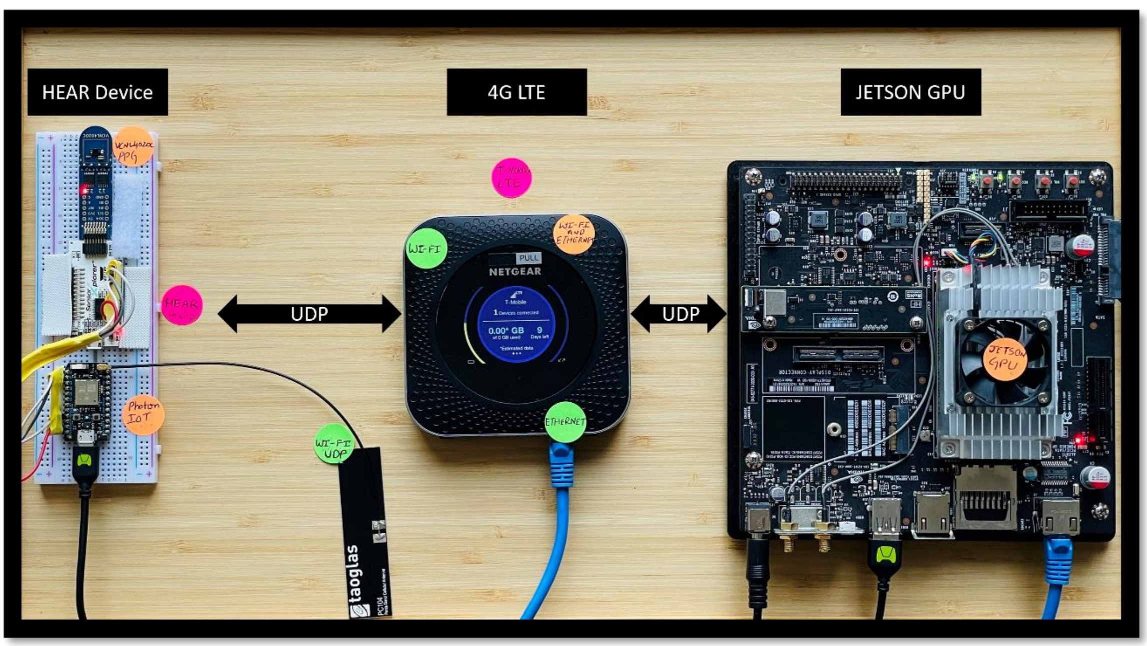

Figure 24 Portable Bench Setup for Experiments (Similar Vehicle setup)

7.2 Experiment Results

While working with one of the well-known surgeons from Michigan, the related outcome of these experiments is thoroughly communicated and experimented. Firstly, a simple experiment is demonstrated in Figure 25 to compute a Random Noise signal both using a CPU and GPU. Here the observation shows how well the computation is being performed for that random signal using COMMA-Z Filter. In all the Experiments conducted the x-axis is the time in seconds and y-axis is the Amplitude in range.

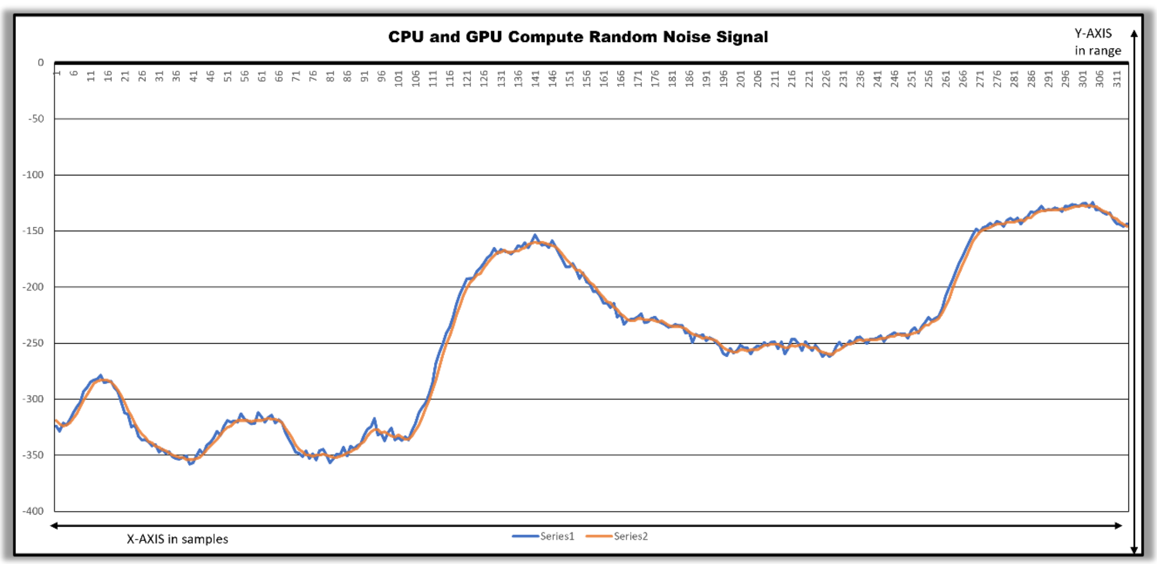

Figure 25 Random Noise Signal Computed on a GPU

From Figure 25 the signal in orange color which is mentioned as series 2 is the GPU computed data and the signal marked in Blue is series 1 which is the CPU computed data and the differences of computation using the novel COMMA-Z classifier behaves differently both in CPU and GPU. Here in this above scenario the GPU and CPU computed the heart data sample in real time. Now let's understand how well a heart data signal is computed both using CPU and GPU with various environmental conditions and scenarios.

Now let's indulge fully into details and understand and analyze in all possible scenarios while indoor and outdoor both for fingertip and earlobe using the experiments setup as shown in Figure 18. The experiment conducted indoor are while resting, walking, dancing and outdoor is while driving at the clinic and gymnasium. In this Research work the raw heart data is computed with various filter as discussed in the methodology section and system design section along with bench system setup from Figure 24.

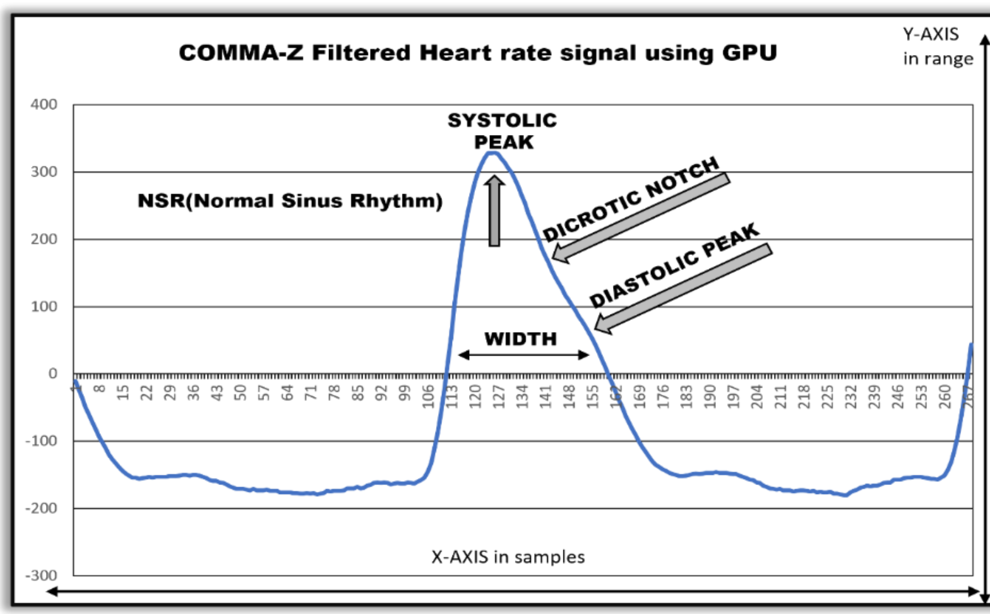

Figure 26 Generated Normal Sinus Rhythm Overview

The software algorithm developed for filtering has been applied on both CPU and GPU and bench marked accordingly for various use cases and conditions. As shown in Figure 26 the wave form clearly shows the PPG signal that is generated from the GPU which looks exactly from the theoretical representation of PPG from Chapter 1. The reason to revisit this signal once again as Figure 26 was because this NSR(normal sinus rhythm) will be used all over the Experiments to compare with other occurring and observed signals and condition to compare with arrhythmias.

Now let’s understand the use cases when a person is resting, standing, walking, driving, and dancing. As demonstrated in Figure 27 the male subject is 29 years old and default current and measurements are used, In Figure 27 observation set A the data is being collected from the fingertip with a default current of 40ma and measurements at 16.625/sec this subject is at a resting condition, the amplitude is the y-axis and time/sec changes at x-axis for all reading and experiments in this chapter.

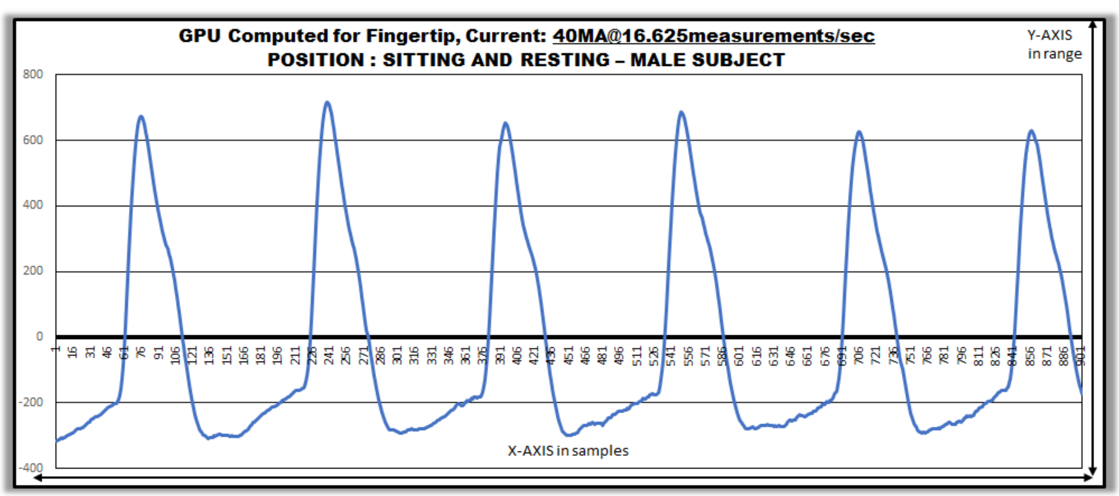

Figure 27 Observation Set A : GPU computed data on a Fingertip

The signal in the Figure 27 is clean and well computed signal with no noise and error signal with constant distance between the R-R interval i.e the big triangle shaped signals with clean dicrotic peak. Here in Figure 28, over the air update was initiated to the algorithm in the particle photon microcontroller to manually update the current to 20ma and measurements/sec to 16.625 to observe the change in the signal for the previous participated subject who is 29 years old male subject. The signal amplitude and the time between the RR intervals has slightly changed. To analyze that the amplitude at the y-axis is not greater than 380 and has reduced when compared with Figure 27 which is 700 showing better computation at the dicrotic peak.

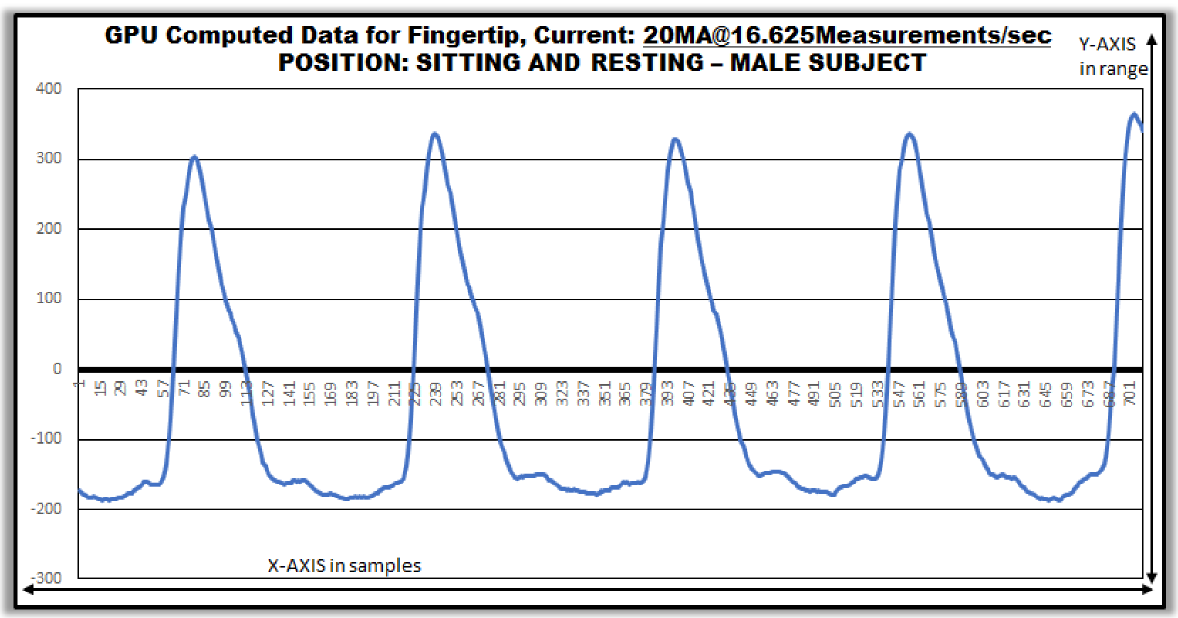

Figure 28 Observation Set B: GPU computed Data for a Fingertip

In Figure 29 which is the observation set C the measurement and current were manually updated and this time the measurements went up untill 250 and we can see that the signals is too clean in such a way that the COMMA-Z filtered out the dicrotic peak and notch as well. Hence this setting is not a valid setting for this person while resting.

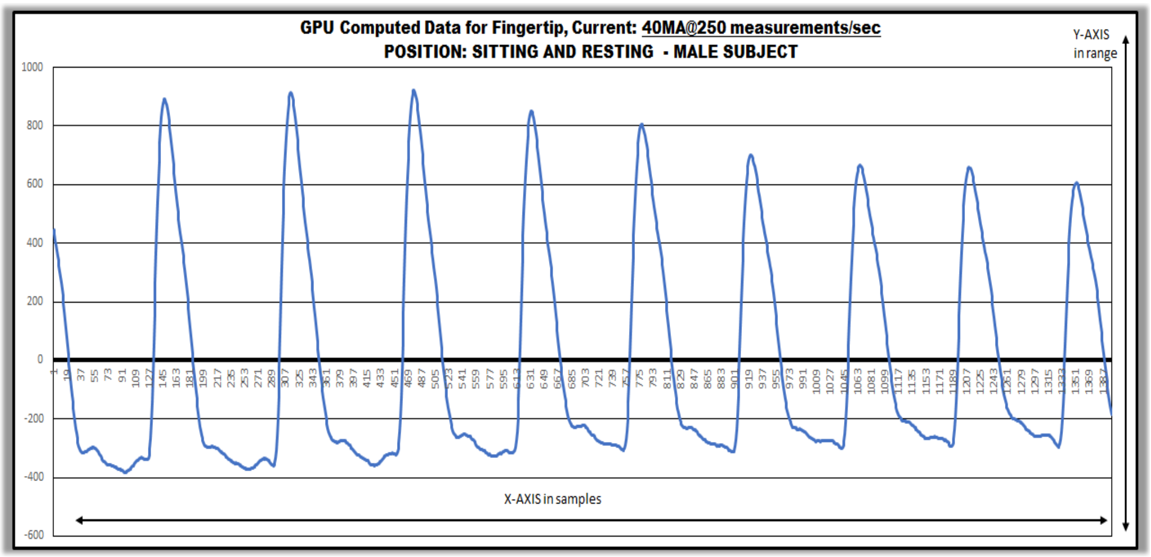

Figure 29 Observation Set C : GPU Computed Data for Fingertip

In Figure 30 observation Set D computes heart data for a male subject who is 35 years old, this experiment was conducted to observe the position of standing and walking the results show jitters at the P wave region and some added noise due to the artifacts of walking and this computation needs more data and enormous amount of it which will be fixed by setting the current sensor values for less penetration of current to the skin because the raw value in this situation would lie between 63000-65000 range of integer values which is too high of a current. Based on the COMMA-Z filter the Figure 30 requires some sensor settings updates.

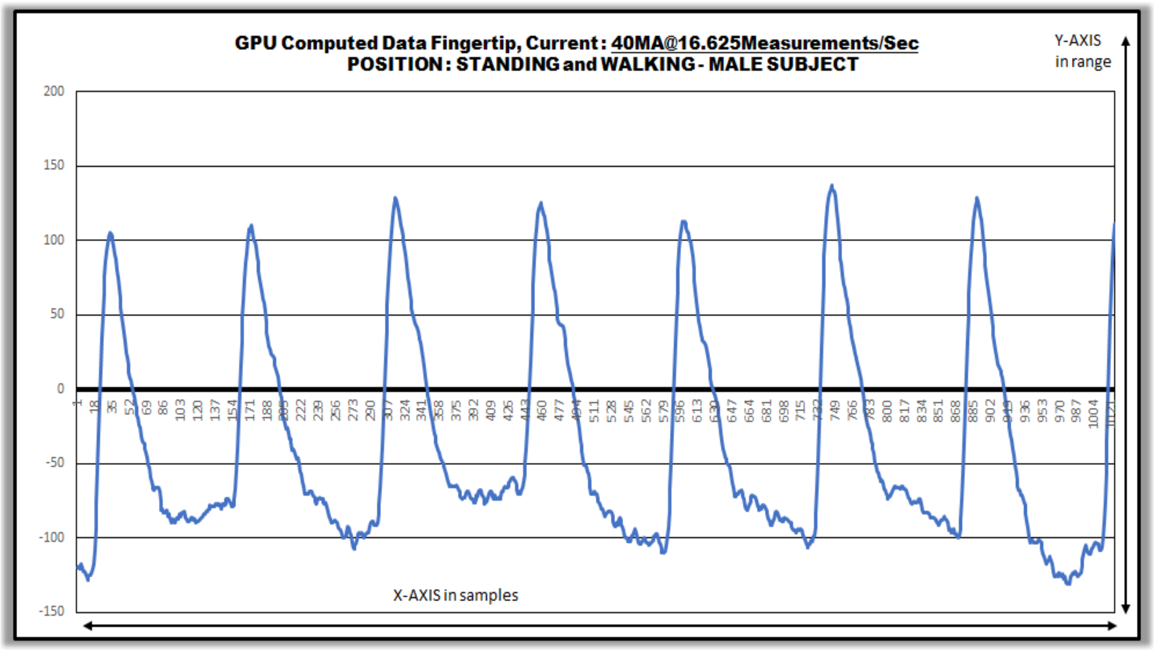

Figure 30 Observation Set D: GPU Computed Data for Fingertip

So, finding a solution for Figure 30 was to design Figure 31 where the current sending that was applied was reduced and increased the sampling rate measurements/sec and finally the results show better output at the dicrotic notch and dicrotic peak when compared between Figure 30 and Figure 31 with almost reduced to 2 percent jitters, but this current and measurements settings of the register will be taken care by the Jetson automatically if it’s observing a raw value out of range(Range between 1-65000).

To conduct this experiment manually the register setting was updated via OTA to the sensor register via the photon IoT microcontroller, the current was set to 30ma performing at 61measuremnts/sec. So finally, the Figure 31 shows better results removing the jitter noise and related artifacts while standing and walking. This observation was not possible on a CPU and requires a GPU to compute the results remained the same in the CPU with very minor changes in the signal. Thus, sometimes feeding more samples to the GPU will also be a disadvantage as we might lose some necessary signals such as stent placement for a patient who might have undergone cardiac surgery and angioplasty as observed in Figure 16 where it shows the stent region, and that region will have an extended waterfall curve and there can be possibility we might not see such a curve as well. Here such scenarios are considered while developing the COMMA-Z algorithm. This concludes that we don't lose the originality of the signal but still providing outstanding results.

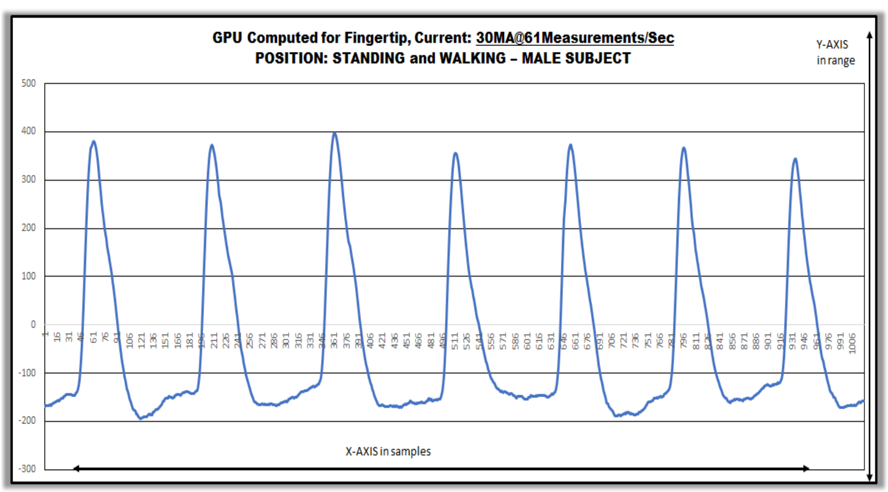

Figure 31 Observation Set E: GPU Computed Data for Fingertip

Some more experiments were conducted using fingertip and this time the position chosen was to dance, move and perform some activity, as shown in Figure 32 the amplitude and width of the signal will reduce because the subject is breathing faster when compared to walking and standing and we can see how good the signal is computed without any noise and vibration.

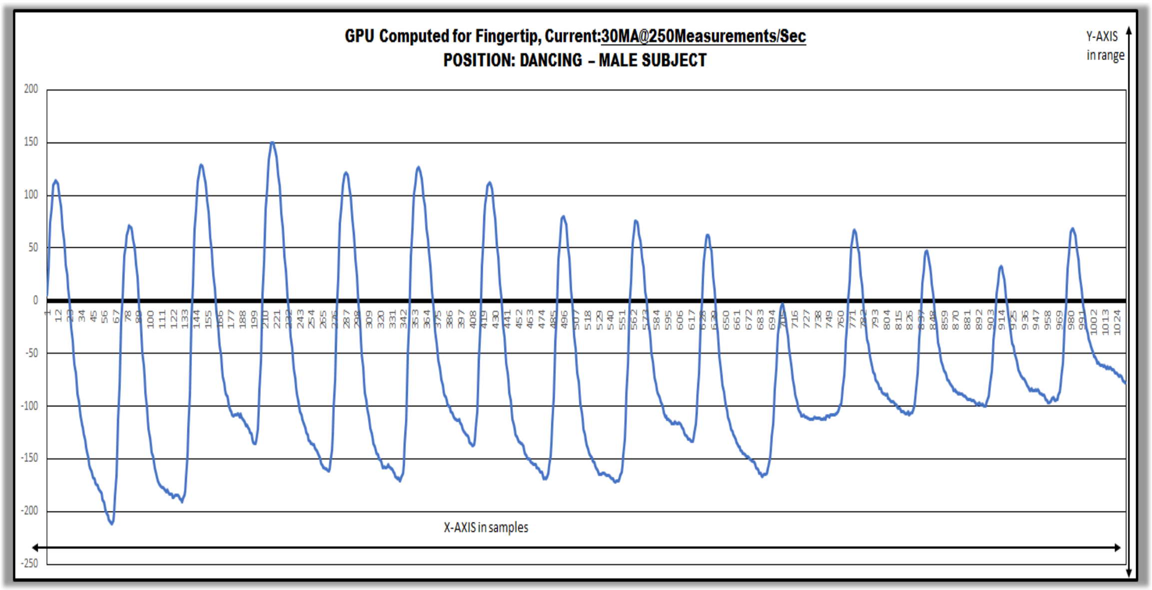

Figure 32 Observation Set F: GPU Computed Data for Fingertip

Here, after multiple trails and settings the current was set to 30ma, and the measurements/sec was set to 250 providing enormous amount of data to the GPU to perform better computation.

By demonstrating these use cases and conditions the filter noise and co-related environmental conditions helped develop a better continuous median-moving filter on a GPU. In Figure 33 similar algorithm method was applied to the earlobe, and this is the region highly recommended in this work to observe, predict and analyze Ventricular and Atrial Fibrillation because here the originality of the signal is better contained than at the fingertip due to the enormous amount of blood vessels.

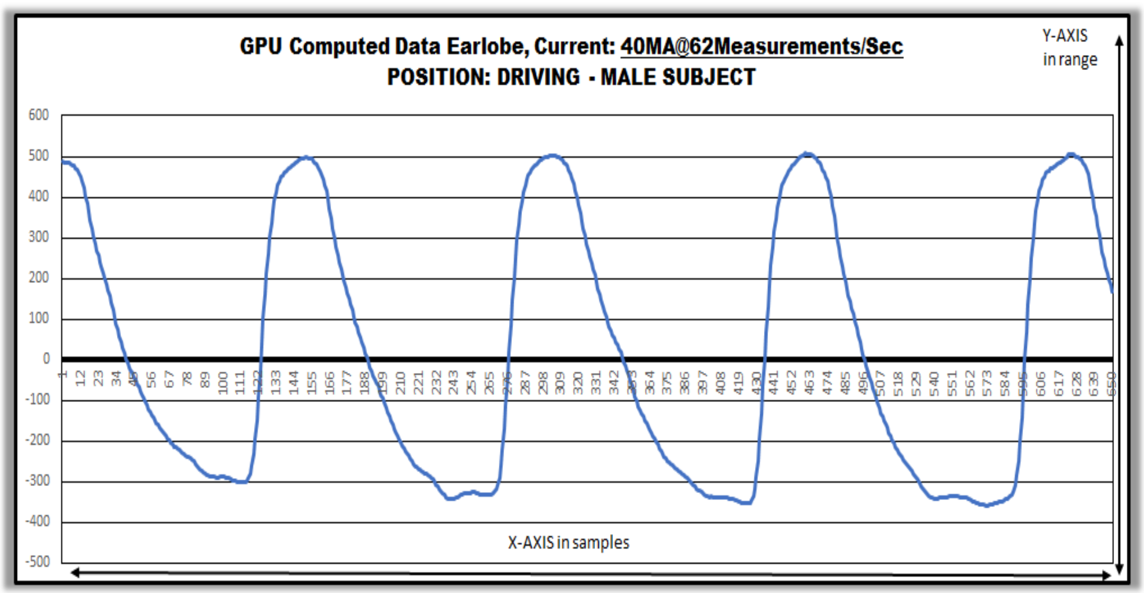

Figure 33 Observation Set G: GPU Computed Data for Earlobe

The participant is a male subject who is 41 years old and the experiment was conducted while the participant was driving, the setup is similar to as shown in Figure 8 and the heart data recording and computing was done in real-time while subject was driving.

Now based on the current and measurements/sec the data shows some unique results without any jitters, noise and unnecessary signals that may have caused due to the road conditions which are filtered by the COMMA-Z filter. The computed data shows width, dicrotic notch and peak but no irregular intervals. So faster and slower atrial and ventricular rate can easily be observed and predicted better on a earlobe than on a fingertip using a GPU. Figure 34 is the GPU computed Atrial Fibrillation data at the earlobe from a male subject who is currently a patient.

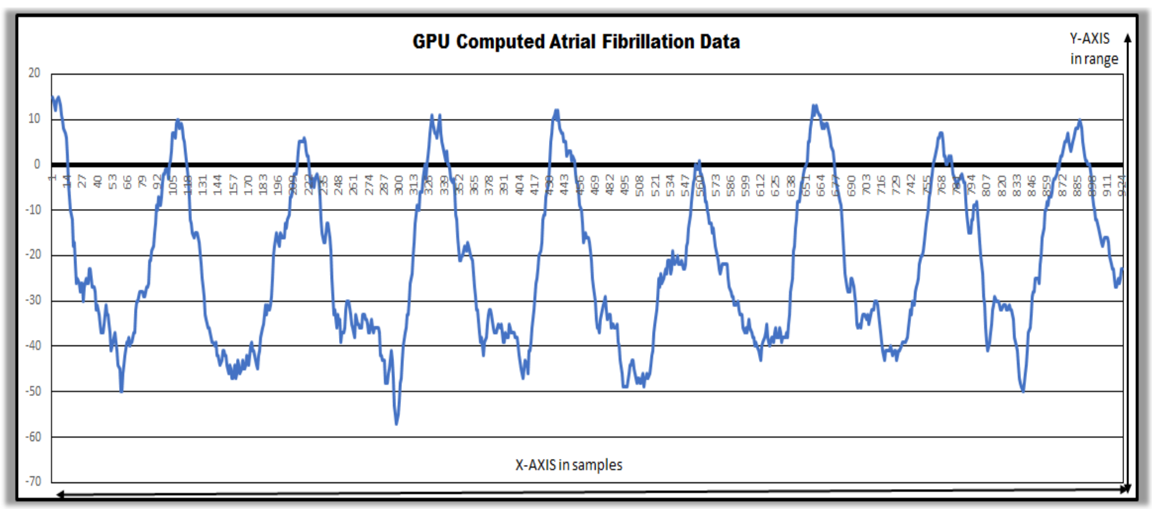

Figure 34 Observation Set H: GPU Computed Atrial Fib Data for Earlobe

As HEAR device requires passive touch capabilities only it was easy and faster to collect data using the PPG technology to compute and the method used to observe, predict, and analyze such signal as discussed in the methodology section in Figure 16. In brief Figure 34 is compared with normal sinus rhythm while applying COMMA-Z, signal differentiation and DFS filter accordingly as described in Figure 16. The signal description in Figure 34 clearly shows the existence of Atrial Fibrillation, similar functions from a GPU were applied to the CPU only device and found that the computation and prediction were not satisfying, and some benchmarking results are also conducted in this chapter. Figure 35 resembles the originality of the raw heart data from the HEAR device even before the data is being sent to the Jetson hardware via UDP for computation. This raw heart data is originally from the earlobe in this observation Set and this raw signal will be computed by those 4 kernels for final output using the GPU.

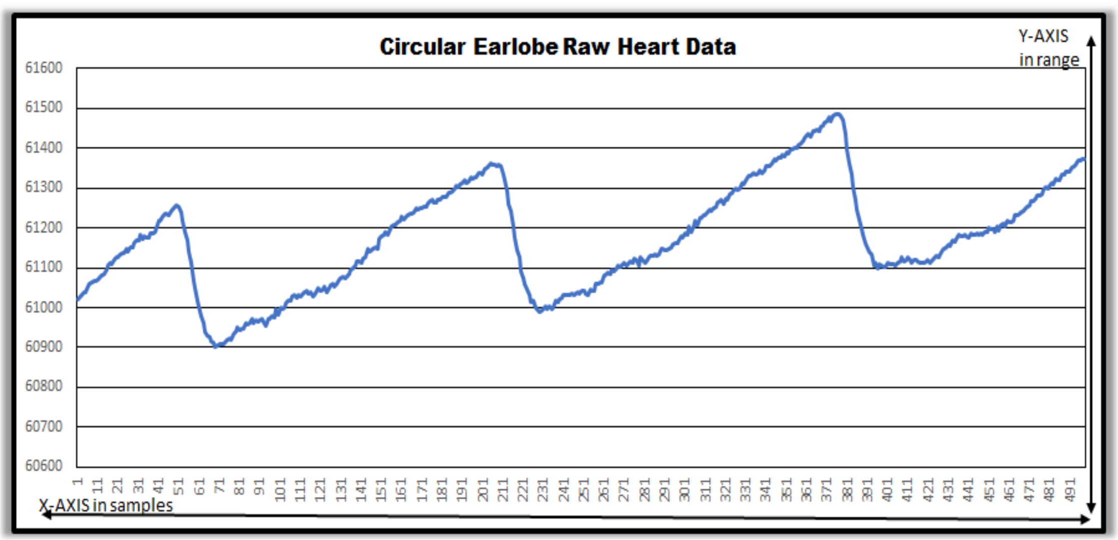

Figure 35 Observation Set I: HEAR device Raw Heart Data

After the Figure 35 raw heart data signal one of the main kernel designs on the

Jetson is the moving average signal that will be combined with median of the 5-point windows size continuously shifting and this moving average removes enormous noise and other errors signals, this signal plays one of the important roles in the COMMA-Z filter implementation.

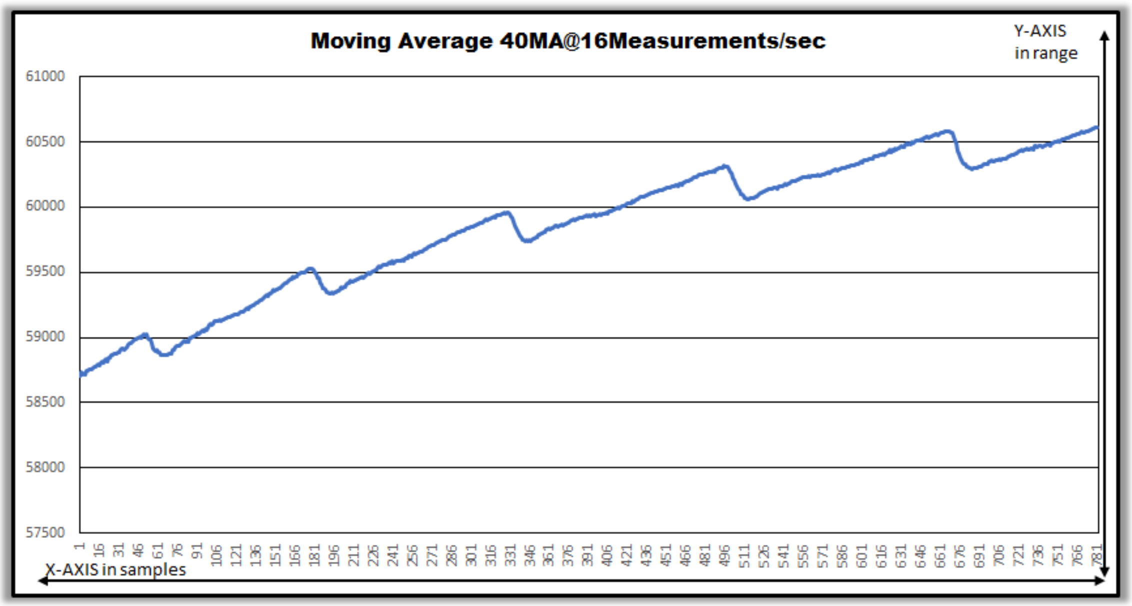

Figure 36 Moving Average Data

In Figure 37 an experiment was conducted to collect Earlobe data from a female subject while driving however the HEAR device sensor settings were manually for couple of trials. The signal is stable when compared with other computations at the fingertip.

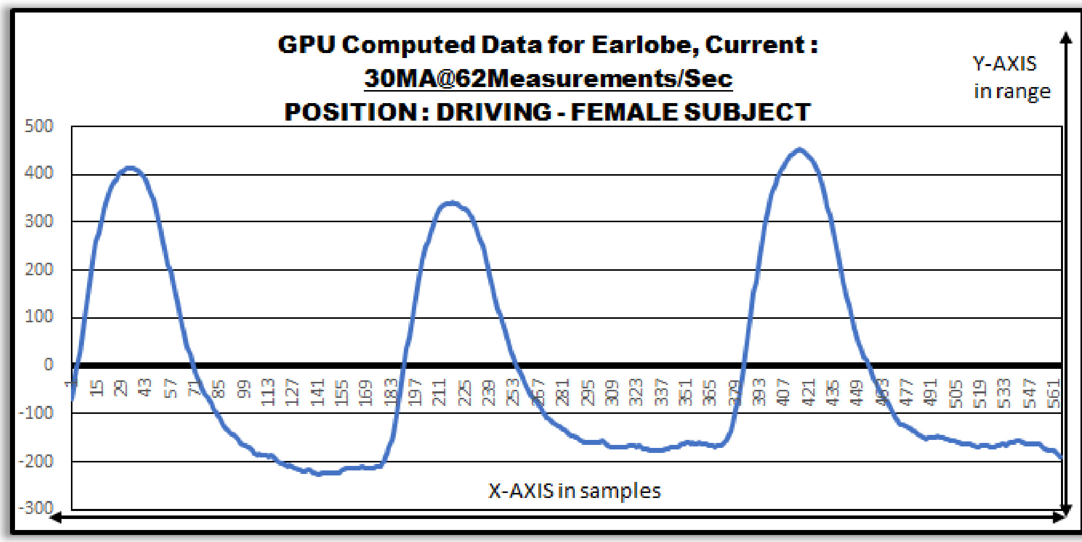

Figure 37 Observation Set J: GPU Computed Data for Earlobe

The COMMA-Z along with the GPU computed signals at the fingertip and earlobe are very interesting and these are the results of one of its kind because for the first time while driving such results are seen and there exists no such results currently based on the literature and research work.

In Figure 38 the observation set K shows that the traditional moving average signal output representation is computed only using a CPU and related functions while still considering placing the HEAR device at the Earlobe. The results consist of various irregular increment in the amplitude of the signal along with various noise and spike that requires betterment. Based on the Figure 38 experiment a slight change in the current and measurements were applied as seen in Figure 39 but with increased sampling rate of 100 samples for the window size median filtering using a CPU, for all the previous experiments

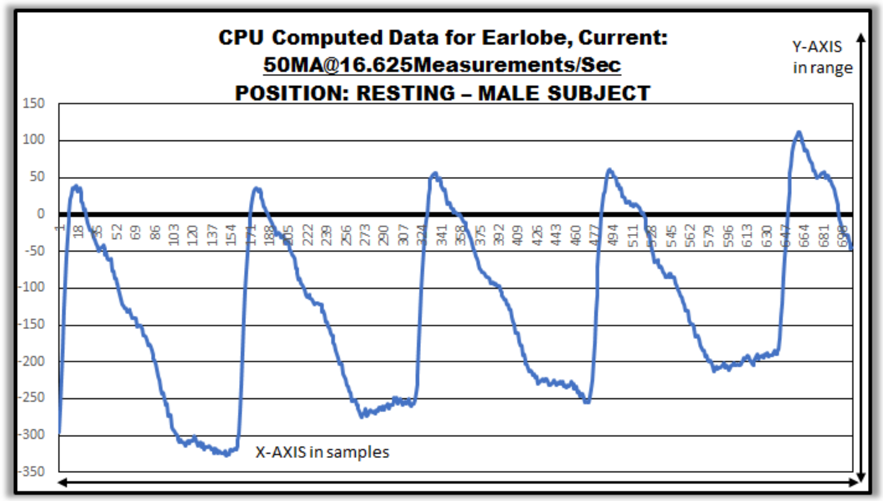

Figure 38 Observation Set k: GPU Computed Data for Earlobe

the maximum parallel threads/blocks chosen was 64 for 5-point window size median filtering on a GPU. We can observe that the signal is slightly improved but consumes more time to compute based on the measurement/ sec and sampling rate.

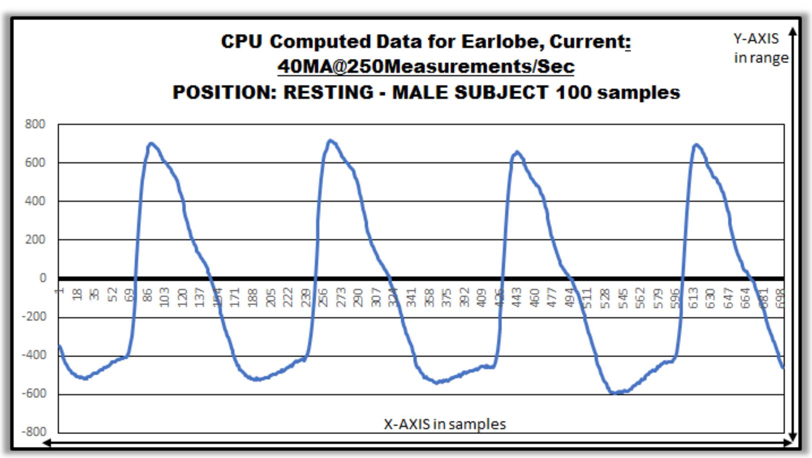

Figure 39 Observation Set L: GPU Computed Data for Earlobe

7.3 Processing Time Analysis

The most interesting section of this chapter is benchmarking the CPU and GPU for the computed results together. The experiment was conducted while a Male subject was driving and the current and measurement/sec were accordingly as seen in Figure 40, Taking a closer look at the signal, we can observe that the GPU computed one which is the orange signal looks promising and better than the CPU computed one. In the Figure 40 the series 2 is the GPU signal which is colored as orange and the series 1 is the CPU which is colored as blue.

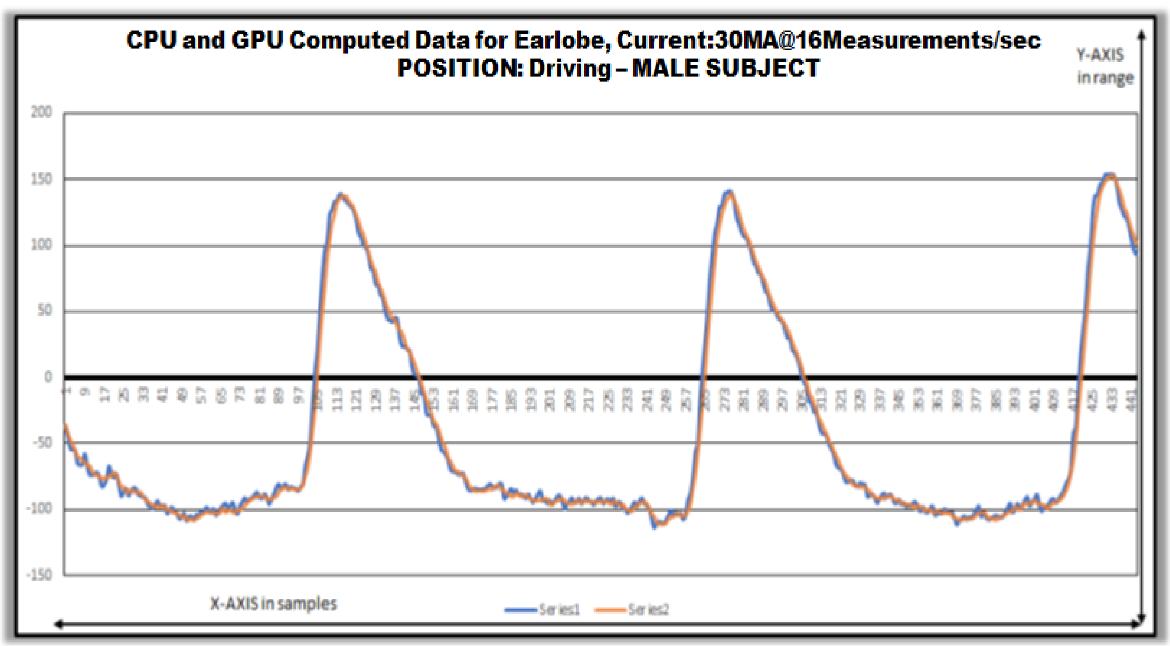

Figure 40 Observation Set M: CPU and GPU Computed Data for Earlobe

In Figure 40 the raw heart data from the HEAR device is being sent to the CPU on Jetson device which is marked as series 1 in the Figure 40 and GPU which is marked as series 2. Here speed does not come into picture because we wanted to compare and see how the novel COMMA-Z filter behaves on both CPU and GPU while driving and observed tremendous changes.

Finally, from Figure 40 its clearly understood that during acute myocardial infarction or any arising conditions the signal looks promising on a GPU than CPU. As discussed with medical professionals even when a stent is placed the observation of the signal with and without stent may look better as well using a GPU than a CPU [90] [87] [123]. This observation will lead to solving many arising problems and helps find easy solutions for medical professionals.

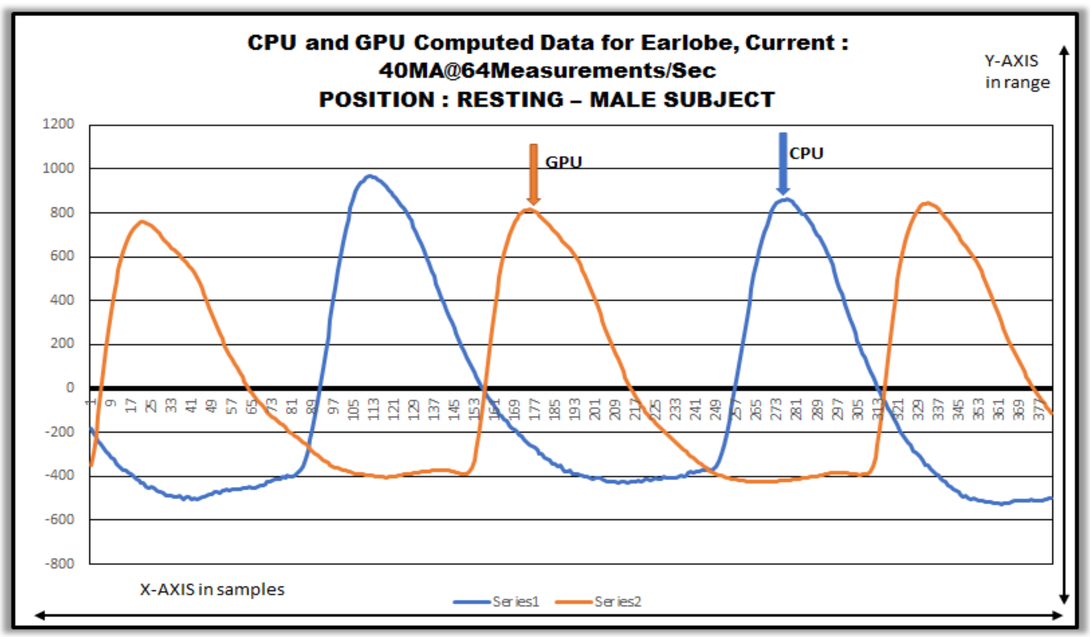

Figure 41 Observation Set N: CPU and GPU Computed Data for Earlobe

Now in Figure 41 the benchmarked speed and betterment of the signal is demonstrated. Here, the raw data to the CPU and GPU was simultaneously fed to observe how fast the prediction and analysis is executed and how well the signals are computed, based on this its discovered that the GPU was 132.20 times faster than the CPU using timers such as CudaEventRecord(). In Figure 41 as per the observation the GPU signal has computed the raw data while the CPU is still computing it. The core concept for the time delay here is because of the 3-point and 5-point median filtering. The 3-point filtering is the only best performance a CPU can get because if it is more than 3-point such as 5-point then the loops have to store the array data repeatedly and moving the window continuously will consume time while losing data based on environmental conditions or improper computation whereas in GPU the best performance can still go up to 8-point but for these scenarios 5-point was the best method because the window moves continuously for all the threads in a block synchronizing the threads. The 5-point was also applied to the CPU but does not look promising in terms if signal computation and is slightly faster but consist of various jitters and require more sampling data. The zero-crossing algorithm behaves similarly for both CPU and GPU but the GPU again outperforms for signal differentiation and DFS for prediction and analysis of occurrences of heart diseases and conditions.

Based on the previous signal the Figure 42 observation set O shows how well the CPU and GPU are computed heart data while driving using earlobe and this time the GPU outperforms and shows some outstanding results. The signals are combined together to represent that the speed and the computation performance of the raw data heart signal using COMMA-Z filter.

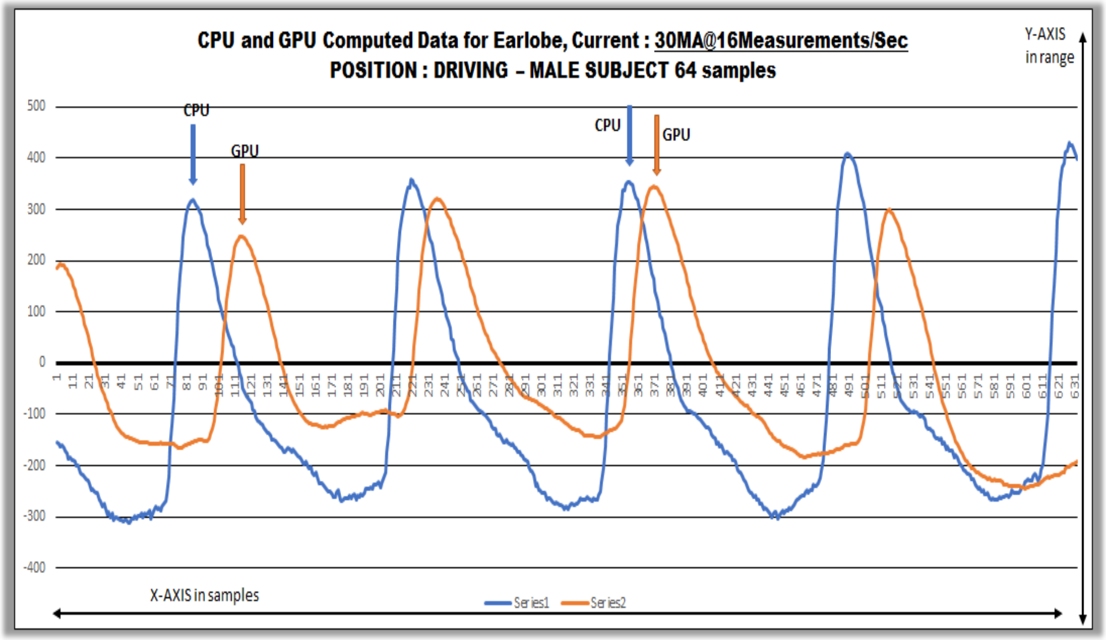

Figure 42 Observation Set O: CPU and GPU Computed Data for Earlobe

In Figure 43 the Physionet data is available to represent how a normal sinus rhythm and ventricular fibrillation look because ventricular condition data cannot be collected from patients as this situation is extreme and the person would be in an emergency care because his/her heart rate is being very high and due to his/her critical condition the patient may end up in a cardiac arrest or sudden death but these signs and predictions in early stages can clearly be predicted using the GPU, COMMA-Z, signal differentiation and DFS algorithms. The below signal is an ECG from Physionet but shows similar signs for PPG because ventricular fibrillation has no rhythm its chaotic signal with very high heart rate, there is one original signal computed in upcoming experiments. The signal differentiation and DFS method can easily predict in not time when computed using a GPU based on the experiments demonstrated.

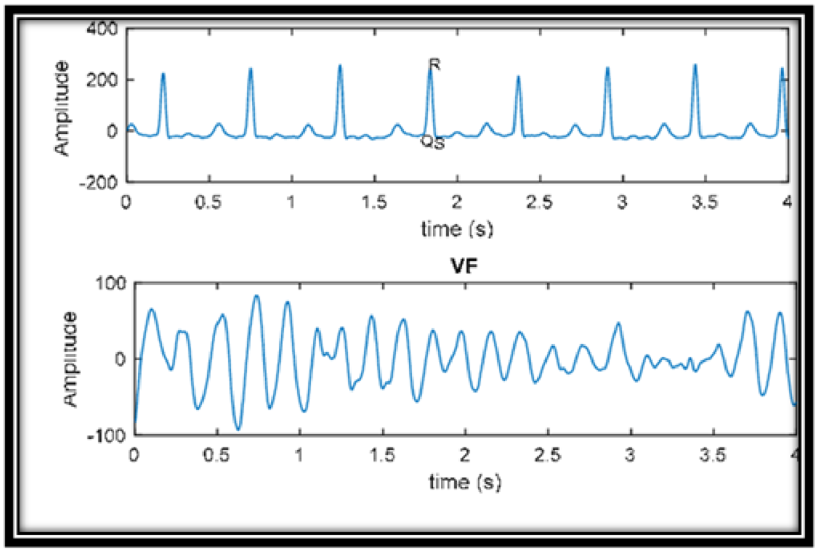

Figure 43 Ventricular and Normal Sinus Rhythm Signal

In Figure 44 some work was done to calculate Herat rate BPM on a third-party device and Jetson hardware and found that the GPU predicts better values than Apple watch and the CPU much faster using thread/blocks and COOMA-Z filter.

Apple watch Heart rate Data	CPU Heart rate Data	GPU Heart rate Data	
68	68	67	Thread/block 1
68	70	68	Thread/block 2
69	70	69	Thread/block 3
75	69	70	Thread/block 1
75	70	71	Thread/block 2
73	71	70	Thread/block 3
75	73	70	Thread/block 1
74	73	70	Thread/block 2
74	74	70	Thread/block 3

Figure 44 Heart Rate BPM on an Apple watch, CPU and GPU

Several experiments were conducted and one such experiment was developed to compute earlobe data while playing squash game. Athletes in Figure 45 participated to this experiment setup supporting enormous amount of Earlobe heart data. Firstly, the resting heart data was collected by both these athletes and then compared with intense activity data. The Earlobe data is computed using novel COMMA-Z Filter while playing in real time, the GPU was placed outside the arena using bench setup as shown in Figure 24. The Athletes are 35 and 34 old with no heart related symptoms or disease or history of any heart conditions.

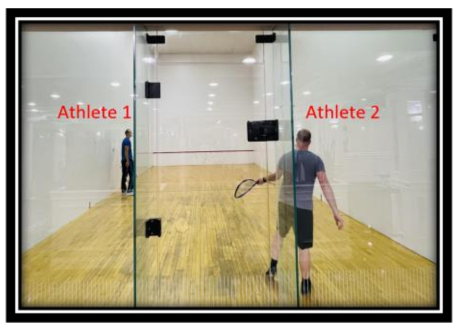

Figure 45 Athletes Heart data while playing squash

Based on the Experiment of collecting heart data and computing that heart data of the squash players, the Figure 46 outputs the computed COMMA-Z filter data. The Athlete 1 is a subject 1 who is 35 years old, when a closer look is taken at the experiment data in Figure 46 the GPU computes better than CPU and here the GPU and CPU speeds are matched to see who computes better, tremendous amount of noise and vibrations from

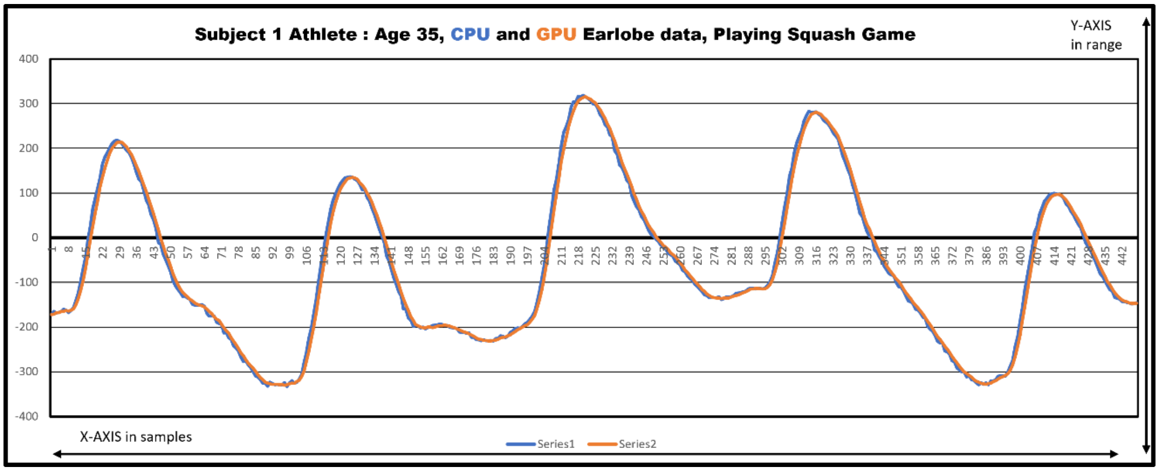

Figure 46 Observation set P: Athletes 1 Heart data while playing squash

the raw signal is computed both by CPU and GPU using COMMA-Z but GPU shows better signal presence than the CPU. The GPU signal is still 132 times faster than CPU as discussed earlier.

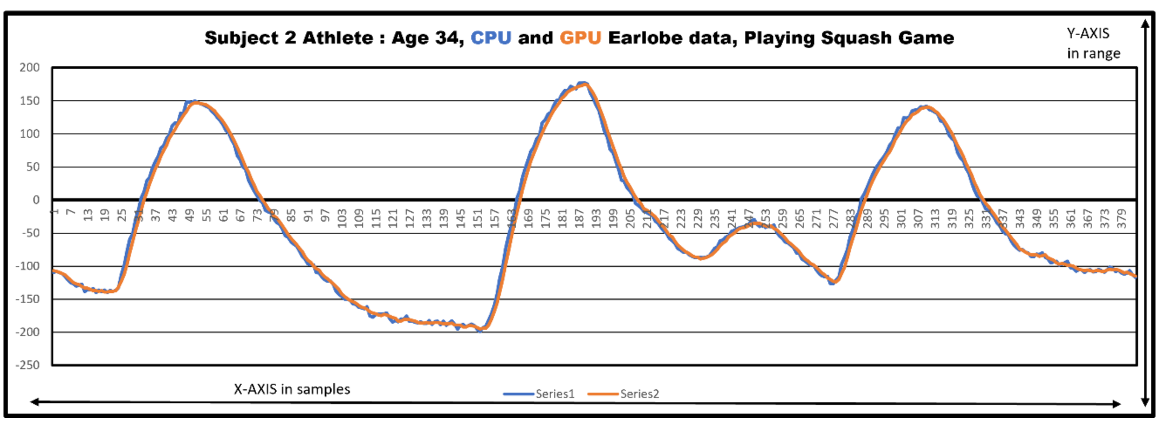

Figure 47 Observation set Q: Athletes 2 Heart data while playing squash

The signal series 1 is the CPU signal and the signal series 2 is the GPU signal both these signal is computed on top of each other, here zooming in will exactly show the difference and amount of computation done by both CPU and GPU. Similarly, Athlete 2 Heart data computation is demonstrated in Figure 47. At x-axis in Figure 47 we observe the signal being computed in real time but at the zero crossing detection at point 241 we see that an incomplete heart data signal has occurred which may be due to a fall or some kind of extreme activity or vibration, such predictions with that much accuracy is not possible if we execute using traditional moving averaging filter because the COMMA-Z filter does this in a different strategy in real time using thread/blocks on a GPU. The Software design discusses more about the system design.

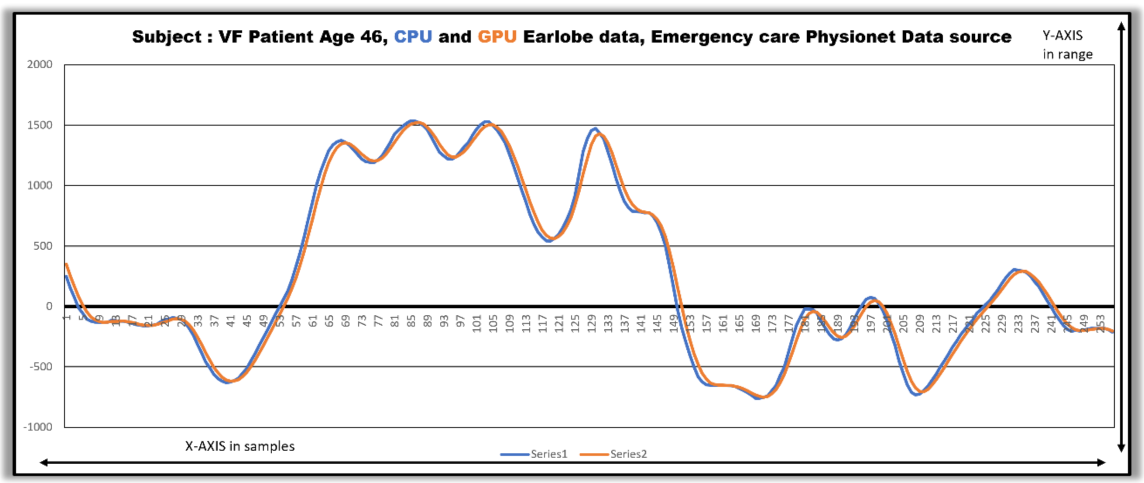

Figure 48 Observation set R: GPU computed Ventricular Fib data for Earlobe

In Figure 48 observation the GPU computes the earlobe simulated ventricular fibrillation data using standalone simulator. The data collection and signal might slightly vary when collected in real time from an arrythmia patient. This type of data from real patients is challenging because this a dangerous condition of the heart and collection of data at the Earlobe or Fingertip requires approvals and authorization. In this experiment in Figure 48 the current work managed to somehow replicate the fingertip as an Earlobe data using a heart simulator. In Figure 49 the Experiment demonstrates the Normal sinus rhythm signal placed on either side of the heart based on the heart electrical sequence from right to left ventricular. In the Figure 49 the left section of the points denotes right ventricular data and the right section denotes left ventricular data, based on the sinus node signal the CPU and the GPU points are plotted for the Normal sinus rhythm for the Fingertip where the orange color points represent the activity data from both CPU and

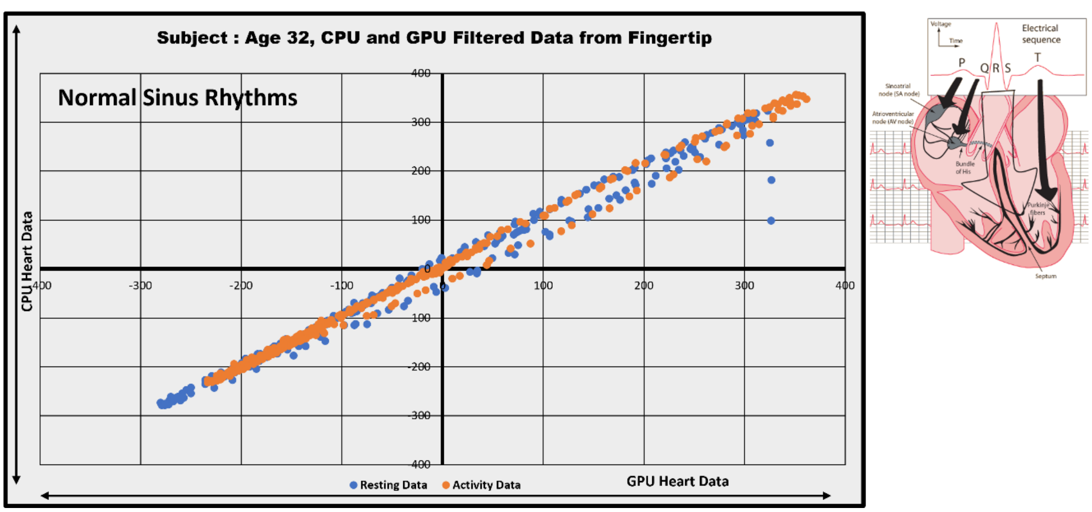

Figure 49 Observation set S: NSR Filtered data representation for Fingertip

GPU and the blue color points represent the resting data, the COMMA-Z filter computes the data simultaneously placing for both left and right sections. The heart image with AV node side is the right ventricular and the opposite to it is the left ventricular divided by spectrum.

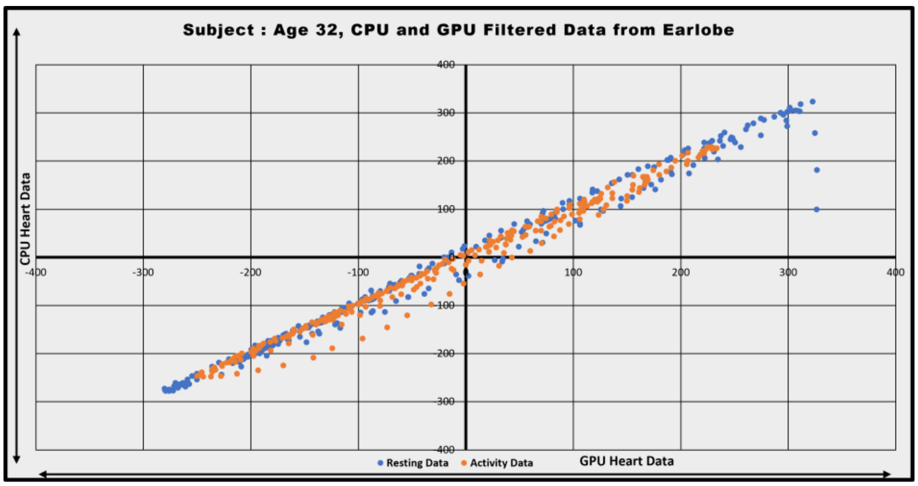

Figure 50 Observation set T: NSR Filtered data representation for Earlobe

As per the Observation Set T in Figure 50 the similar COMMA-Z filter for Normal Sinus Rhythm data shows better results for activity data when compared with the resting data at the Fingertip. The heart data when compared with activity data in Figure 49 has produced better and challenging results when compared with activity data shown in Figure 50. This shows that the COMMA-Z computes data not only for resting heart rate but also for activity heart data.

The Figure 51 observation data is very interesting showing the ventricular fibrillation occurrences at the right and left ventricular region of the heart, the Figure 51 demonstrated negative and the positive points that are clearly captured and computed for an Earlobe data that is marked in orange color, but the blue color Fingertip data marked along with it proves that the ventricular data can be easily recorded and analyzed in no time using COMMA-Z filter. The observation of the signal itself shows how the Ventricular data is spread across the heart ventricles when measured along with the NSR data.

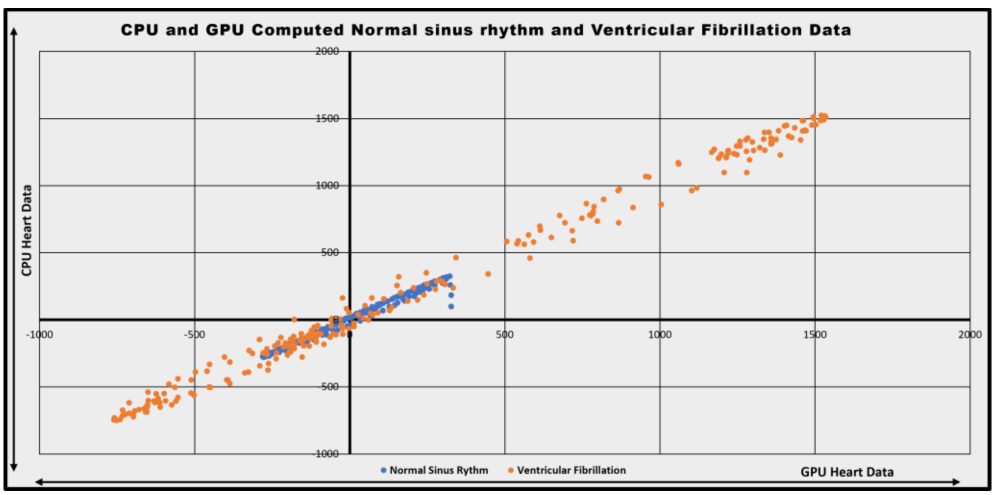

Figure 51 Observation set U: NSR and Ventricular Fib Data

7.3 Summary

Experiments are designed for various use cases and outcomes and the most interesting ones are detailed and discussed. Clinical data was developed at the Clinics, Gym, Hospitals and while driving. Physionet source data set also helped to verify and understand some studies but most of the data here is provided for only ECG and for PPG it’s just the Fingertip or Wrist data. This Physionet data was initially considered as a baseline signal for understanding the diseases and related outcome. The Experiments and methods and the result outcomes are first of kind that is being observed and demonstrated in this research. The Heart data from the HEAR device at the earlobe is being computed on a GPU using Novel COMMA-Z filter along with signal differentiation and DFS filter to study VF and AF arrhythmias and electrical activity of the heart before and after Heart surgeries. Most of the other heart diseases can be developed but here this work concentrates only for Atrial and Ventricular Fibrillation diseases. This work baselines the Normal sinus rhythm to provide analysis studies and comparison for medical professionals along with AF and VF as shown in Figure 16. Figures 34,48,51 show various AF and VF heart data computation using COMMA-Z Filters. The Novel filtering was conducted at the Fingertip and later to the Earlobe to understand the scenarios. This research also demonstrates that the GPU is 132 times faster than the CPU for computing the heart data which was benchmarked while driving. Finally, the conclusion is that the arrhythmias occurrences and study can be easily developed and understood or predicted and analyzed well in advance on a GPU due to its high-performance capabilities and CUDA techniques which require to be carefully engineered to execute the algorithms parallely for tremendous results.

CHAPTER EIGHT

CONCLUSION AND FUTURE WORK

Certainly, there are huge efforts from the government and vehicle manufacturers and medical professionals to understand the electrical activity of the Heart on everyday basis.

Today's vehicles are equipped with high performance computing hardware and related safety technologies. Despite Huge efforts of these technologies and vast R&D work these vehicles are equipped with hardware that can be used to perform challenging tasks. Many engineers and doctors are optimistic about the growing technology both in automotive and medical. The method to understand human heart rate and monitoring heart data while driving is eventually a challenging task but at the same time it's a promising technique to avoid heart related emergencies and fatalities over the time. Today's vehicles are more interactive and responsive with increasing capabilities of safety and minimizing the number of crashes caused by human error.

Silent heart attack or the silent myocardial is very dangerous condition and has a potential strike rate in USA. Current research proposes to monitor electrical activity of the heart continuously for any change in activity on everyday basis in real-time. Diseases such as myocardial infarction, cardiomyopathy, irregular heart intervals and history of heart surgeries are conditions lead to signs of development of atrial and ventricular fibrillation. This phase of development of these arrhythmias and other heart related conditions requires to be monitored on everyday basis so that they can be prevented from any arising emergency conditions. There are various wearable devices in the market and each one of them perform certain tasks extremely well when compared to another. On an average daily a person spends not less than 1 hour behind the wheel in USA to travel close to 30 miles in a day. Automakers are trying to incorporate different methods to monitor heart data for health-related conditions within the vehicle, but none are available and successfully proven yet. Medical professionals are required to understand patient's data and observe any results so that they could be treated earlier for any arising heart conditions or prevailing conditions for diagnosis because timing is all it matters here. Driver and vehicle agency is promoting methods of safe driving for patient with conditions and surgeries because they can be troublesome after few weeks or months and sometime years. This work is a combination of solutions to all the problems that has been discussed in this chapter from a person driving to heart arrhythmias to medical professionals to driver and vehicle safety agency. Considering all these this project is entirely developed from ground up from hardware bringup to software development and integration and testing. In this work a portable device called HEAR device is placed to the Earlobe of the driver while driving, the vehicle itself consists of integrated GPU and LTE hardware within the vehicles that is used for other technology purposes. The hear device can be used in clinics and hospitals but it requires GPU access in the cloud for computation. In either case the hear device in this project enables connecting to the GPU to perform parallel computation of Heart data in real time using novel COMMA-Z filter to observe, predict and analyze the occurrence of arrhythmias and heart conditions. This final novel filter data is computed further using signal differentiations and DFS to benchmark arrhythmias rhythm with normal sinus rhythm. The arrhythmias currently considered and developed in the research is atrial and ventricular fibrillation only. If there were any surgeries such as angioplasty or shunt replacement or any potential surgery, then those conditions and related scenarios can be easily monitored in the final results after being computed on a GPU using HEAR device and COMMA-Z Filter. Today some of the life-threatening alarm's issued by bedside monitors containing ECG pretend to be false but studies show that they have occurred in the past due to the leads attached to the chest and they are uncomfortable and such monitoring is not possible in vehicles or for any real-time on an everyday basis. Heterogeneous computing is a combination of CPU and GPU and research including the COVID-19 medicine development would like to study all the variants of this diseases using the GPU for developing results. Studies show that COVID-19 itself induces Myocardial Infarction along with hypertension to cause heart arrhythmias and conditions and also the post infectious myocardial infarction caused by blood clots in the patient's body after any viral disease such as the Covid-19. Based on the current work the experiment section demonstrates results being conducted on a bench setup similar to the vehicle setup. These experiments are also conducted at a fingertip and earlobe with multiple subjects and varying HEAR device PPG sensor register settings. The GPU and CPU were benchmarked and proven that the GPU computed and executed the signals comparatively better than the CPU in real-time. Even in harsh conditions and environments and road conditions the COMMA-Z filer showed outstanding results while driving. The HEAR device and GPU computation show better heart rate data results when compared with Apple Watch and any other third-party devices in the market. The entire research and development are within the innovation of HEAR device and the novel comma-s filter and making use of existing vehicles resources such as the GPU to perform parallel computing and this work could not be possible without such filters being developed and deployed on a GPU.

The Future research works opens door now for lot of ideas and enhancements such as brining up an AI model and to train the models of the users or patients who are drivers while using their current heart activity along with uploading his/her previous generations heart data for any signs of heart conditions. This model-based training using the final COMMA-Z, signal differentiation and DFS data will be used as a primitive training block for comparison of the heart electrical activity for current and future generations while also creating a history of data for their family, this method does require access to the cloud services to store their previous generations data for comparisons and predictions. Other diseases such as the tachycardia, bradycardia and other heart related conditions can be designed and developed similar but signal differentiation and DFS may or may not be a preferred method to compare those signals with normal sinus rhythm. Disease such as seizures are also ones that can be treated while driving and they could give rise to heart conditions. Diseases such as epileptic disorders and cardiogenic syncope lead to dangerous conditions if misdiagnosed and developing research work for such diseases is important as well.

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