Non-contact Heart Rate Estimation using High Radio Frequency Radar

AL-HASANOL GUMANTI BIN SUDIRMAN

B.ENG (HONS.) ELECTRICAL ENGINEERING (ELECTRONICS)

UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS AND COPYRIGHT

Author's Full Name : AL-HASANOL GUMANTI BIN SUDIRMAN

Date of Birth : 23 FEBUARY 1997

Title : Non-contact Heart Rate Estimation using High Radio Frequency Radar and Deep Learning

Academic Session : ______________________________

I declare that this thesis is classified as:

- ☐ CONFIDENTIAL (Contains confidential information under the Official Secret Act 1997)*
- ☐ RESTRICTED (Contains restricted information as specified by the organization where research was done)*
- ☑ OPEN ACCESS I agree that my thesis to be published as online open access (Full Text)

I acknowledge that Universiti Malaysia Pahang reserves the following rights:

1. The Thesis is the Property of Universiti Malaysia Pahang
2. The Library of Universiti Malaysia Pahang has the right to make copies of the thesis for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by:

(Student's Signature)	(Supervisor's Signature)
970223-14-5395	Ir. Ts. Dr. Mohd Zamri bin Ibrahim
New IC/Passport Number	Name of Supervisor
Date:	Date: 27 June 2022

NOTE : * If the thesis is CONFIDENTIAL or RESTRICTED, please attach a thesis declaration letter.

THESIS DECLARATION LETTER (OPTIONAL)

Librarian,
Perpustakaan Universiti Malaysia Pahang,
Universiti Malaysia Pahang,
Lebuhraya Tun Razak, 26300,
Gambang, Kuantan.

Dear Sir,

CLASSIFICATION OF THESIS AS RESTRICTED

Please be informed that the following thesis is classified as RESTRICTED for a period of three (3) years from the date of this letter. The reasons for this classification are as listed below.

Author's Name
Thesis Title

Reasons (i)

(ii)

(iii)

Thank you.

Yours faithfully,

____
(Supervisor's Signature)

Date:

Stamp:

Note: This letter should be written by the supervisor, addressed to the Librarian, *Perpustakaan Universiti Malaysia Pahang* with its copy attached to the thesis.

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Electrical Engineering (Electronics).

____

(Supervisor's Signature)

Full Name : IR. TS. DR. MOHD ZAMRI BIN IBRAHIM

Position : SENIOR LECTURER

Date : 27 JUNE 2022

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

AL-HASANOL

(Student's Signature)

Full Name : AL-HASANOL GUMANTI BIN SUDIRMAN

ID Number : EA18063

Date : 5 JUNE 2022

Non-contact Heart Rate Estimation using High Radio Frequency Radar

AL-HASANOL GUMANTI BIN SUDIRMAN

Thesis submitted in fulfillment of the requirements
for the award of the
B.Eng (Hons.) Electrical Engineering (Electronics)

College of Engineering

UNIVERSITI MALAYSIA PAHANG

JUNE 2022

ACKNOWLEDGEMENTS

There are no words to express how grateful I am to my family for their unwavering support, understanding, and love throughout my life. Years of reciprocating venting are owed to my mum and father.

I'd also like to thank my advisor, Ir. Ts. DR. Mohd Zamri bin Ibrahim, for inviting me to join his research group and for his ongoing life teachings, which I shall treasure.

Finally, I would like to thank God for letting me through all the difficulties. I have experienced your guidance day by day. You are the one who let me finish this thesis

ABSTRAK

Kadar jantung, kadar pernafasan, suhu teras dan tekanan darah adalah empat penunjuk penting yang paling penting. Elektrokardiografi (ECG) dan plethysmography induktansi pernafasan adalah contoh kaedah sentuhan yang biasanya digunakan dalam perjalanan kajian corak degupan jantung dan pernafasan (RIP) seseorang. Terdapat minat untuk membangunkan monitor tanda vital tanpa sentuh yang lebih selesa untuk digunakan. Kaedah pengukuran yang tidak melibatkan sentuhan mempunyai beberapa kelebihan, termasuk yang berikut: Ia tidak merengsakan kulit, menimbulkan ketidakselesaan, atau membawa kepada jangkitan dengan cara yang sama seperti yang dilakukan oleh elektrod dan tali (cth. dalam kes pesakit melecur teruk. atau mencederakan). Ini amat penting dalam jangka masa yang panjang, menjadikan pengesan pilihan terbaik untuk pemantauan berterusan jangka panjang berkat kesesuaiannya dalam hal ini. Pesakit tidak menyedari bahawa mereka sedang diukur, oleh itu mereka kurang berkemungkinan membuat sebarang perubahan pada tanda-tanda vital mereka. Ini membolehkan peningkatan dalam kebolehpercayaan keputusan. Oleh itu, untuk mengesan tanda-tanda vital tanpa perlu membuat sentuhan langsung dengan kulit, sensor wayarles perlu dibangunkan.

Adalah dijangkakan bahawa teknologi ini akan mempunyai pelbagai kegunaan; walau bagaimanapun, beberapa aplikasi komersial yang paling penting termasuk pemeriksaan keselamatan dan sistem keselamatan untuk kereta, serta perubatan dan penjagaan kesihatan. Di pelbagai pusat pemeriksaan untuk pengangkutan dan keselamatan penumpang, seperti lapangan terbang, stesen kereta api, dan juga kasino, terdapat minat dalam pengesanan aktiviti fisiologi yang menyimpang. Sebagai contoh, pemasangan peranti sedemikian pada tempat pendaftaran di lapangan terbang akan membekalkan kami maklumat berharga mengenai degupan jantung dan kadar pernafasan masa nyata subjek. Jika dia cemas atau ada sesuatu yang dia ingin sembunyikan daripada kita, kami ingin tahu. Di samping itu, adalah sangat penting untuk mengenal pasti pemandu trak komersial yang mempunyai kadar degupan jantung yang tidak teratur, yang mungkin disebabkan oleh penggunaan dadah, jumlah tidur yang tidak mencukupi, atau tekanan.

Untuk mengekstrak tanda-tanda penting dengan tepat dari lokasi terpencil menggunakan radar gelombang berterusan modulasi frekuensi (FMCW) yang beroperasi pada 60GHz dan 77GHz, pelbagai teknik pemprosesan isyarat telah digunakan pada data yang dikumpul oleh radar ini. Kaedah seperti berasaskan fasa, anggaran parametrik, dan analisis tetingkap pembolehubah masa, bersama-sama dengan gabungan saluran kepelbagaian output berbilang input (MIMO), telah digunakan dalam kajian ini dengan matlamat untuk mengesan kadar denyutan dan pernafasan peserta dengan tepat. . Dalam badan kerja ini, perbandingan dibuat antara masa pemerolehan dan ketepatan pengesanan tanda penting yang sebelum ini telah dicapai dalam sistem radar gelombang mikro tercanggih yang beroperasi pada frekuensi yang lebih rendah. Keputusan pengukuran seorang peserta yang diambil pada pelbagai jarak akan dilaporkan dan dibandingkan dengan penemuan sebarang ukuran hubungan lain yang berkaitan. Yang penting, keupayaan dan had penggunaan teknik pada sistem masa nyata akan digambarkan dengan bantuan cip pengesanan tanda vital mmwave Texas Instruments. Ini kerana penggunaan teknik masa nyata adalah kritikal. Diagnosis dan pemantauan sindrom apnea tidur

obstruktif (OSAS ialah masalah pernafasan tidur yang paling biasa) dan penyakit pernafasan lain adalah pasaran yang jelas untuk teknologi ini. OSAS menjejaskan kirakira 4% lelaki dan 2% wanita di negara Barat [14].

ABSTRACT

Heart rate, respiration rate, core temperature, and blood pressure are the four most important vital indicators. Electrocardiography (ECG) and respiratory inductance plethysmography are examples of the contact methods that are typically utilised in the course of a study of a person's pattern of heartbeat and respiration (RIP). There is an interest in developing contactless vital sign monitors that are more comfortable to use. A measurement method that does not involve contact has a number of advantages, including the following: It does not irritate the skin, create discomfort, or lead to infection in the same way that electrodes and straps do (e.g. in case of patient with severe burns or injures). This is of utmost significance over lengthy periods of time, making the detector an excellent choice for long-term continuous monitoring thanks to its suitability in this regard. The patients are not aware that they are being measured, thus they are less likely to make any changes to their vital signs. This allows for an increase in reliability of the results. Therefore, in order to detect vital signs without having to make direct touch with the skin, a wireless sensor will need to be developed.

It is anticipated that this technology will have a wide variety of uses; however, some of the most important commercial applications include security screenings and safety systems for automobiles, as well as medicine and healthcare. At various checkpoints for transportation and passenger safety, such as airports, train stations, and even casinos, there is an interest in the detection of aberrant physiological activity. For instance, the installation of such a device at a point of registration at an airport will supply us with valuable information regarding the subject's real-time heartbeat and breathing rates. If he is anxious or if there is something he wants to conceal from us, we would like to know. In addition, it is of the utmost importance to identify commercial truck drivers who have an irregular heartbeat rate, which may be the result of drug use, an insufficient amount of sleep, or stress.

In order to accurately extract vital signs from a remote location using frequency modulation continuous wave (FMCW) radars operating at 60GHz and 77GHz, multiple signal processing techniques have been applied to the data collected by these radars. Methods such as phase-based, parametric estimation, and time-varying window analysis, in conjunction with multiple input multiple output (MIMO) diversity channel combining, were utilised in this study with the goal of accurately detecting the participants' heart rates and respiration rates. In this body of work, a comparison is made between the acquisition times and accuracy of vital sign detection that have previously been achieved in state-ofthe-art microwave radar systems operating at lower frequencies. The results of a single participant's measurements taken at a variety of distances will be reported and compared to the findings of any other relevant contact measurements. Importantly, the capabilities and limitations of applying the techniques to a real-time system will be illustrated with the help of a Texas Instruments mmwave vital sign detection chip. This is because realtime application of the techniques is critical. The diagnosis and monitoring of obstructive sleep apnea syndrome (OSAS is the most common sleep breathing problem) and other respiratory diseases is an obvious market for this technology. OSAS affects roughly 4% of men and 2% of women in Western countries [14].

TABLE OF CONTENT

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background

Monitoring one's heart rate is an important component in developing an accurate picture of one's health, level of stress, and physical fitness. In particular, the periodic monitoring of elderly patients, patients receiving palliative care, and patients undergoing post-operative rehabilitation offers a quantifiable metric that can be used to determine whether or not intervention from a medical professional is required [1]. This is becoming increasingly important as there is a growing trend away from providing medical care to patients in hospitals and instead towards providing care for patients in their own homes rather than in hospitals [2]. Wearable devices that operate with electrocardiogram (ECG) or photoplethysmography (PPG) sensors have made significant strides in ambulatory heart rate monitoring. These devices monitor a patient's heart rate continuously.

In particular, smart watches and fitness bands offer a capability known as "wear and forget," and they have made continuous heart rate monitoring both affordable and widespread. Wearable technology is an excellent solution for the general public; however, it is plagued by issues such as "forget to wear" and "forget to charge," despite the fact that wearables are an excellent solution. Because of this, there is a low rate of compliance, which makes them unsuitable for monitoring patients who have issues with their physical or mental health. There are also alternatives, such as beds that are equipped with sensors [3,] but these can only monitor patients who are in a single location. Because of these limitations, non-contact heart rate monitoring solutions have been developed, such as those that are based on imaging and radio-frequency (RF) techniques. In regard to the former, a camera (operating in either the visible or infrared spectrum) is utilised in order to identify minute variations in the extent to which blood vessels in the face have expanded [4]. These cannot be used if there is anything that could potentially block the line of sight to the patient, including obstructive clothing. As a result of the use of cameras, they also raise concerns with regard to privacy. RF-based techniques function by making an educated guess regarding the micro displacement of the heart by observing minute variations in the reflected radio signal. To obtain these measurements, the majority of research done up until this point has considered using a stationary device that is mounted on a wall [5, 6]. On the other hand, this kind of sensor is extremely sensitive to the orientation and position of the user [7].

1.2 Problem statements

The World Health Organization estimates that out of a total of 278 million positive cases of COVID-19, there have been a total of 5.39 million deaths as a result of the positive cases. As a result, there is a critical need for a strategy that can either stop or assist in the reduction of the number of lives lost. COVID-19 is an illness that affects the respiratory system and is primarily transmitted by droplets in the air. The coughing and sneezing of an infected person is the most common way that these droplets are released into the air. Once symptoms appear, they become less infectious, which results in a gradual decrease in the amount of virus that is carried by an individual. However, infected individuals continue to shed the virus after they have recovered from COVID-19 for approximately two weeks in both their saliva and their stools. This virus shedding occurs in both cases. People who are infected with the virus but only have mild symptoms or none at all may still have a very high viral load in their upper respiratory tracts. Spitting, touching their mouths or noses, or even just talking can potentially cause the virus to spread from one person to another. It has also been discovered that SARS-CoV-2 can remain on surfaces for days at a time.

In mild cases, people may only experience symptoms such as a runny nose or a sore throat, but the most commonly reported symptoms are fever, a dry cough, and tiredness. In the most severe cases, people who are infected experience difficulty breathing, and in the end, they may fail to function properly due to organ failure. Some cases are fatal. The Chinese government has placed the city of Wuhan and its population under a quarantine or lockdown, and they have also halted all trains and flights leaving the city. They have stopped operating some of the long-distance bus routes, including the ones that originate or terminate in Beijing. On March 11, the World Health Organization (WHO) declared the outbreak to be a pandemic, which indicates that a sustained transmission between people is occurring in multiple countries, causing disease or death.

1.3 Objectives

The main objective of this project is:

- To develop a non-contact heart and breathing rate monitoring device.
- To investigate high frequency radio that can measure heart rate movement.
- To analyse the performance of the non-intrusive measurement with the conventional method.

1.4 Scopes

The noncontact detection and monitoring of human cardiac activity via bedding and clothing has the potential to be a useful tool in applications relating to intensive care monitoring as well as home health care. Patients whose conditions can be disrupted or made worse by contact sensors include burn victims and infants at risk of sudden infant death syndrome. A noncontact heart and respiration rate monitor could provide vital signs monitoring for these patients without the need for affixed electrodes. The vast majority of alternatives to conventional heart monitors call for the use of leads and contacts, in addition to exact control or placement, all of which are frequently impossible or undesirable in a variety of contexts. On the basis of this, I can relate my objective, which was to develop a device that monitors a person's heart rate and breathing rate without requiring physical contact. The device that is utilised is manufactured by Texas Instruments and bears the model number IWR6843ISK. The creation of this project is carried out with the assistance of a computer, the programming language Python, and an application from a third party that was supplied by Texas Instrument.

After I had successfully developed the device and the programme using Python, the next step was to determine whether or not the device is viable and whether or not it is capable of detecting heartrate movement using 60 GHz mmwave. Careforce Medicare Supplies is the company that supplies the Oximeter known as the Yonker fingertip pulse oximeter YK-81C, which is used to perform this comparison with the results from the IWR6843ISK. The outcome is incorporated into the concluding documentation.

In conclusion, we will compare the results of the non-intrusive measurement with those obtained using the more traditional approach. The experiments that I carried out can be divided into two categories: those involving the distance without an obstacle and those involving the distance with an obstacle. The distances that were maintained throughout those experiments were 30, 60, 90, 120, and 150 centimetres. A measuring tape was used to determine the distance, and duct tape was used to mark the measurement. A plastic Tupperware container and a pillow were used as the obstacle. Every single one of the readings that were taken was recorded.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The requirements for frequency allocation, high-throughput wireless user services, dependable mobile connectivity, sensors, and the internet of things are driving the demand for the development of millimetre wave (mmwave) sensors (IoT). Wireless transmissions that operate at higher frequencies are able to make use of larger bandwidths and a greater number of channels, which ultimately leads to faster services and a greater number of users operating within a given frequency band. In the following section, I will discuss both the conventional and the contemporary electrocardiogram machines (ECG).

Because of advancements in system-on-a-chip (SoC) technology as well as smaller antenna structures, mmwave sensors are also significantly smaller and less expensive. This makes it possible to deploy several mmwave devices in the same area to meet the data demands of mobile and Internet of Things applications. Despite its obvious benefits, mmwave technology faces significant challenges in the propagation of higher-frequency electromagnetic waves. These challenges can result in lower signal-to-noise ratios (SNR) for a signal of interest due to route loss and signal blockages caused by small objects such as a mobile user's hand. The solution to this problem can be found in the development of more advanced signal processing technologies, as well as an increase in the support provided by infrastructure and backhaul networks. When it comes to the latter, each application has its own unique set of requirements and challenges, which can change depending on the environment, the system, the frequency, and the amount of time.

The primary objective of this research is to demonstrate how existing mmwave radar systems can be utilised to identify vital signs in humans.

2.1.1 What is an Electrocardiogram (ECG)

An electrocardiogram, also known as an ECG, is one of the most straightforward and speediest diagnostic tools that can be utilised in order to obtain information regarding the condition of the heart. Electrodes are used to record electrical activity. These electrodes are small plastic patches that adhere to the skin and are placed in strategic locations on the chest, arms, and legs. Lead wires serve to establish a connection between the electrodes and an electrocardiogram (ECG) machine. After that, the electrical activity of the heart is measured, then interpreted, and finally written down. There is no evidence of any electrical stimulation being delivered to the body.

The contractions of the various chambers and valves of the heart are coordinated by electrical impulses that are generated by the body's own electrical system. This helps to ensure that blood continues to flow normally throughout the body. An electrocardiogram will record the electrical impulses in order to provide information regarding the rate at which the heart is beating, the rhythm of the heart beats (whether they are regular or irregular), as well as the strength and timing of the electrical impulses as they move through the various parts of the heart. This information will be used to determine whether or not the patient has a heart condition that requires treatment. Variations on an electrocardiogram can be used to diagnose a wide variety of conditions related to the heart.

2.1.2 Working Principle of Electrocardiogram

The electrocardiograph should be able to pick up signals with a magnitude of 0.5 mV to 5.0 mV, despite their extreme insignificance. In addition, it needs to be able to detect a direct current component of up to 300 mV, which is caused by electrodes making contact with the skin, as well as a common-mode component of up to 1.5 V. The contact that occurs between the electrodes and the skin is the root cause of both of these aspects (due to the potential between the electrodes and the ground). It is possible for an electrocardiogram (ECG) signal to have a useful bandwidth that ranges from 0.5 to 100 Hz and even occasionally reaches 1 kHz; however, the width of this bandwidth will change depending on the application. When there is a significantly larger amount of external high frequency noise, interference at 50 or 60 Hz, and DC electrode offset potential, it is typically somewhere in the neighbourhood of 1 mV peak-to-peak. The noise comes from a wide variety of different origins. Movement that affects the skinelectrode interface is one of these sources. Other sources include muscle contractions or electromyographic spikes, respiration (which can be rhythmic or sporadic), electromagnetic interference (EMI), and noise from other electronic devices that couple into the input. Movement can also affect the skin-electrode interface.

To get things rolling, a biopotential amplifier will first need to be built so that the electrocardiogram (ECG) can be processed. After that, the patient will have electrodes attached to them in order to determine the potential difference that exists between the two arms. The primary objective of a biopotential amplifier is to increase the amplitude of a low-level electric signal that is produced by a biological source. This makes it possible for the signal to be subjected to additional processing, recorded, or displayed.

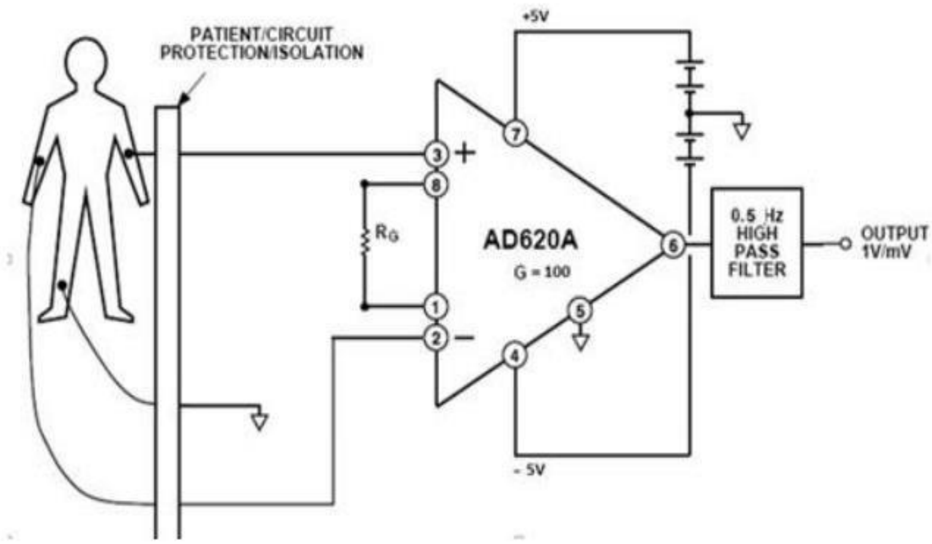


Figure 1 ECG Amplifier [8]

To be useful biologically, all biopotential amplifiers must meet certain basic requirements:

They must have a high input impedance in order to provide minimal signal loading. The load on biopotential electrodes can cause signal distortion. A biopotential amplifier's input circuit must also protect the subject being studied.

The amplifier should include isolation and protection circuitry to keep the current flowing through the electrode circuit at safe levels.

The load, which is usually an indicating or recording device, is driven by the output circuit. To achieve maximum fidelity and range in the readout, the amplifier must have a low output impedance and be capable of supplying the load's power.

Biopotential amplifiers must operate within the frequency spectrum of the biopotentials they amplify. Due to the low level of such signals, it is critical to limit the amplifier's bandwidth in order to achieve optimal signal-to-noise ratios. Filters can be used to accomplish this.

Figure 1 depicts an ECG amplifier, and Figure 2 depicts the circuit of the ECG amplifier constructed during this demonstration. The protection circuit, the instrumentation amplifier, and the high pass filter are the three main stages.

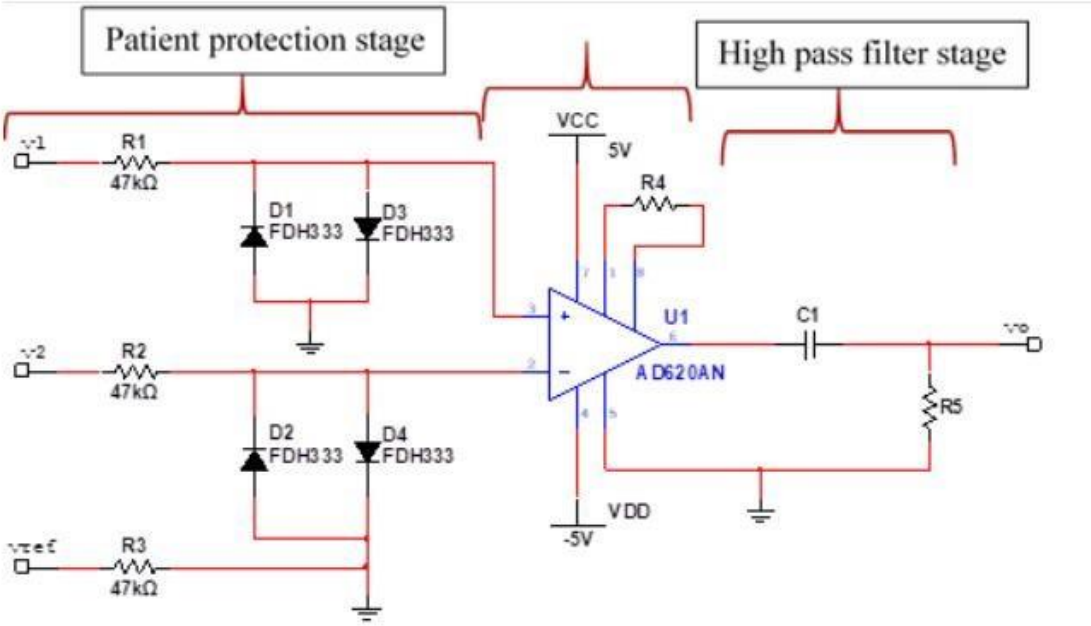


Figure 2 Biopotential amplifier [9]

2.2 Einthoven triangle theory

The Einthoven's triangle is an illustrative formation of three limb leads in an electrocardiographic triangle formed by the two shoulders and the pubis. The heart is in the centre of an inverted equilateral triangle. Willem Einthoven, who proposed its existence, is honoured with its name. Einthoven used these measuring points as contacts for his string galvanometer, the first practical ECG machine, by immersing the hands and feet in pails of salt water.[9]

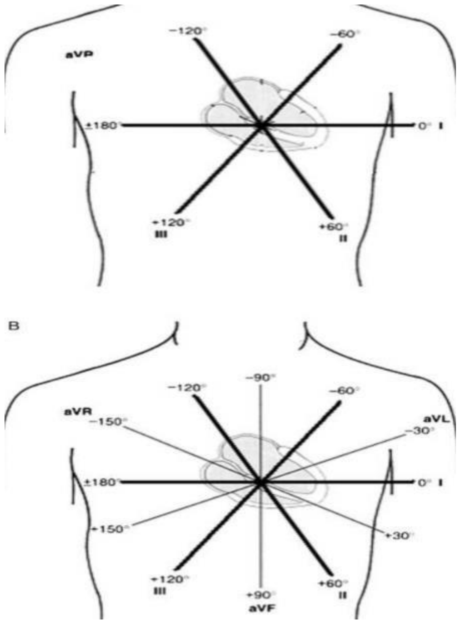


Figure 3 Lead Placement[9]

2.3 What is a Mmwave radar

Millimetre wave radar, also known as mmWave radar, is a subset of radar that performs its function by utilising electromagnetic waves with extremely short wavelengths. This subset of radar is also known as mmWave radar. Millimetre wave radar is also sometimes referred to by its acronym mmWave radar. Radar systems send out signals through the use of electromagnetic waves, which are then reflected by whatever is in the line of sight of the radar. By collecting the signal that is reflected back from an object, a radar system is able to determine the distance to the object, as well as its velocity and the angle of reflection. Other information that can be determined includes the angle of reflection.

2.3.1 Working principle for Mmwave radar

MmWave radars broadcast signals with millimetre wavelengths. One of the benefits of this technology is that it has a short wavelength in the electromagnetic spectrum. Indeed, system components such as antennas required to process mmWave signals are small in size. Another benefit of short wavelengths is their high precision. An mmWave system operating at 76–81 GHz (corresponding to a wavelength of about 4 mm) will be capable of detecting movements as small as a fraction of a millimetre. A complete mmWave radar system includes radio frequency (RF) components such as transmit (TX) and receive (RX); analogue components such as clocking; and digital components such as analogue-to-digital converters (ADCs), microcontrollers (MCUs), and digital signal processors (DSPs). These systems were traditionally implemented with discrete components, which increased power consumption and overall system cost. Because of the complexity and high frequencies, system design is difficult.

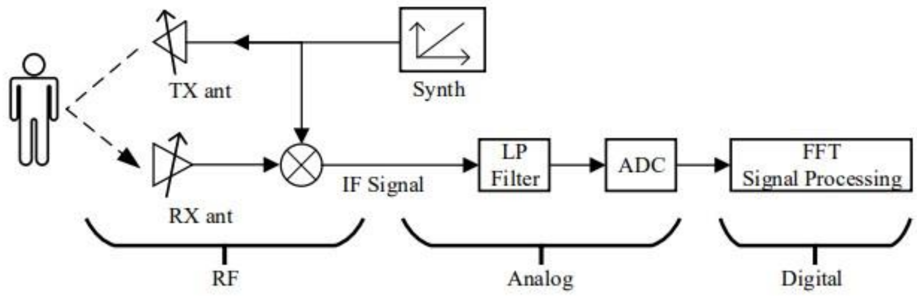


Figure 4 A simplified block diagram of the FMCW radar system [10]

The "mixer" was used to combine the signals from the receiving (RX) and transmitting (TX) ends to produce an intermediate frequency (IF) signal. The output of the mixer contained two signals: the sum and difference of the Rx and Tx chirp frequencies. To limit the signal, a low-pass filter was also used, allowing only signals with different frequencies to pass.

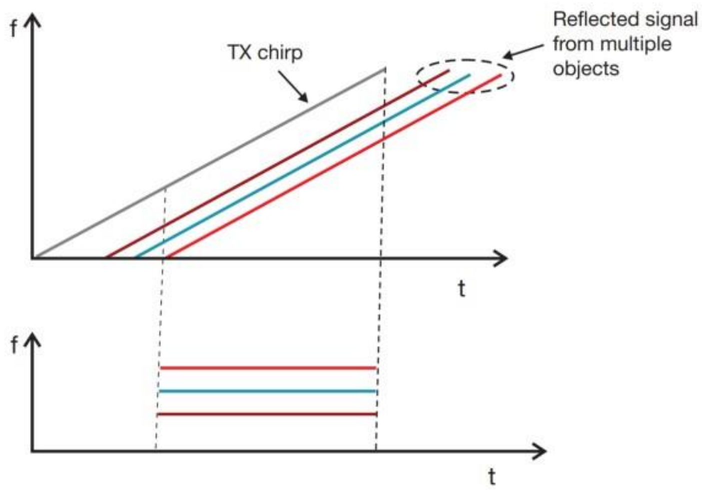


Figure 5 Frequency domain representation of TX and Rx Chirps and the IF [11]

Each peak in the IF signal's frequency spectrum corresponds to one or more detected objects, and the frequency corresponds to the object's range when analysed.

Due to the doppler effect, the frequency and phase of the reflected chirp changes as the object moves closer or farther away from the radar. Because the wavelength is on the order of 3.5 mm, even a small change causes a large phase shift. A large change in phase is easier to detect than a small change in frequency. Thus, phase information is used in FMCW radars to detect object velocity. Multiple chirps are used to determine the velocity of an object. The velocity is calculated by recording the phase difference between successive reflected chirps. **2.3.2 Manufacturer provide Mmwave radar**

The following pieces of information can be deduced about the chip based on the table: its operating frequency; the type of radar system; whether or not MIMO is available; whether or not the chip comes with a development kit; and whether or not the system has an application programming interface (API). Despite the fact that a number of companies are currently working on the process of developing SoC mmwave chips, the number of SoC mmwave products that are currently available is obviously quite limited. This is because of the fact that the process of developing SoC mmwave chips requires a great deal of time and resources. The following is a list of those that can currently be purchased for application in environments that are regarded as being commercial in nature.

Even though there are a few companies that sell solutions for SoCs, the systems themselves are not capable of performing an independent evaluation. You won't find any SoCs that aren't able to stand on their own and be evaluated here. This is the only list that contains such products.

Manufacturer	Type	Frequency	MIMO	Dev. Kit	API
Texas Instruments (TI)	FMCW	60-64GHz	✓	✓	✓
Peraso	CW	60GHz	×	×	×
Acconeer	Pulsed	60-64GHz	×	✓	✓
Sivers IMA	CW	57-71GHz	✓	×	×
Omniradar	FMCW	57-64GHz	×	✓	✓
STMicroelectronics	FMCW	77-81GHz	✓	×	×
TI	FMCW	77-81GHz	✓	✓	✓
NXP	FMCW	77-81GHz	✓	✓	✓

Figure 6 Mmwave SoC

System-on-chips (SoCs) such as the Acconneer and the Omniradar already have the on-chip antennas installed, but additional antennas for the other SoCs need to be purchased separately. It is not known whether or not the Omniradar is capable of accessing both of these channels, which indicates that the system would at best be configured as a single input multiple output configuration. Even though the Omniradar has two separate receiving elements, it is not known whether or not both of these channels can be accessed at the same time (SIMO). Designs for printed circuit boards, also known as PCBs, are required for any and all system configurations that call for the use of evaluation modules or development kits (EVM). In most cases, the manufacturer will offer design recommendations, layout patterns, device footprints, and possibly even CAD data. This is standard procedure. When designers make an early investment in an EVM kit, they gain the ability to rapidly build applications for the device and determine whether or not their requirements can fundamentally be met; after this, adjustments can be made based on the use case. In the following paragraphs, we will discuss the various components of mmwave systems' hardware, beginning with the mmwave antenna.

2.4 Summary

To summarize the chapter, an electrocardiogram, or ECG, is one of the simplest and fastest heart diagnostic instruments. Electrodes record electricity.

Small plastic electrodes adhere to the chest, arms, and legs. Lead wires connect electrodes to an ECG machine. Then, heart electrical activity is measured, interpreted, and recorded. No indication of body-wide electrical activation.

Electrical impulses generated by the body's electrical system coordinate heart contractions. This improves blood flow throughout the body. An ECG records electrical impulses to determine the heart's pace, rhythm (regular or irregular), strength, and timing as they pass through the heart. This information will assess if the patient has a treatable heart problem. Electrocardiogram variations help diagnose heart problems.

Electrocardiographs should be able to detect signals as little as 0.5 to 5 mV. It must also detect direct current of up to 300 mV, induced by electrodes touching the skin, and common-mode current of up to 1.5 V. Electrode-skin contact causes both aspects (due to the potential between the electrodes and the ground). An ECG signal's bandwidth might range from 0.5 to 100 Hz and even 1 kHz, depending on the application. When there's a lot of external high-frequency noise, 50 or 60 Hz interference, and DC electrode offset potential, it's around 1 mV peak-to-peak. Noise has several sources. One source is skin-electrode movement. Muscle contractions or electromyographic spikes, rhythmic or sporadic respiration, electromagnetic interference (EMI), and electrical device noise are further possibilities. Movement affects skin-electrode interface.

Before processing the electrocardiogram (ECG), a biopotential amplifier must be developed. Then, electrodes are placed to the patient's arms to measure the potential difference. A biopotential amplifier boosts a low-level biological electric signal. This enables signal processing, recording, and display.

Biopotential amplifiers must meet specific parameters to be beneficial biologically. High input impedance reduces signal loading. Biopotential electrode load can distort signals. Biopotential amplifier input circuits must protect subjects. The amplifier should have isolation and protective circuits to limit electrode current.

Output circuit drives load, usually an indicator or recorder. For best fidelity and range, the amplifier must have a low output impedance and supply load power.Biopotential amplifiers must match the biopotentials' frequency spectrum. Due to low signal levels, the amplifier's bandwidth must be limited to ensure ideal signal-to-noise ratios. Filters do this.Figure 1 shows an ECG amplifier, while Figure 2 shows its circuitry. Main stages include the protection circuit, instrumentation amplifier, and high pass filter.Einthoven's triangle is an electrocardiographic triangle created by the shoulders and pubis. An inverted equilateral triangle contains the heart. Willem Einthoven suggested its creation. Einthoven used the hands and feet as contacts for his string galvanometer, the first practical ECG. [9].mmWave radar uses electromagnetic waves with extremely short wavelengths. mmWave radar is a radar subgroup. Millimetre wave radar is often called mmWave radar. Radar sends out electromagnetic waves that are reflected by whatever is in its line of sight. By collecting an object's reflected signal, a radar system may estimate its distance, velocity, and reflection angle. Other information includes reflection angle.

Millimeter-wave radars broadcast signals. This technology's small electromagnetic wavelength is a benefit. mmWave antennas and other system components are tiny. Short wavelengths are accurate. A 76–81 GHz mmWave system can detect motions as small as a fraction of a millimetre. A comprehensive mmWave radar system includes RF components like transmit (TX) and receive (RX), analogue components like clocking, and digital components like ADCs, MCUs, and DSPs (DSPs). Traditional discrete components increased power consumption and system cost. Complexity and high frequencies complicate system design. "Mixer" combined RX and TX signals to create an IF signal. Mixer outputs sum and difference of Rx and Tx chirp frequencies. A low-pass filter was used to limit the signal, allowing only different-frequency impulses through. Each peak in the IF signal's frequency spectrum corresponds to a detected item, and its frequency indicates its range.

Due to the doppler effect, the reflected chirp's frequency and phase change as an object approaches or recedes from the radar. Even a little change in the 3.5 mm wavelength creates a huge phase shift. Large phase changes are simpler to notice than minor frequency changes. FMCW radars detect object velocity using phase information. Multiple chirps measure an object's speed. Recording the phase difference between reflected chirps calculates velocity.

The table 6 shows the chip's operating frequency, radar type, MIMO availability, development kit availability, and API availability (API). Although many firms are creating SoC mmwave chips, the number of commercial products is restricted. Because building SoC mmwave processors takes time and resources. These can be purchased for use in commercial contexts. Some firms sell SoC solutions, but the systems can't undertake independent evaluations. No SoCs that can't be analysed are included. Only this list has these items. Acconneer and Omniradar SoCs have on-chip antennas, however other SoCs need additional antennae. It's unknown if the Omniradar can access both channels, therefore it may only be a single-input, multiple-output device. Omniradar features two different receiving parts, however it's unknown if both may be accessed at once (SIMO). All system configurations requiring evaluation modules or development kits require PCB designs (EVM). Most manufacturers include design guidelines, layout patterns, device footprints, and CAD data. It's normal. When designers invest early in an EVM kit, they can quickly construct apps and assess if their needs can be met; improvements may then be made based on the use case. In the next paragraphs, we'll explore mmwave antennas and other devices.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, for the sake of your convenience, we will discuss the specifics of the project in a format that is more condensed than previous chapters. In addition, we will go over the component's specifications as well as its function later on in the lesson. As a direct consequence of this, the strategy that was utilised to successfully complete this project will be dissected in great depth by offering an explanation of it in the form of a flowchart as well as a block diagram. This will be carried out in order to solve the issue that was outlined earlier.

3.2 Hardware

3.2.1 IWR6843ISK

Since TI chips were used in this work, they will be the focus, however, some of the general concepts could surely be applied to the other SoCs. The IWR6843ISK is shown in Figure 5

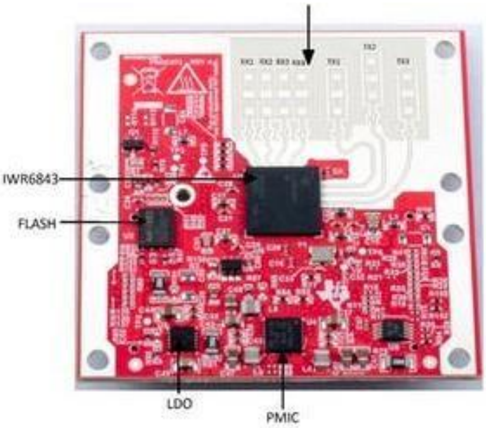


Figure 7 IWR6843ISK

3.2.2 Functional Diagram of IWR6843ISK

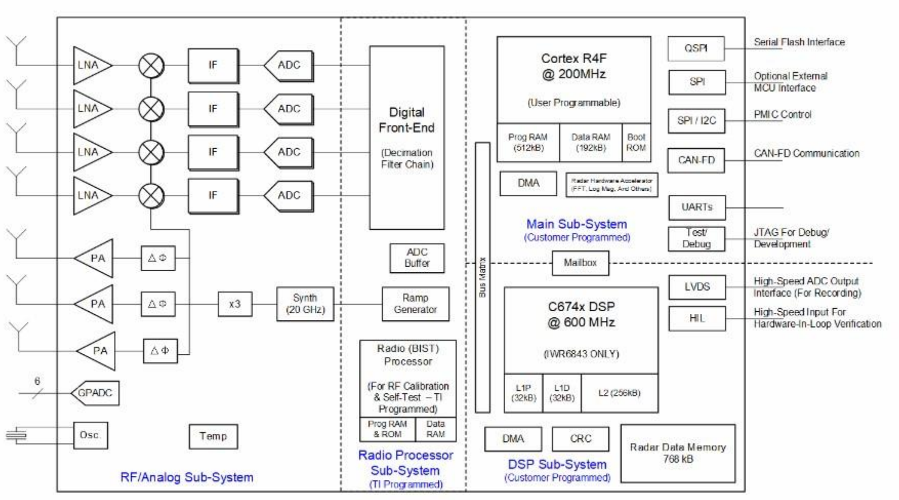


Figure 8 Functional Diagram of IWR6843ISK [13]

• FMCW transceiver ○ Integrated PLL, transmitter, receiver, Baseband, and ADC ○ 60- to 64-GHz coverage with 4-GHz continuous bandwidth ○ Four receive channels ○ Three transmit channels ○ Supports 6-bit phase shifter for TX Beam forming ○ Ultra-accurate chirp engine based on fractional-N PLL ○ TX power: 12 dBm

○ RX noise figure:

- 12 dB ○ Phase noise at 1 MHz:
- –93 dBc/Hz

3.2.3 Yonker Fingertip Pulse Oximeter YK-81C

The Fingertip Pulse Oximeter is a cutting-edge medical device that detects arterial SPO2 and PR in a non-invasive and continuous manner. It can be used on the finger to measure human haemoglobin saturation and heart rate. The product can be used in the home, hospital (including clinical use in internist surgery, anaesthesia, paediatrics, intensive care, and other areas), oxygen clubs, social medical organisations, and sports physical care (it can be used before or after sports). It's not a good idea to operate during a sporting event). It also applies to athletes, mountaineering enthusiasts, seniors over 60, patients (at-home convalescents or those who require first-aid treatment), people who work more than 12 hours per day, and people who work in a hermetic environment.

Figure 9 Yonkers Oximeter [12]

The Fingertip Pulse Oximeter is intended for use in medical institutes (not ICUs) or at home to measure blood oxygen saturation and pulse. Human haemoglobin saturation and heart rate can be measured using the fingertip Pulse Oximeter. The product is suitable for use in the home, hospital (including clinical use in internist/surgery, anaesthesia, paediatrics, intensive care, and so on), oxygen club, social medical organisations, and physical care in sports (it can be used before or after sports). Sport procedure operation is not advised). It is also applicable to mountaineering enthusiasts, patients (convalescents at home or those in need of first aid treatment), elders over 60, those working more than 12 hours, spotters, and those working in hermetic conditions.[12]

Specification	
DISPLAY TYPE	OLED display
Sp02 Measurement range	70% ~ 100%
Accuracy	80%~100%(±2%)
Resolution	1%
PR	30BPM ~ 240 BPM

Figure 10 Yonkers YK-81c Specification

3.3 Block diagram

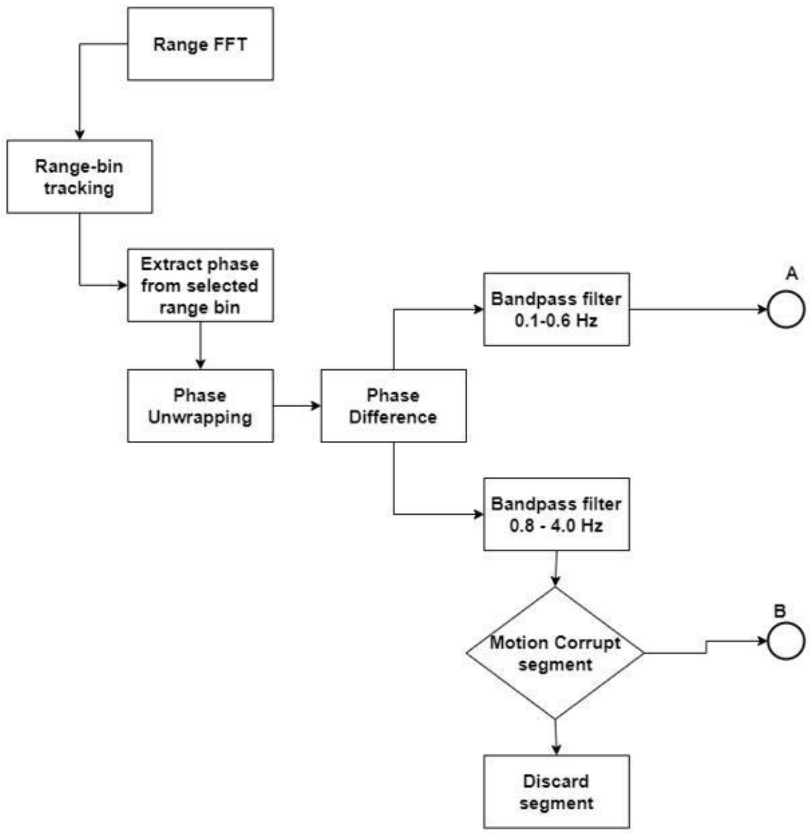


Figure 11 Block Diagram Process Within IWR6843ISK

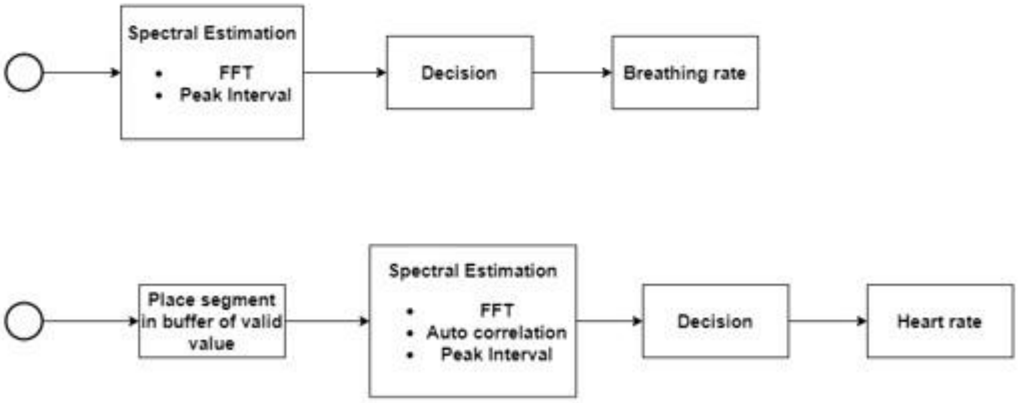


Figure 12 Block Diagram by Python

Based on the figure 11 and 12, the process starts at Range Fast Fourier Transform (FFT) where a Fast Fourier Transform (FFT) is performed on the ADC data to obtain the range profile. The magnitude of the range-profile is displayed on the PC-GUI. Next, the target range-bin corresponding to the target is found by finding the max-value in the range profile within the user-specified range limits. Continuing to the phase extraction, the phase value of the selected range-bin is computed from the complex range profile data and these phase values are measured over time. The assumption is that the subject is in the same range-bin throughout these measurements. If the subject moves to a different range-bin then it will take a few seconds before the algorithm locks into the new target range-bin.

Next, the phase unwrapping is a phase where the phase values are between [-π, π] and need to be unwrapped to obtain the actual displacement profiles. Phase unwrapping is performed by adding or subtracting 2 π from the phase whenever the phase difference between consecutive values is greater or less then ± π. The unwrapped phase is displayed as the chest displacement on the PC-GUI. The phase difference operation is performed on the unwrapped phase by subtracting successive phase values. This helps in enhancing the heart-beat signal and removing any phase drifts. Next the process goes to impulsive noise removal. The unwrapped differential phase might be corrupted by several noise-induced phase wrapping errors. This impulse-like noise is removed by computing a forward a(m)-a(m+1) and backward a(m)-a(m-1) phase difference for each a(m) and if these exceed a certain threshold then a(m) is replaced by an interpolated value. Bandpass filtering is where the phase values (after unwrapping and phase differences) are passed through two bandpass filters (serially-cascaded Bi-Quad IIR filter). These bandpass filters operate in real-time input data to generate a continuous stream of output data. The data after bandpass filtering is displayed as the breathing waveform and heart waveform in the PC-GUI.

Next, the process goes to motion corrupted segment removal or Gain Control. The purpose of this is to reduce the impact of any large amplitude movements on the heartrate estimation. The waveform is divided into segment of L=20 samples (corresponding to 1 second). If the energy within this data segment exceeds a user-defined threshold ($E > E_{Th}$), then all the samples in that data segments or block are either scaled or alternatively discarded from the timedomain cardiac waveform. Next is the Vital sign waveforms. Bandpass filter output is stored in the breathing waveform and cardiac waveform buffer and preprocessing steps such as windowing, gain control can be done on these prior to spectral estimation. Spectral Estimation is a buffer that are passed on to the spectral estimation block. Several different types of spectral estimation techniques can be implemented. The current implementation provides an FFT, auto-correlation and an estimate based on the interpeak distances in the time domain waveforms to estimate the vital signs. Finally, Vital Sign Decision, the final heartrate and breathing rate decisions are made based on the confidence metric from different spectral estimation methods

3.4 System Framework

Figure 13 below shows the overall framework of millimetre wave radar hardware. Based on the IWR6843ISK chip, the system built a complete modular circuit. The circuit consists primarily of:

- Computer
- IWR6843ISK mmwave sensor

- UART serial port for communication with the millimetre wave sensor module commend system.

- UART serial port for data transmission interface to obtain raw data of millimetre wave sensor.

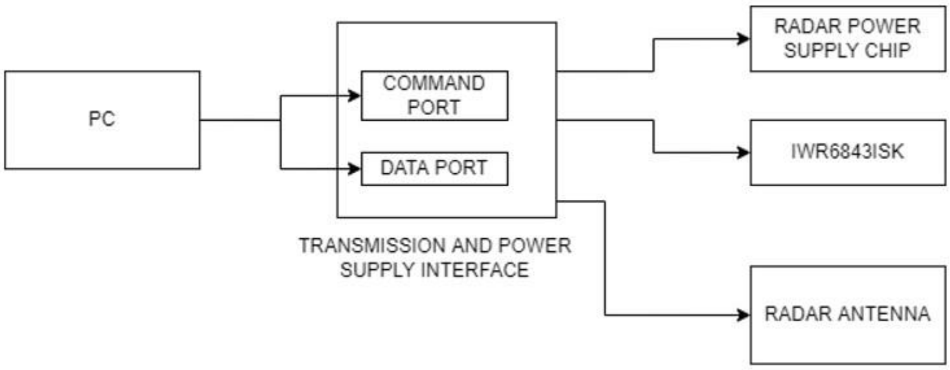


Figure 13 Hardware Overall Structure Diagram

3.5 Tools

Either for the purpose of modelling the procedure or for the purpose of writing the report on it, certain tools are necessary in order to carry out this project successfully. They are necessary whether you are modelling the procedure or writing the report on it. Microsoft Word 2019 can be seen being used to create a report and thesis for the project that is being discussed in the image that can be found below. The image can be found by clicking on the following link. In addition to that, the code was compiled with the assistance of the programme known as Visual Studio Code. Python 3 is used to assist in the process of writing code for various applications.

Figure 14 Microsoft Word 2022

Figure 15 Python 3.10

Figure 16 Visual Studio Code

3.6 Coding Block Diagram

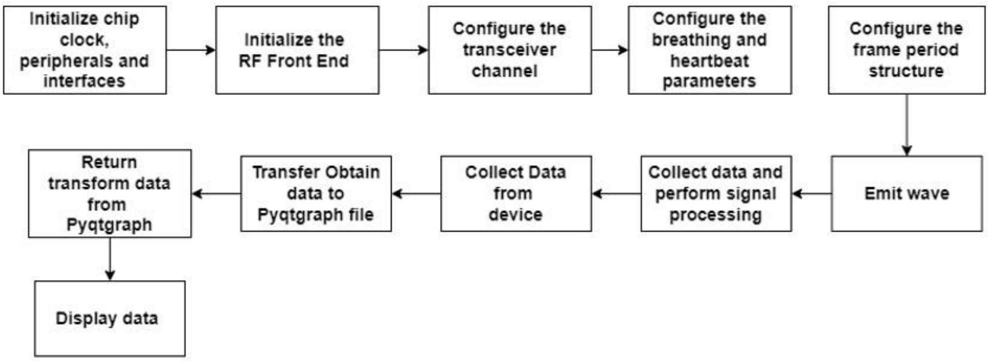


Figure 17 Coding Block Diagram

When creating the block diagram for the code, the first step is to initialise the chip clock, as well as the peripherals and interface. The iwr6843isk has two settings, the first of which is the functional mode, and the second of which is the flashing mode. Flashing is for when the user wants to upload a coding to the chip, and functional mode is for when the user wants to run the device with the coding that was uploaded. The next step is to start up the radio frequency (RF) front end. The iwr6843isk has both a front and a back radio frequency (RF). Either through the use of coding or the graphical user interface, this can be changed. The next step is to configure the channel for the transceiver. The iwr6843isk has four receive antennas (RX), three transmit antennas (TX), and a field of view (FoV) that is 120 degrees in both the azimuth and elevation directions. Last but not least, we need to configure the parameters for our breathing and heartbeat. The coding is responsible for carrying this out. After all of that, the antenna will perform the signal processing, as well as transmit the wave, collect all of the raw data, and then store it. The waveform that you see is a representation of this data. After that, the data that was collected is copied over to the pytqgraph file. Here is where all of the unprocessed data is converted into a format that Python can understand. At long last, the information is presented.

3.7 Physical Setup

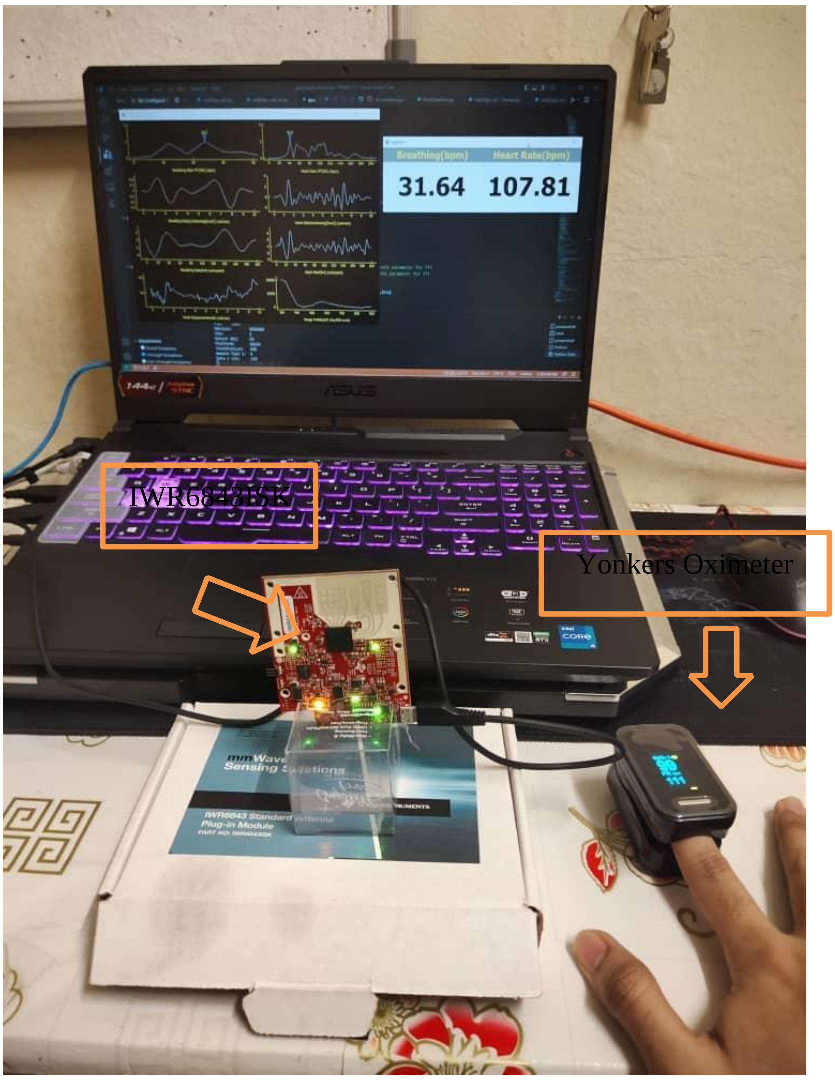


Figure 18 The millimeter-wave radar monitor system

According to the illustration that was just presented, the configuration is as it should be, with the IWR6843ISK located in the front with nothing in front of it. The apparatus is mounted on a box so that it is at a height that is parallel to the chest. After some time has passed, the patient's finger will be placed on the oximeter, and the chest will be positioned in front of the device.

3.8 PC Terminal Interface Design

Waveform Wi

Breathing and heartrate Window

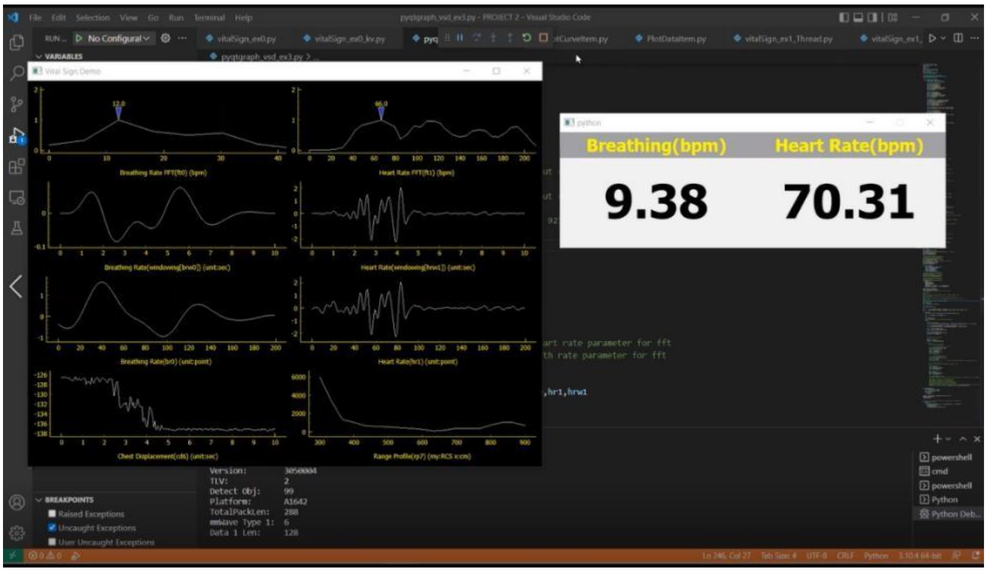


Figure 19 PC Terminal Interface

This is the display for the windows on the computer terminal. There are two windows, the first of which displays the waveform, and the second displays the heartbeat rate and breathing rate respectively. The waveform windows demonstrate the method that is used to determine the rates of breathing and heartbeat. The Fast Fourier Transformation procedure is illustrated here.

3.9 Experiment Parameter

Experiment	No Obstacle	With Obstacle
Distance	30-150cm	30-150cm
Obstacle	No	Plastic lid
Repeat of test	3	2
No. of participants	10	10

Figure 20 Experiment parameters

According to the table that was just presented, this article contains a total of 2 experiments. To begin, we will conduct the trials with the radar's line of sight clear of any obstruction. Throughout the course of these studies, the distance is increased by 30, 60, 90, 120, and 150 centimetres. There is nothing that can stop the participants or the radar from reaching their destination. In order to obtain data that is more precise, the test is carried out three times. There are ten male participants ranging from slim to overweight, all of whom are between the ages of 24 and 26, and all of whom are male.

The next part of the experiment involves positioning an obstruction in front of the gadget. Throughout the course of these studies, the distance is increased by 30, 60, 90, 120, and 150 centimetres. There is an obstruction in the form of a plastic cover standing between the participants and the radar. In order to obtain data that is more precise, the test is carried out twice. There are ten male participants ranging from slim to overweight, all of whom are between the ages of 24 and 26, and all of whom are male.

3.10 Experiment Setup

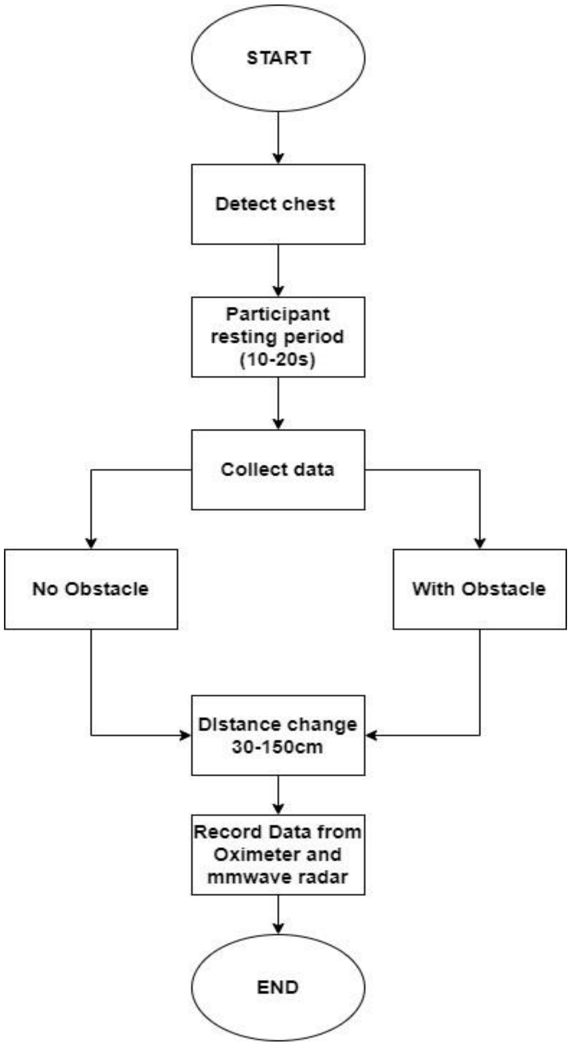


Figure 21 Flowchart for experiments procedure

Utilising the data presented in the preceding figure, the experiment is carried out as described below. To begin, the participant is positioned so that their chest is 30 centimetres away from both the radar and the chair they are seated on. After that, the participants are given ten to twenty seconds of rest time in order to normalise their heart and breathing rates. The fingertip oximeters of the participants are then attached to the device. At long last, the data have been collected. After that, this is done again for a distance of 60, 90, 120, and 150 centimetres from the radar to the participant's chest.

After that, the test is carried out once more, but this time there is an obstruction in the form of a plastic lid placed between the participant's chest and the radar.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

The outcomes of this experiment are presented in Figure below, and it is evident that it was carried out in an environment that was subject to careful observation and control, such as a laboratory. All of the people who took part in the research were male and ranged in age from 24 to 26 years old; while they were being tested, their breathing was monitored under controlled conditions. After making sure that the subjects' chests were within the normal range for detection and positioning them so that they faced the millimeter-wave sensor, the results were recorded. The chests of the subjects were positioned so that they faced the sensor. Following that, the distances of IWR6843ISK were adjusted to have new values of thirty centimetres, sixty centimetres, ninety centimetres, one hundred and fifty centimetres, and one hundred fifty centimetres, respectively. As a result of the fact that this was a non-contact detection experiment, both the measured environment and the movement of the human body were significantly disrupted. As a consequence of this, it is imperative that the human body be kept as still as possible throughout the entirety of the test. For the purpose of data collection, ten participants, all of whom are males, have been assembled. The ages range anywhere from 24 to 26 years of age. The body is distinct from measurements such as height and weight.

4.2 Result for distance without obstacle

4.2.1 Distance of 30cm between chest and device

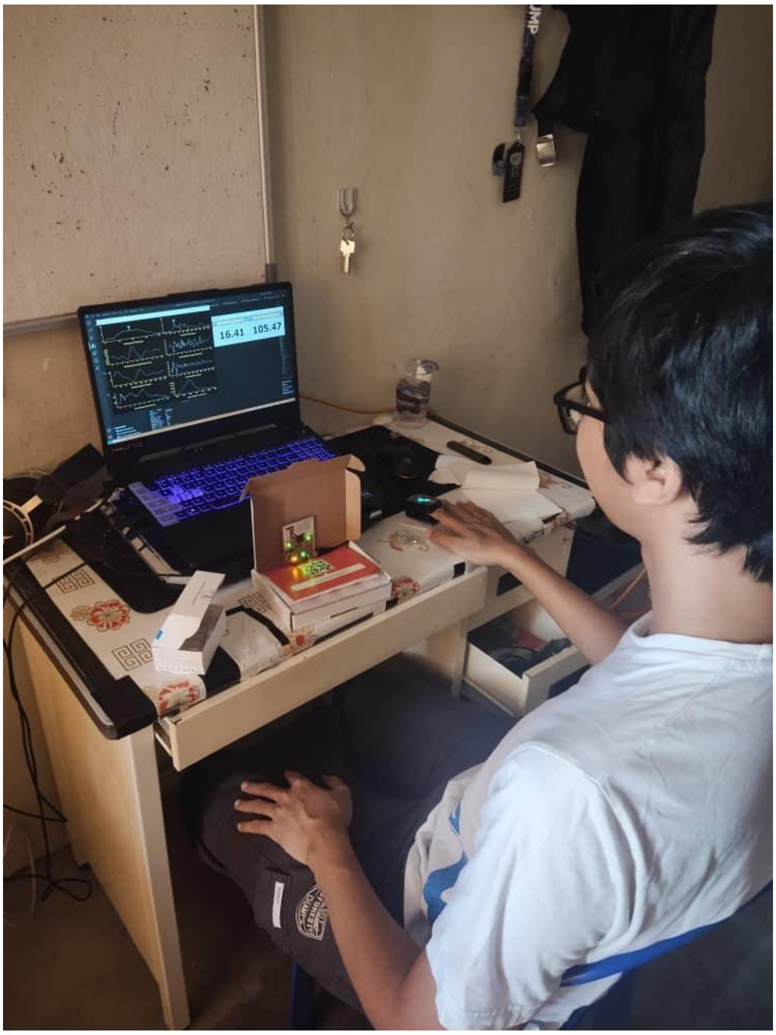
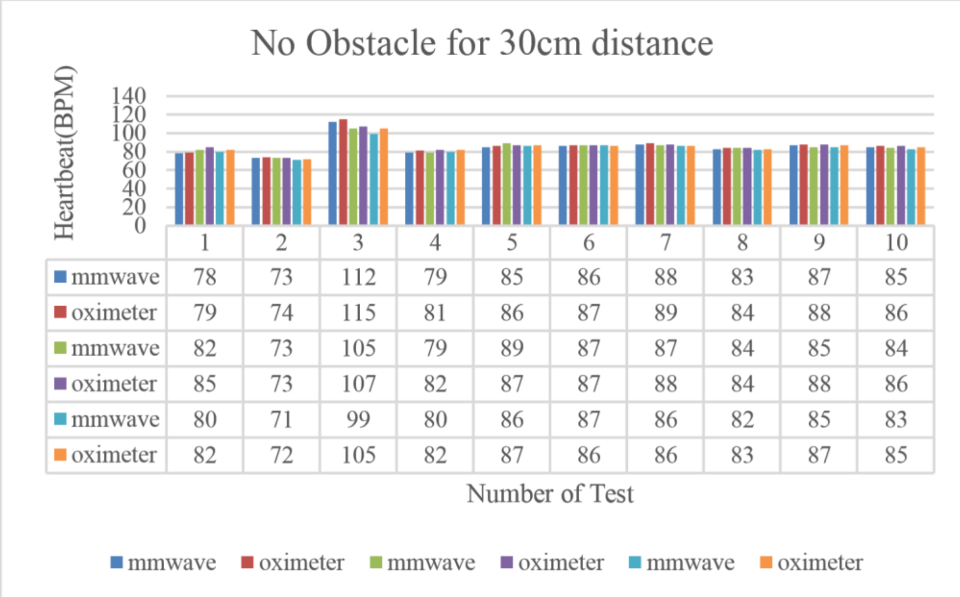


Figure 22 Setup for distance of 30cm

Before beginning the experiments, the distance was determined with the help of measuring tape, and it was then marked with more measuring tape. In order to accurately measure distances of 30 centimetres, the back of the chair rests on the measuring tape. Each participant in the experiments must take a seat on the chair, with their backs positioned so that they are supported by the back rest. After the participant has been seated, I will give them some time to unwind and calm down in order to ensure that the data that we collect is as accurate as possible. This is the outcome that the experiment is looking for the most. After having the participant relax for a few minutes, I will then place an oximeter on their finger in order to compare the results of the mmwave radar and the oximeter. It could take some time before the result becomes stable. As a consequence, I have a delay of ten to thirty seconds before I get the result because it takes the mmwave radar some time to become stable and accurately get the participant's heartbeat and breathing rate.



	1	2	3	4	5	6	7	8	9	10
mmwave	78	73	112	79	85	86	88	83	87	85
oximeter	79	74	115	81	86	87	89	84	88	86
mmwave	82	73	105	79	89	87	87	84	85	84
oximeter	85	73	107	82	87	87	88	84	88	86
mmwave	80	71	99	80	86	87	86	82	85	83
oximeter	82	72	105	82	87	86	86	83	87	85

Figure 23 Result for distance of 30cm

The result for a distance of thirty centimetres with no obstructions is as shown above. The test is carried out once more for each of the ten participants. It is now time to collect the results of the mmwave and oximeter. Because the results are viewed from the top down, this indicates that each column contains information pertaining to a single individual. The following step is to perform each experiment thrice. The average value for the graph comes in at 85.6833, while 85 serves as the median and 87 is the mode. The highest possible score is 115, and the lowest possible score is 71. The variance, expressed as a standard deviation, is 8.630830953. 1.114235485 is the value of the standard error.

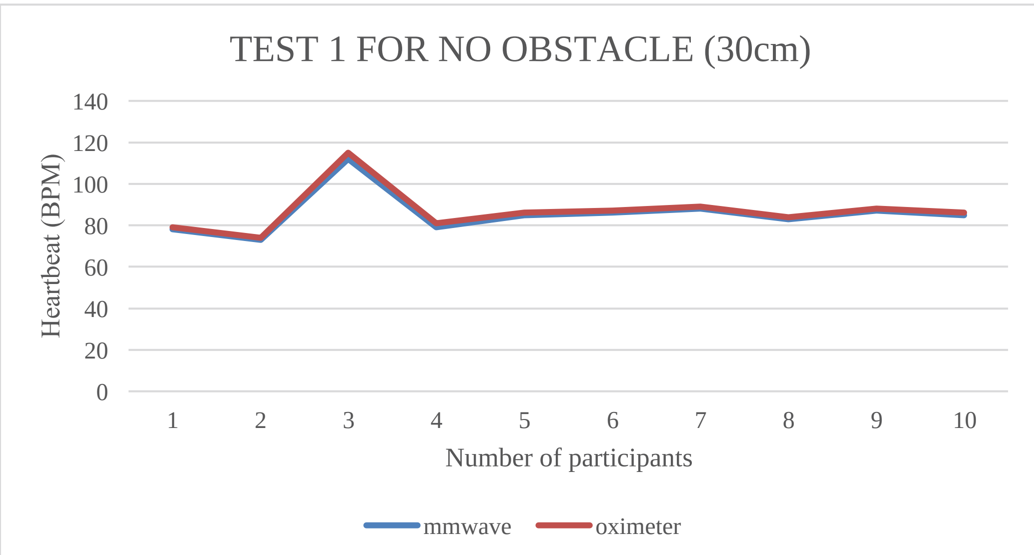


Figure 24 Waveform for Test 1 No obstacle (30cm)

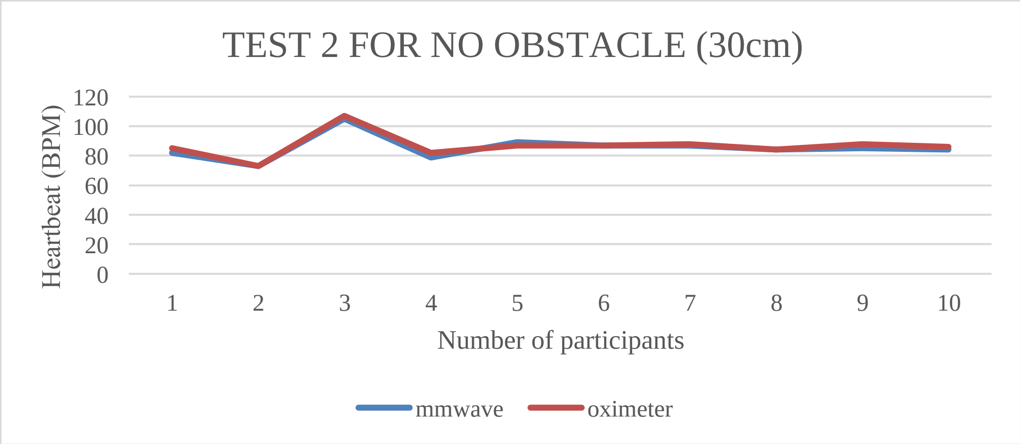


Figure 25 Waveform for Test 2 No obstacle (30cm)

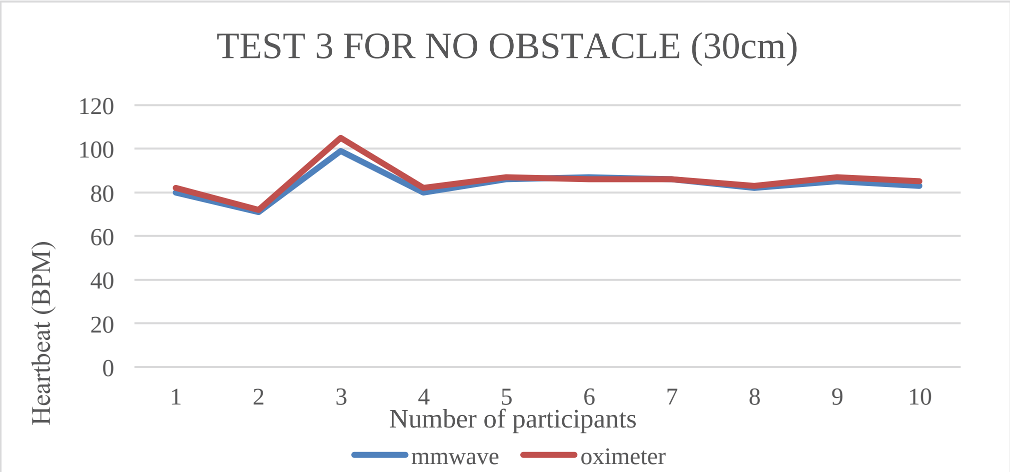


Figure 26 Waveform for Test 3 No obstacle (30cm)

According to the data presented above, the waveform produced by the mmwave radar is just as accurate as the waveform produced by the oximeter when measured over a distance of 30 centimetres with no obstructions in the way.

When there are no obstructions in the way, we can deduct from the waveforms that the mmwave radar is accurate at a distance of 30 centimetres.

4.2.2 Distance of 60cm between chest and device

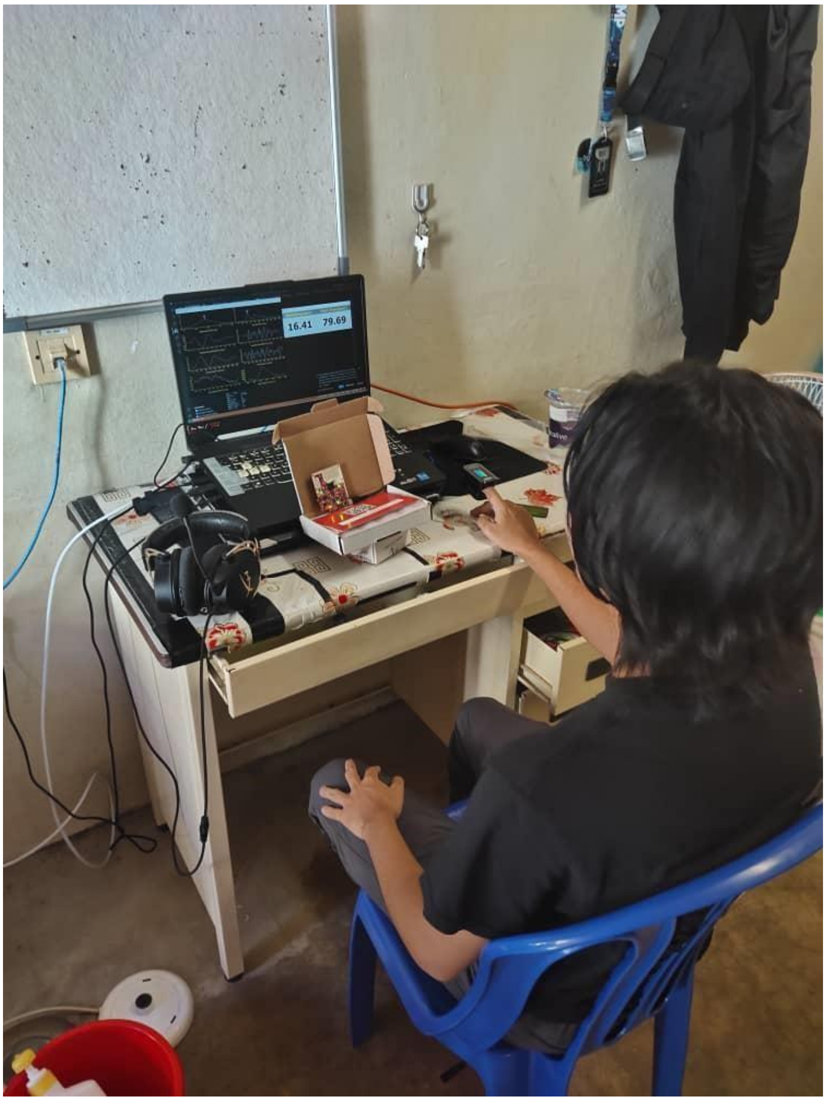
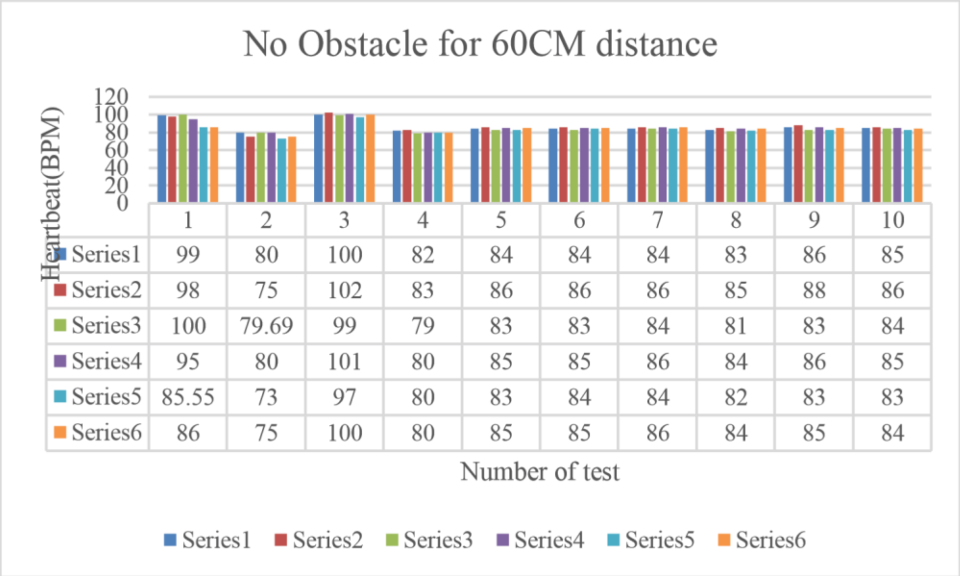


Figure 27 Setup for distance of 60cm

Before beginning the experiments, the distance was measured using measuring tape, and once it was determined, it was marked using additional measuring tape. The back of the chair is placed on top of the measuring tape in order to ensure that distances of sixty centimetres are measured accurately. Each person who is going to take part in the experiment is going to have to take a seat on the chair and position their backs in such a way that the back rest will support them. As soon as the participant has been seated, I will allow them some time to relax and settle down in order to guarantee that the information that we gather is as precise as is practically possible. This is the result that the experiment is anticipating having the greatest impact on. In order to compare the results of the mmwave radar and the oximeter, I will first have the participant relax for a few minutes, and then I will place an oximeter on their finger. It's possible that it won't be until some time has passed before the result becomes stable. It takes the mmwave radar some time to become stable and accurately get the participant's heartbeat and breathing rate. As a result, I have a delay of ten to thirty seconds before I get the result. This is because it takes some time for the mmwave radar to become stable.



	1	2	3	4	5	6	7	8	9	10
Series1	99	80	100	82	84	84	84	83	86	85
Series2	98	75	102	83	86	86	86	85	88	86
Series3	100	79.69	99	79	83	83	84	81	83	84
Series4	95	80	101	80	85	85	86	84	86	85
Series5	85.55	73	97	80	83	84	84	82	83	83
Series6	86	75	100	80	85	85	86	84	85	84

Figure 28 Result for distance of 60cm

The result for a distance of sixty centimetres with no obstructions is as shown above. The test is carried out once more for each of the ten participants. It is now time to collect the results of the mmwave and oximeter. Because the results are viewed from the top down, this indicates that each column contains information pertaining to a single individual. The following step is to perform each experiment thrice. The average value for the graph is 85.82066667, the median is 84, and the most common value is also 84. The highest possible score is 102, and the lowest possible score is 73. It has been determined that the standard deviation is 6.653772949. The standard error is calculated to be 0.858998394.

Figure 29 Waveform for Test 1 No obstacle (60cm)

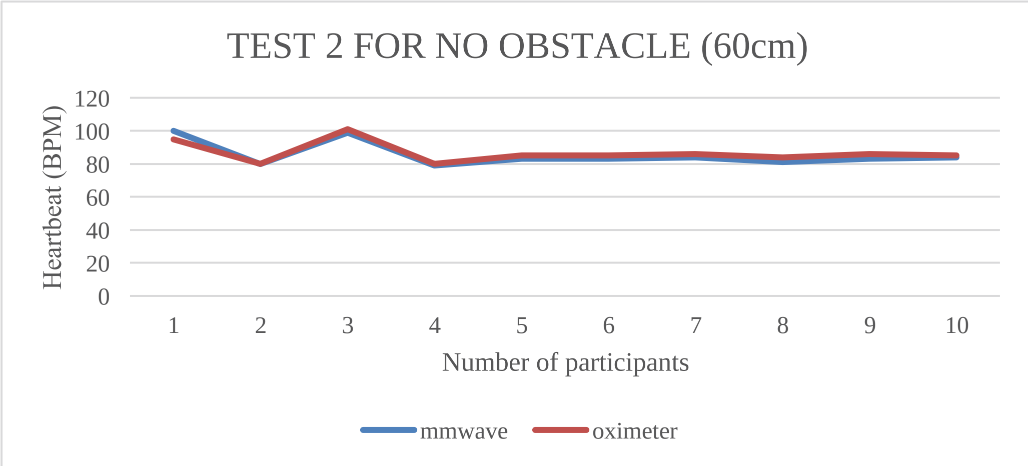
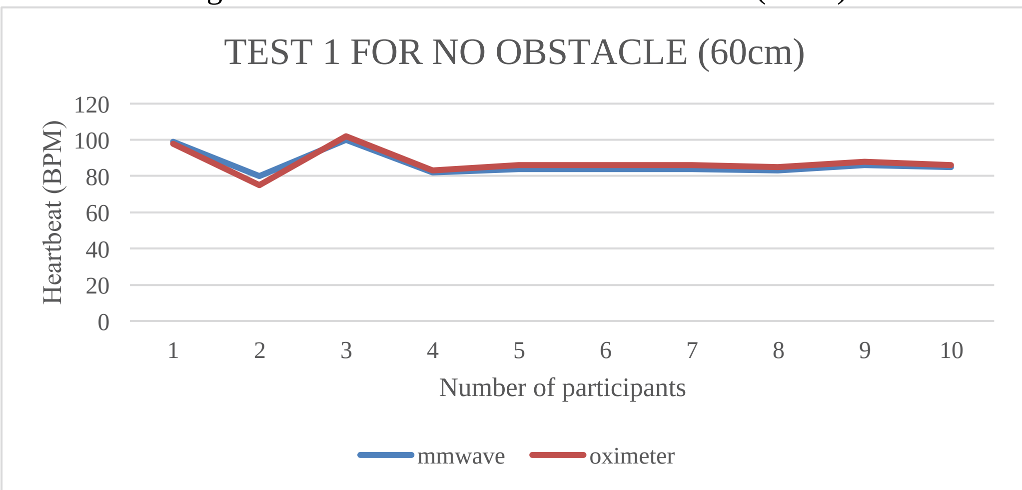


Figure 30 Waveform for Test 2 No Obstacle (60cm)



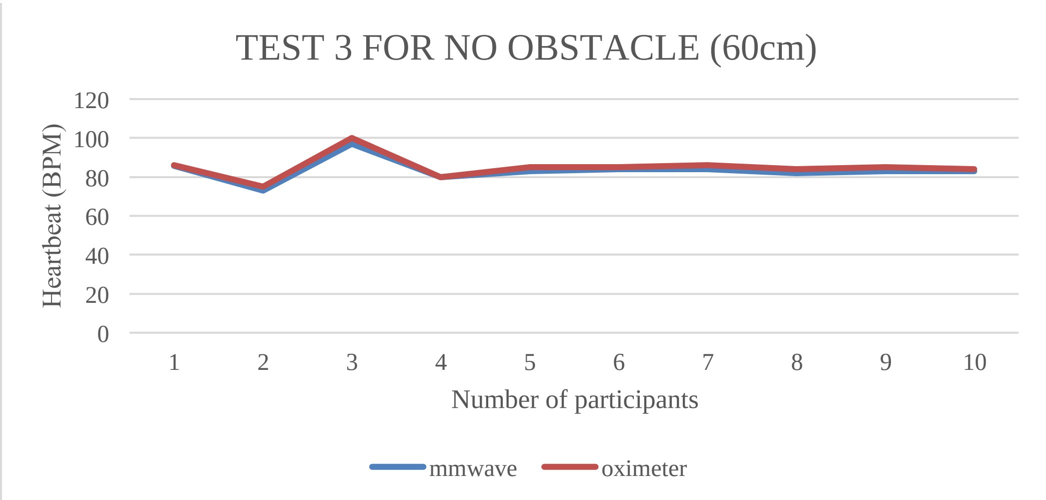


Figure 31 Waveform for Test 3 No Obstacle (60cm)

Following the figures presented above, we are able to draw the conclusion that the waveform generated by the mmwave radar at a distance of 60 cm when there is no obstruction in the way is just as accurate as the waveform generated by the oximeter at the same distance. When there are no obstacles in the way of the mmwave radar's path, we can deduct from the waveforms that the device can produce accurate readings at a distance of sixty centimetres.

4.2.3 Distance of 90cm between chest and device

Figure 32 Setup for distance of 90cm

Before beginning the experiments, the distance was measured using measuring tape, and once it was determined, it was marked using additional measuring tape. The back of the chair is placed on the measuring tape in order to ensure that distances of 90 centimetres are measured accurately. Each person who is going to take part in the experiment is going to have to take a seat on the chair and position their backs in such a way that the back rest will support them. As soon as the participant has been seated, I will allow them some time to relax and settle down in order to guarantee that the information that we gather is as precise as is practically possible. This is the result that the experiment is anticipating having the greatest impact on. In order to compare the results of the mmwave radar and the oximeter, I will first have the participant relax for a few minutes, and then I will place an oximeter on their finger. It's possible that it won't be until some time has passed before the result becomes stable. It takes the mmwave radar some time to become stable and accurately get the participant's heartbeat and breathing rate. As a result, I have a delay of ten to thirty seconds before I get the result. This is because it takes some time for the mmwave radar to become stable.

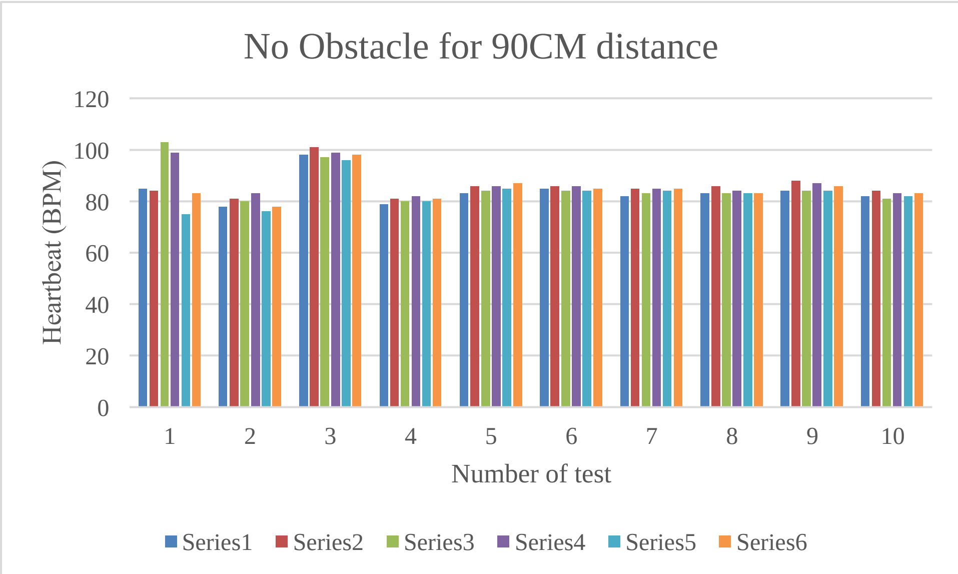


Figure 33 Result for distance of 90cm

The results of the test are as shown above for a distance of 90 cm with no obstructions. The test is carried out again with the remaining ten participants. It is now time to collect the results of the mmwave and oximeter. Because the results are viewed from the top down, this indicates that each column contains information pertaining to a single individual. The following step is to perform each experiment thrice. The graph has a mean value of 85.2, a median value of 84, and the mode value is also 84. The lowest point in the range is 75, and the highest point is 103. It has been determined that the standard deviation equals 6.016361872. The value of the standard deviation is 0.776708978.

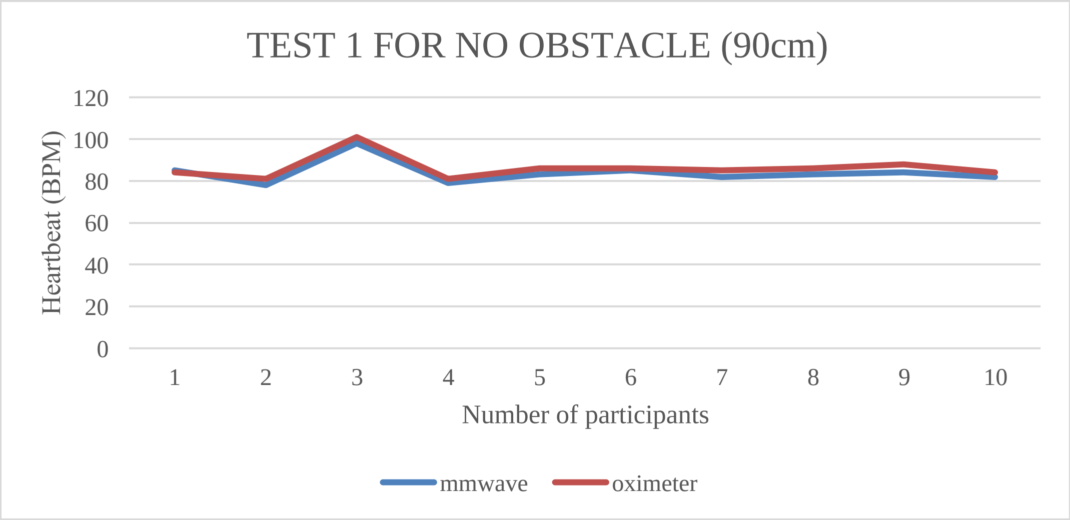


Figure 34 Waveform for Test 1 No Obstacle (90cm)

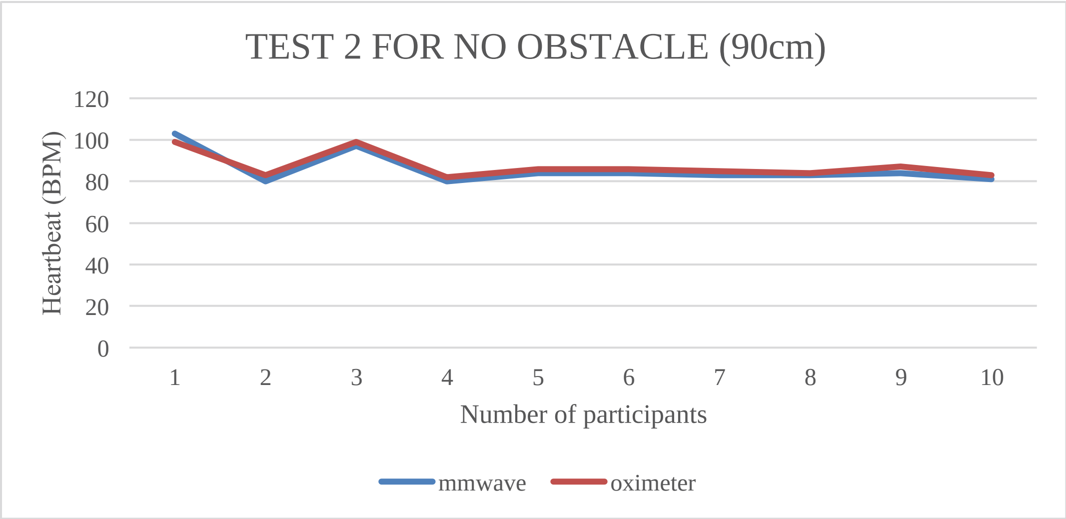


Figure 35 Waveform for Test 2 No Obstacle (90cm)

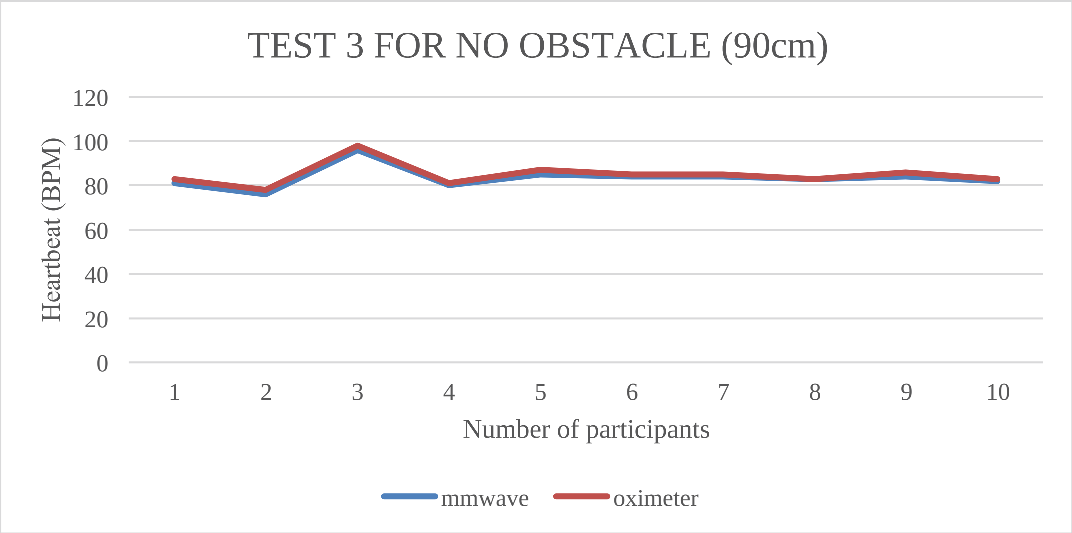


Figure 36 Waveform for Test 3 No Obstacle (90cm)

Following the results that were presented earlier, we are able to come to the conclusion that the waveform generated by the mmwave radar at a distance of 90 cm when there is no obstruction in the way is just as accurate as the waveform generated by the oximeter at the same distance. This is the conclusion that we are able to come to because of the fact that we were able to determine that the waveform generated by the oximeter at the same distance. We are able to deduce from the waveforms that the device is capable of producing accurate readings at a distance of 90 centimetres when there are no obstructions in the way of the path that the mmwave radar takes.

4.2.4 Distance of 120cm between chest and device

Figure 37 Setup for distance of 120cm

Before beginning the experiments, the distance was determined by measuring it with one piece of measuring tape, and once that was done, another piece of measuring tape was used to mark the distance. When measuring distances up to 120 centimetres, the back of the chair is placed on top of the measuring tape to ensure that the measurements are as accurate as possible. Each person who is going to take part in the experiment is going to have to take a seat on the chair and position their backs in such a way that the back rest will support them. This is going to be a requirement in order for them to be able to participate. As soon as the participant has been seated, I will give them some time to unwind and get comfortable in order to ensure that the data that we collect is as accurate as is reasonably achievable in the circumstances. This is the anticipated outcome that will be influenced the most by the experiment that was carried out. In order to compare the findings of the oximeter and the mmwave radar, I will first have the participant relax for a few minutes, and then I will place an oximeter on their finger. After that, I will compare the findings of the two devices. It's possible that the result won't become stable until some time has passed after the experiment has been conducted. The mmwave radar needs some time to stabilise before it can accurately determine the participant's heartbeat and breathing rate. As a direct consequence of this, there is a lag time of anywhere between ten and thirty seconds before I get the result. This is due to the fact that the mmwave radar needs some time to become stable before it can be used..

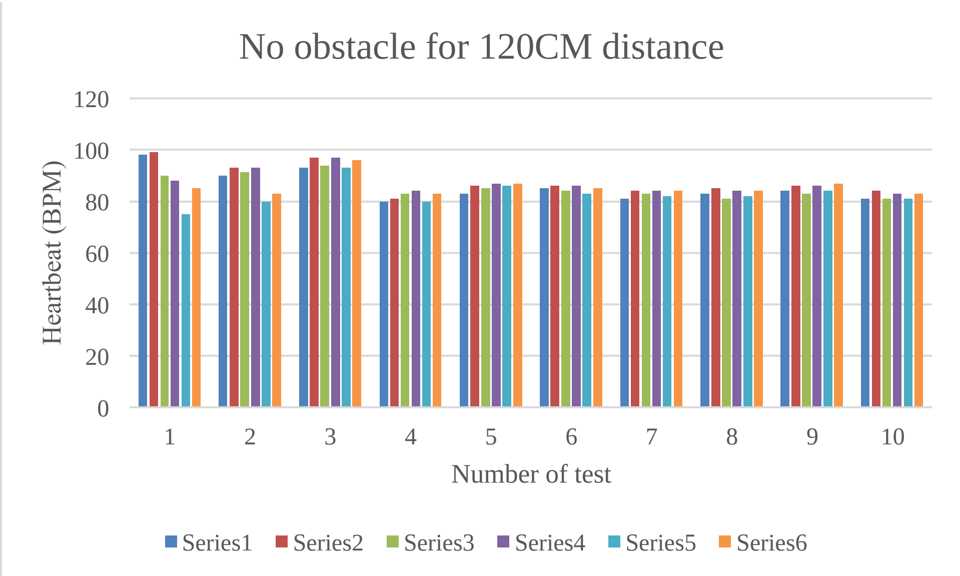


Figure 38 Result for distance of 120cm

The results of the test are as shown above for a distance of 120 cm with no obstructions. The test is carried out again with the remaining ten participants. It is now time to collect the results of the mmwave and oximeter. Because the results are viewed from the top down, this indicates that each column contains information pertaining to a single individual. The following step is to perform each experiment thrice. The average value for the graph comes in at 85.823, while the median sits at 84 and the mode at 83. The minimum value in the range is 75, while the highest possible is 99. It has been determined that the standard deviation equals 5.087479913. The standard error is calculated to be 0.656790833.

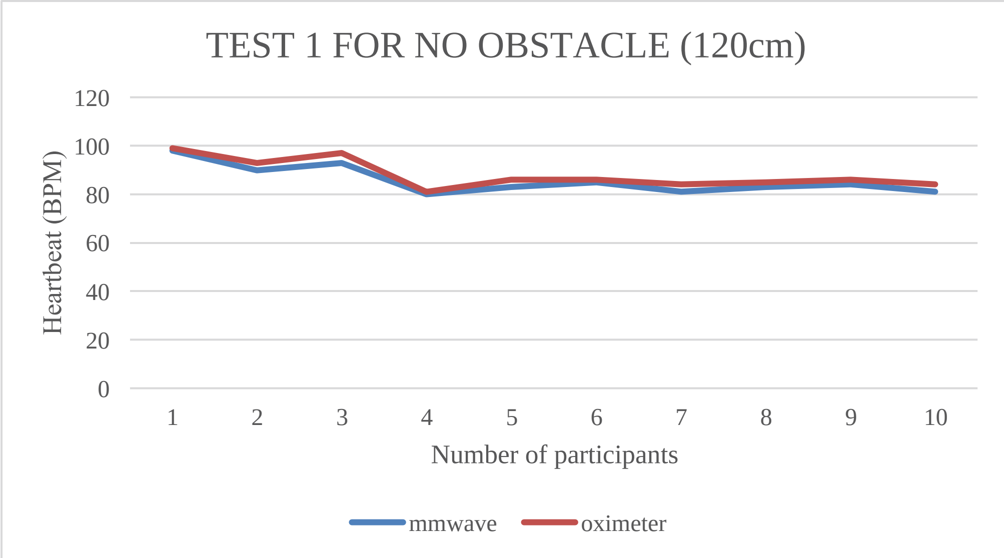


Figure 39 Waveform for Test 1 No Obstacle (120cm)

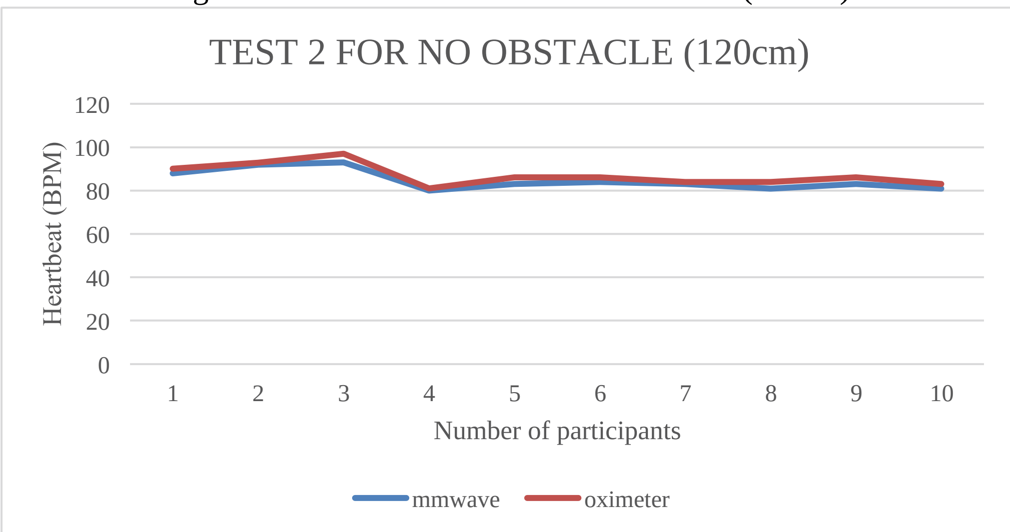


Figure 40 Waveform for Test 2 No Obstacle (120cm)

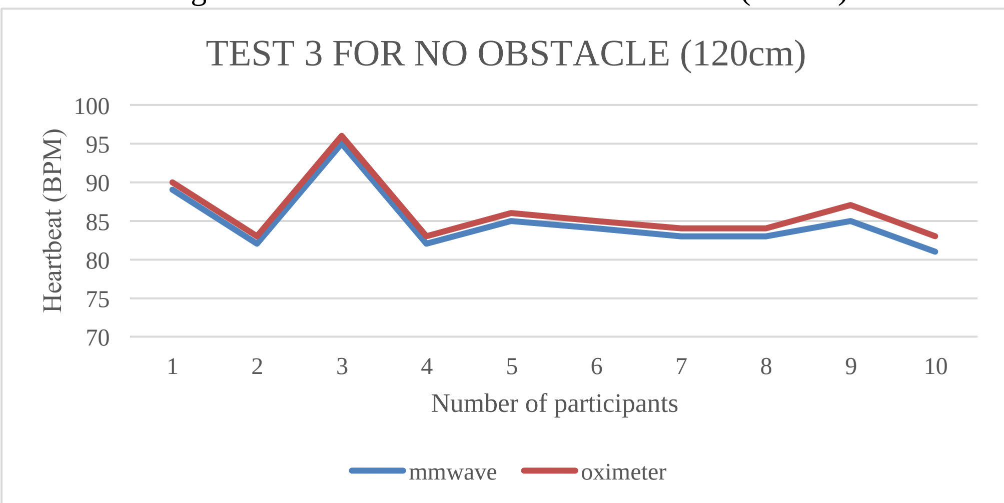


Figure 41 Waveform for Test 3 No Obstacle (120cm)

Following the results that were presented earlier, we are able to arrive at the conclusion that the waveform generated by the mmwave radar at a distance of 120 cm when there is no obstruction in the way is just as accurate as the waveform generated by the oximeter at the same distance. This conclusion was reached because both waveforms were generated at the same distance. Because we were able to determine that the waveform generated by the oximeter at the same distance, we were able to arrive at this conclusion. This is the conclusion that we are able to come to because we are able to determine that the waveform. We are able to conclude, based on the waveforms, that the device is capable of producing accurate readings at a distance of 120 cm when there are no obstructions in the way of the path that the mmwave radar takes.

4.2.5 Distance of 150cm between chest and device

Figure 42 Setup for distance of 150cm

Before beginning the experiments, the distance was determined with the help of measuring tape, and it was then marked with more measuring tape. In order to accurately measure distances of 150 centimetres, the back of the chair rests on the measuring tape. Each participant in the experiments must take a seat on the chair, with their backs positioned so that they are supported by the back rest. After the participant has been seated, I will give them some time to unwind and calm down in order to ensure that the data that we collect is as accurate as possible. This is the outcome that the experiment is looking for the most. After having the participant relax for a few minutes, I will then place an oximeter on their finger in order to compare the results of the mmwave radar and the oximeter. It could take some time before the result becomes stable. As a consequence, I have a delay of ten to thirty seconds before I get the result because it takes the mmwave radar some time to become stable and accurately get the participant's heartbeat and breathing rate.

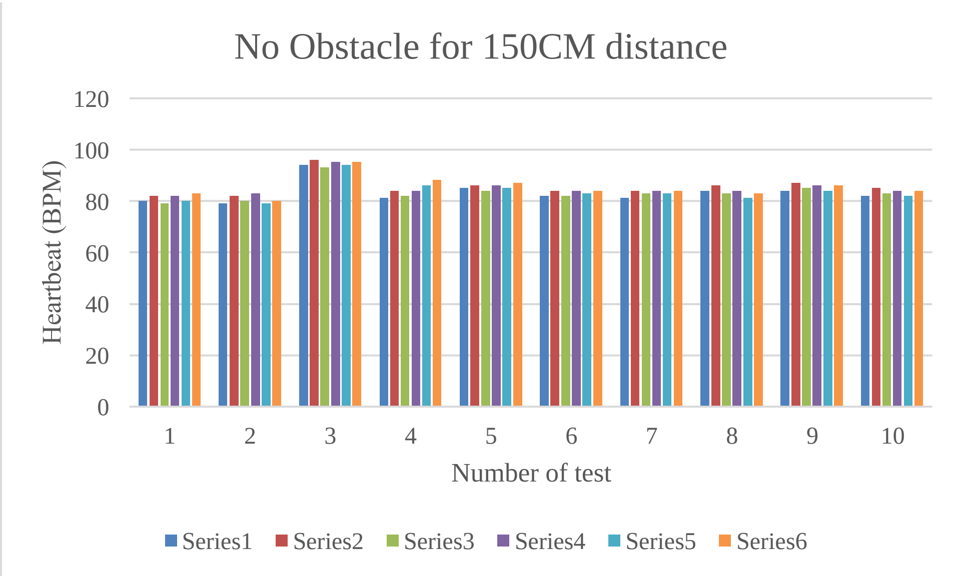


Figure 43 Result for distance of 150cm

The result for a distance of 150 centimetres with no obstructions is as shown above. The test is carried out again with the remaining ten participants. It is now time to collect the results of the mmwave and oximeter. Because the results are viewed from the top down, this indicates that each column contains information pertaining to a single individual. The following step is to perform each experiment thrice. The average value for the graph is 84.41666667, the median value is 84, and the most common value is also 84. The lowest possible score is 76, while the highest possible score is 96. It has been determined that the standard deviation equals 3.958649259. There is a 0.511059422 standard deviation in the data.

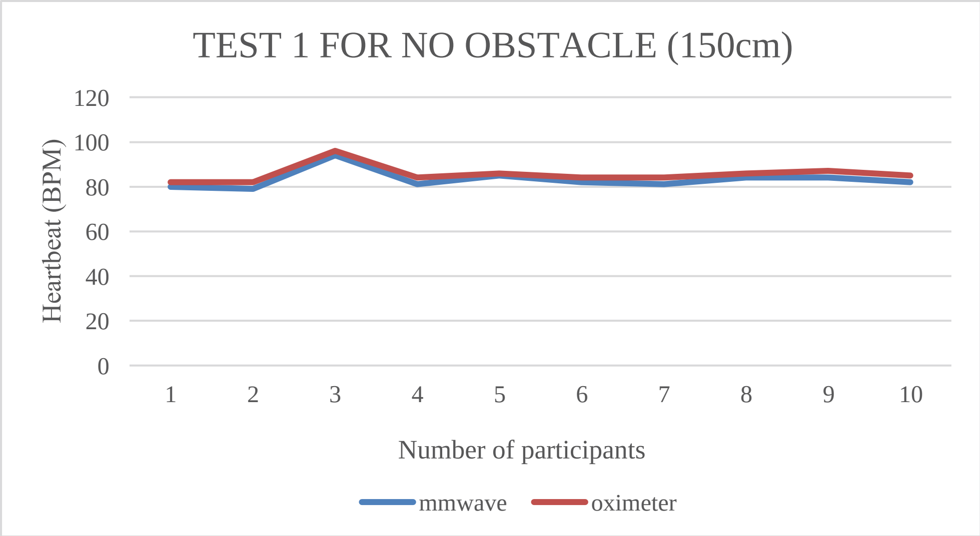


Figure 44 Waveform for Test 1 No Obstacle (150cm)

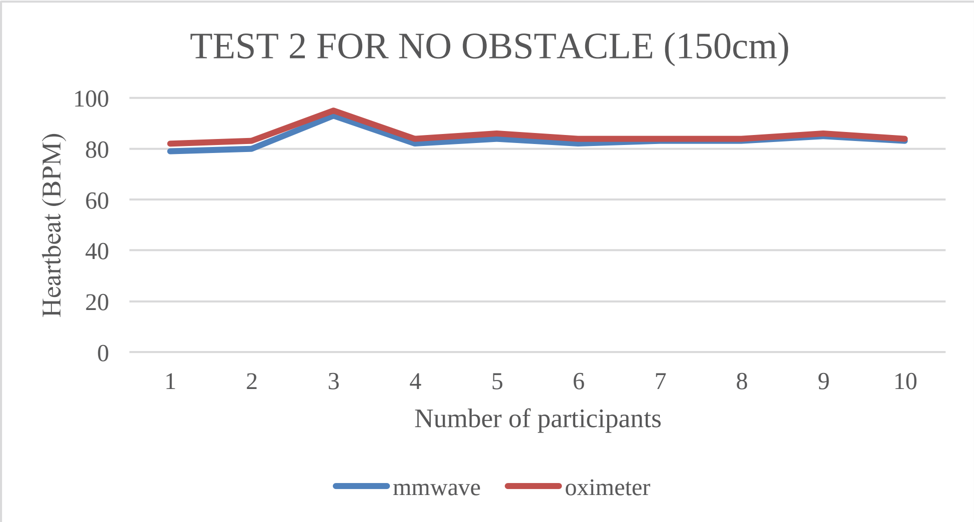


Figure 45 Waveform for Test 2 No Obstacle (150cm)

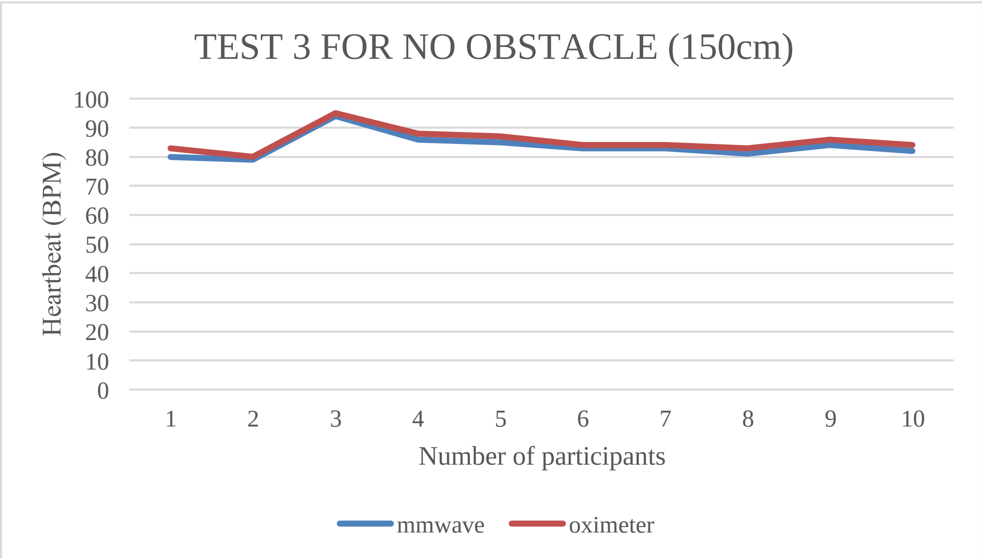


Figure 46 Waveform for Test 3 No Obstacle (150cm)

Following the results that were presented earlier, we are able to draw the conclusion that the waveform generated by the mmwave radar at a distance of 150 cm when there is no obstruction in the way is just as accurate as the waveform generated by the oximeter at the same distance. This conclusion was reached as a result of the findings that were presented earlier. Because we were able to determine that the waveform generated by the oximeter at the same distance, we were able to arrive at this conclusion. This is the conclusion that we are able to come to because we are able to determine that the waveform. We are able to conclude, based on the waveforms, that the device is capable of producing accurate readings at a distance of 150 centimetres when there are no obstructions in the way of the path that the mmwave radar takes.

4.3 Result for distance with obstacle

4.3.1 Distance of 30cm between chest and device

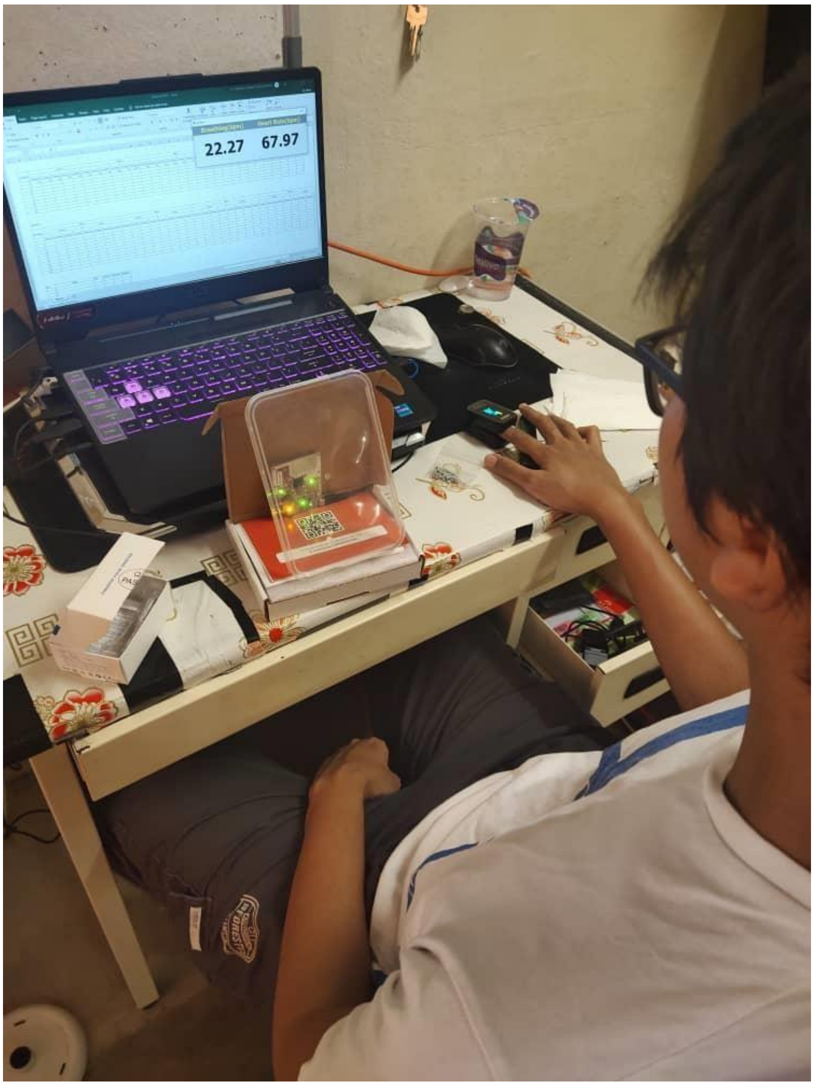


Figure 47 Setup for distance of 30cm with obstacle

Before beginning the experiments, the distance was measured using measuring tape, and once it was determined, it was marked using additional measuring tape. The back of the chair is placed on the measuring tape so that one can obtain precise readings of distances that are 30 centimetres in length. Each person who is going to take part in the experiment is going to have to take a seat on the chair and position their backs in such a way that the back rest will support them. As soon as the participant has been seated, I will allow them some time to relax and settle down in order to guarantee that the information that we gather is as precise as is practically possible. This is the result that the experiment is anticipating having the greatest impact on. Additionally, a barrier is positioned in front of the apparatus. In order to compare the results of the mmwave radar and the oximeter, I will first have the participant relax for a few minutes, and then I will place an oximeter on their finger. It's possible that it won't be until some time has passed before the result becomes stable. It takes the mmwave radar some time to become stable and accurately get the participant's heartbeat and breathing rate. As a result, I have a delay of ten to thirty seconds before I get the result. This is because it takes some time for the mmwave radar to become stable.

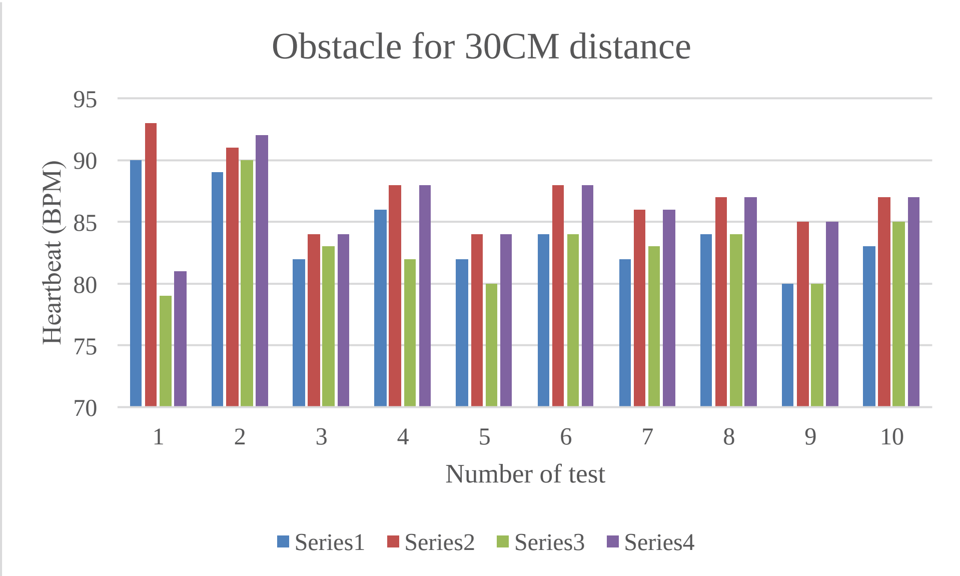


Figure 48 Result for distance of 30cm with obstacle

The results of the test are as shown above for 30 centimetres with an obstruction. The test is carried out again with all ten participants. It is now time to collect the results of the mmwave and oximeter. Because the results are viewed from the top down, this indicates that each column contains information pertaining to a single individual. The following step involves repeating each experiment twice. The average value displayed by the graph is 85.175, while the median is 84.5 and the mode is 84. The highest possible score is 93, and the lowest possible score is 79. It has been determined that the standard deviation equals 3.403523815. The value of the standard deviation is 0.538144366.

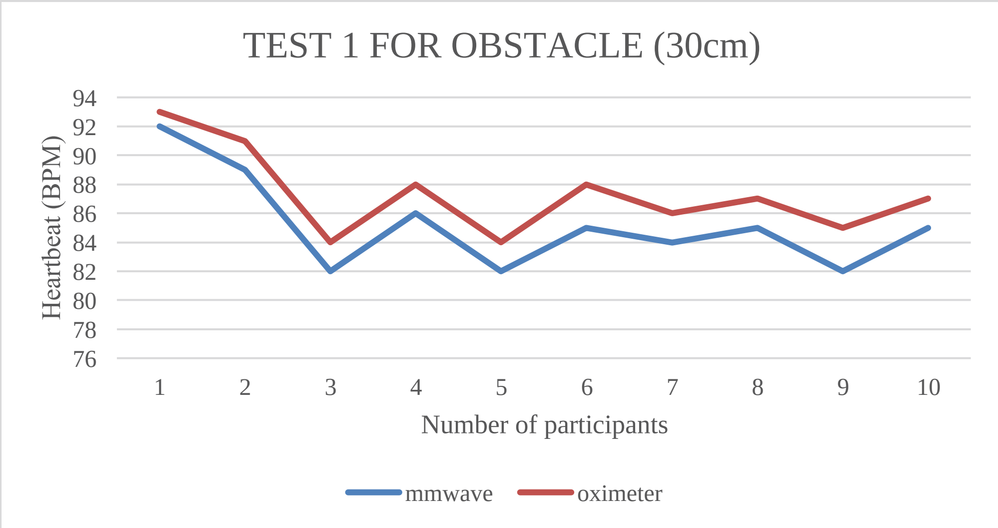


Figure 49 Waveform for Test 1 with Obstacle (30cm)

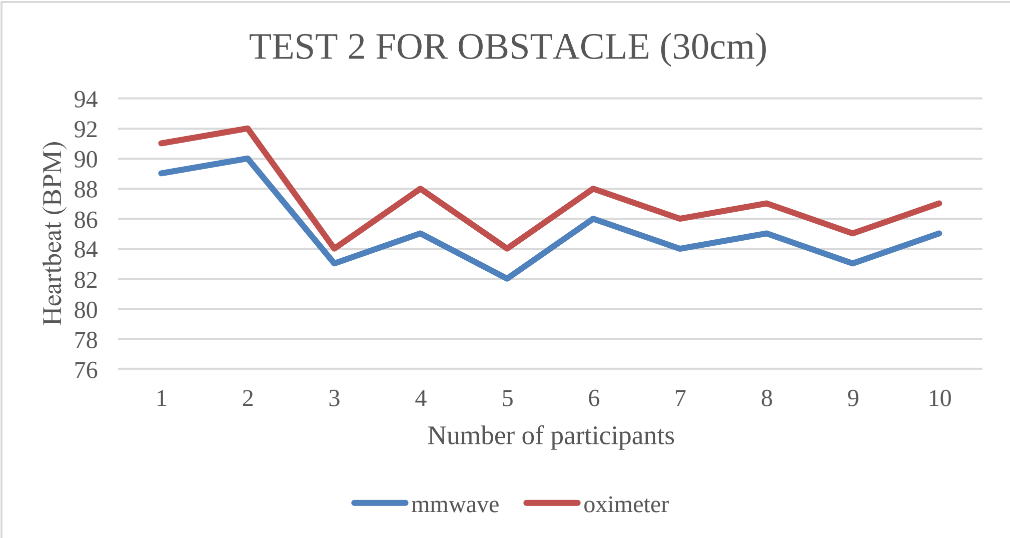


Figure 50 Waveform for Test 2 with Obstacle (30cm)

When there is an obstruction in the path of the mmwave radar, the error is likely to be quite significant when compared to the situation in which there is no obstruction. The data that was presented earlier allows for the reasoning of this conclusion. The waveform is fundamentally the same when there is an obstruction present at a distance of 30 centimetres; the only difference is that there is an error of +-4.

4.3.2 Distance of 60cm between chest and device

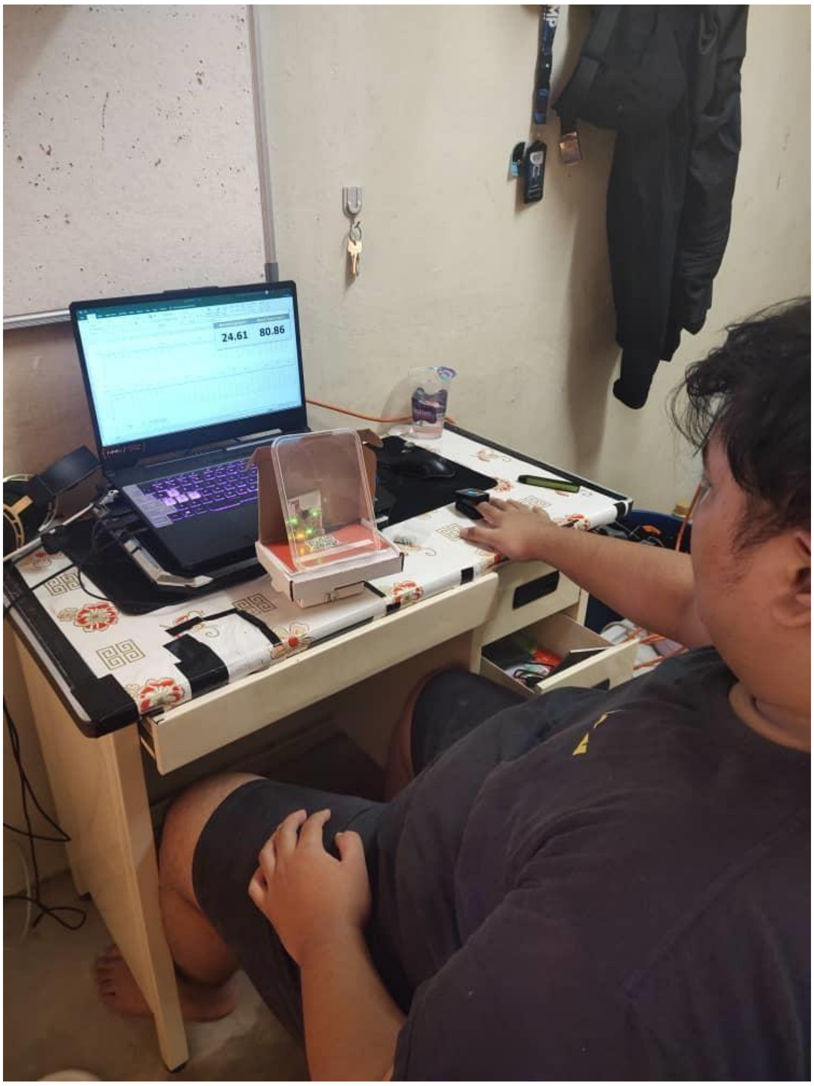


Figure 51 Setup for distance of 60cm with obstacle

Before beginning the experiments, the distance was measured using measuring tape, and once it was determined, it was marked using additional measuring tape. The back of the chair is placed on top of the measuring tape in order to ensure that distances of sixty centimetres are measured accurately. Each person who is going to take part in the experiment is going to have to take a seat on the chair and position their backs in such a way that the back rest will support them. As soon as the participant has been seated, I will allow them some time to relax and settle down in order to guarantee that the information that we gather is as precise as is practically possible. This is the result that the experiment is anticipating having the greatest impact on. Additionally, a barrier is positioned in front of the apparatus. In order to compare the results of the mmwave radar and the oximeter, I will first have the participant relax for a few minutes, and then I will place an oximeter on their finger. It's possible that it won't be until some time has passed before the result becomes stable. It takes the mmwave radar some time to become stable and accurately get the participant's heartbeat and breathing rate. As a result, I have a delay of ten to thirty seconds before I get the result. This is because it takes some time for the mmwave radar to become stable.

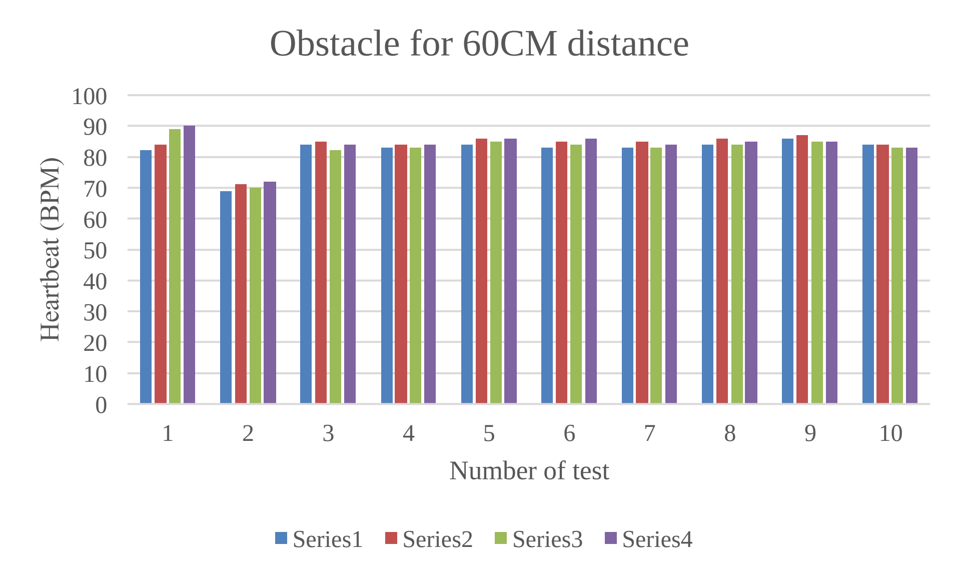


Figure 52 Result for distance of 60cm with obstacle

The result for 60 centimetres with an obstruction is as shown above, and the test is carried out once more for each of the ten participants. It is now time to collect the results of the mmwave and oximeter. Because the results are viewed from the top down, this indicates that each column contains information pertaining to a single individual. The following step involves repeating each experiment twice. The average value on the graph is 83.15, the median value is 84, and the most common value is also 84. The highest value in this range is 90, and the lowest value is 69. It has been determined that the standard deviation equals 4.577257044. The margin of error is 0.723727885, to be exact.

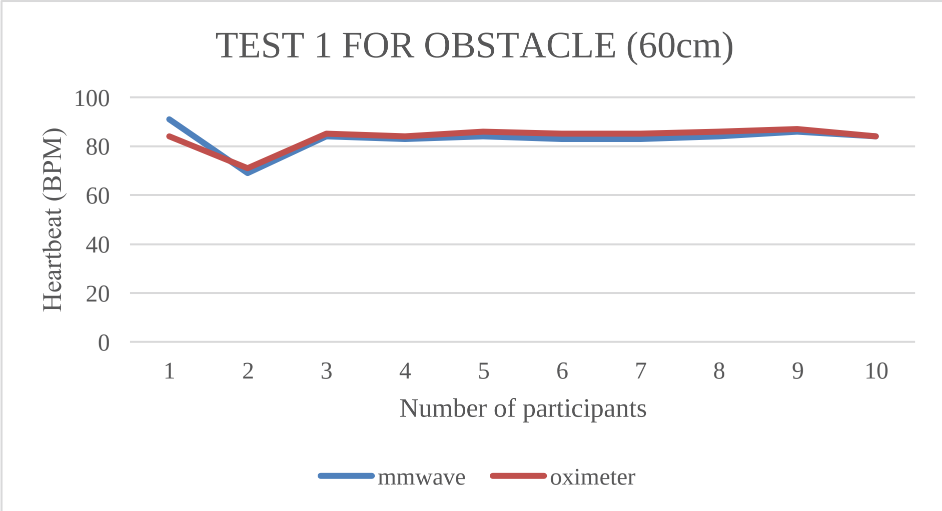


Figure 53 Waveform for Test 1 with Obstacle (60cm)

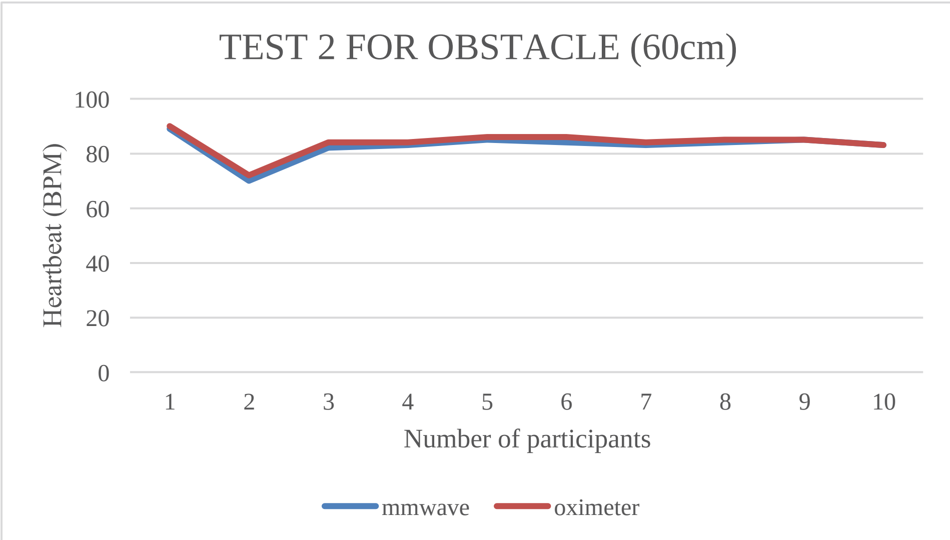


Figure 54 Waveform for Test 2 with Obstacle (60cm)

After looking at the numbers for the distance of 60 centimetres with an obstruction, I was taken aback to find that the result is accurate. I was expecting it to be inaccurate. The waveform that is produced by the oximeter is identical to the one that is produced by the mmwave radar; however, the error in the measurement value for the heartbeat is only plus or minus two (bpm). Because of this, I believe that the ideal distance when there is an obstruction is sixty centimetres (cm) away from it.

4.3.3 Distance of 90cm between chest and device

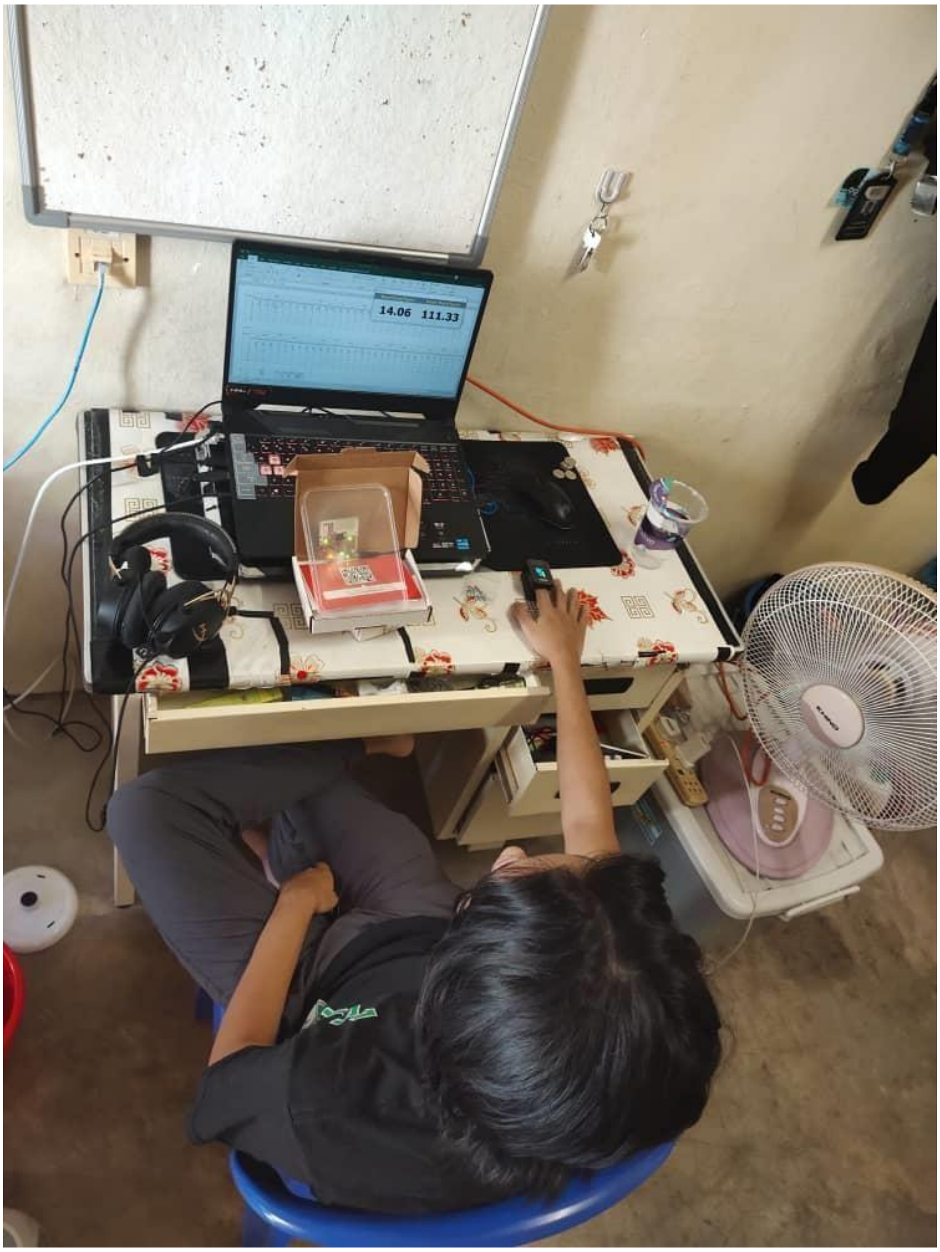


Figure 55 Setup for distance of 90cm with obstacle

Before beginning the experiments, the distance was determined by measuring it with one piece of measuring tape, and once that was done, another piece of measuring tape was used to mark the distance. It is important to accurately measure distances of 90 centimetres, so the back of the chair is placed on top of the measuring tape. Each person who is going to take part in the experiment is going to have to take a seat on the chair and position their backs in such a way that the back rest will support them. This is going to be a requirement in order for them to be able to participate. As soon as the participant has been seated, I will give them some time to unwind and get comfortable in order to ensure that the data that we collect is as accurate as is reasonably achievable in the circumstances. This is the anticipated outcome that will be influenced the most by the experiment that was carried out. A barrier is also placed in front of the apparatus as an additional safety measure. In order to compare the findings of the oximeter and the mmwave radar, I will first have the participant relax for a few minutes, and then I will place an oximeter on their finger. After that, I will compare the findings of the two devices. It's possible that the result won't become stable until some time has passed after the experiment has been conducted. The mmwave radar needs some time to stabilise before it can accurately determine the participant's heartbeat and breathing rate. As a direct consequence of this, there is a lag time of anywhere between ten and thirty seconds before I get the result. This is due to the fact that the mmwave radar needs some time to become stable before it can be used.

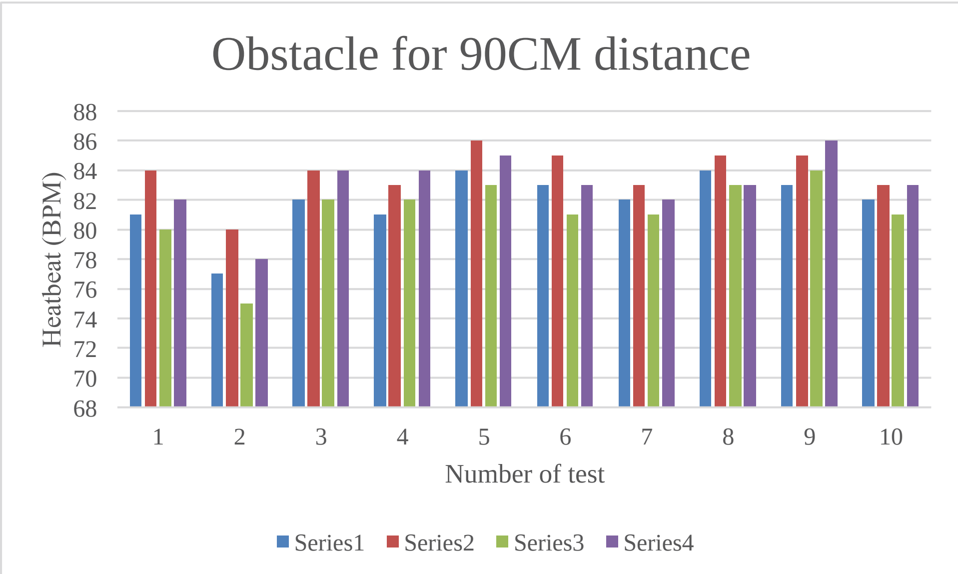


Figure 56 Result for distance of 90cm with obstacle

The result for 90 centimetres with an obstruction is as shown above, and the test is carried out once more for each of the ten participants. It is now time to collect the results of the mmwave and oximeter. Because the results are viewed from the top down, this indicates that each column contains information pertaining to a single individual. The following step involves repeating each experiment twice. The average value found in the graph is 82.475, while the median is 83 and the most common value is also 83. The lowest point in the range is 75, and the highest point is 86. It has been determined that the standard deviation equals 2.264412529. The standard error is calculated to be 0.358035058.

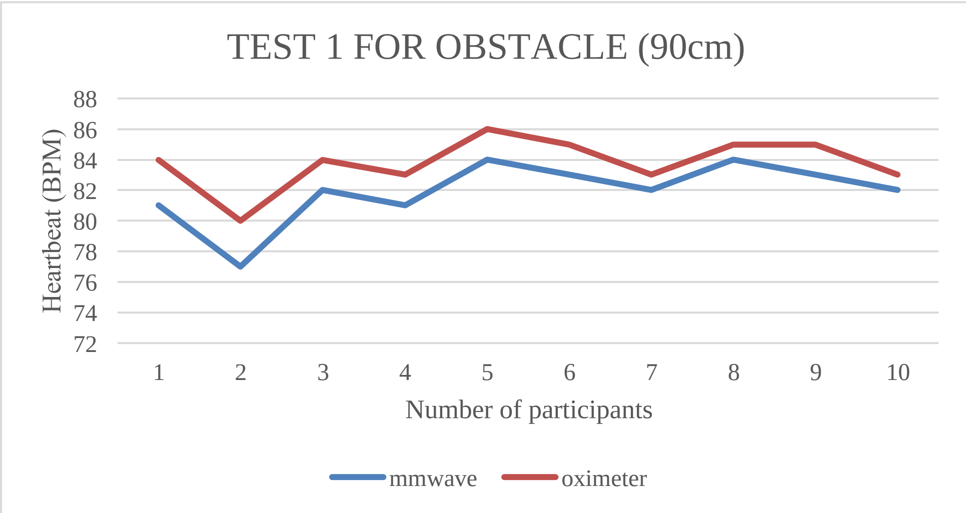


Figure 57 Waveform for Test 1 with Obstacle (90cm)

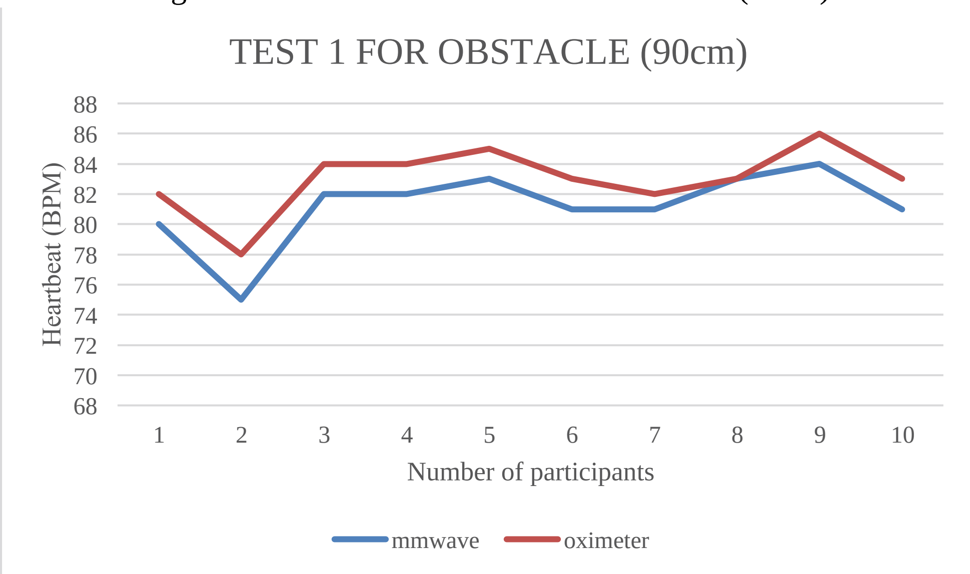


Figure 58 Waveform for Test 2 with Obstacle (90cm)

Because it provides the necessary context, the evidence that was presented earlier makes it possible to draw this conclusion as a reasonable inference. This is because it paves the way for the drawing of the conclusion. When there is an obstruction present at a distance of 90 centimetres, the waveform is not fundamentally altered in any way; the only difference is that there is an error of +-4.

4.3.4 Distance of 120cm between chest and device

Figure 59 Setup for distance 120cm with obstacle

Before beginning the experiments, the distance was determined by measuring it with one piece of measuring tape, and once that was done, another piece of measuring tape was used to mark the distance. It is important to accurately measure distances of 120 centimetres, so the back of the chair is placed on top of the measuring tape. Each person who is going to take part in the experiment is going to have to take a seat on the chair and position their backs in such a way that the back rest will support them. This is going to be a requirement in order for them to be able to participate. As soon as the participant has been seated, I will give them some time to unwind and get comfortable in order to ensure that the data that we collect is as accurate as is reasonably achievable in the circumstances. This is the anticipated outcome that will be influenced the most by the experiment that was carried out. A barrier is also placed in front of the apparatus as an additional safety measure. In order to compare the findings of the oximeter and the mmwave radar, I will first have the participant relax for a few minutes, and then I will place an oximeter on their finger. After that, I will compare the findings of the two devices. It's possible that the result won't become stable until some time has passed after the experiment has been conducted. The mmwave radar needs some time to stabilise before it can accurately determine the participant's heartbeat and breathing rate. As a direct consequence of this, there is a lag time of anywhere between ten and thirty seconds before I get the result. This is due to the fact that the mmwave radar needs some time to become stable before it can be used.

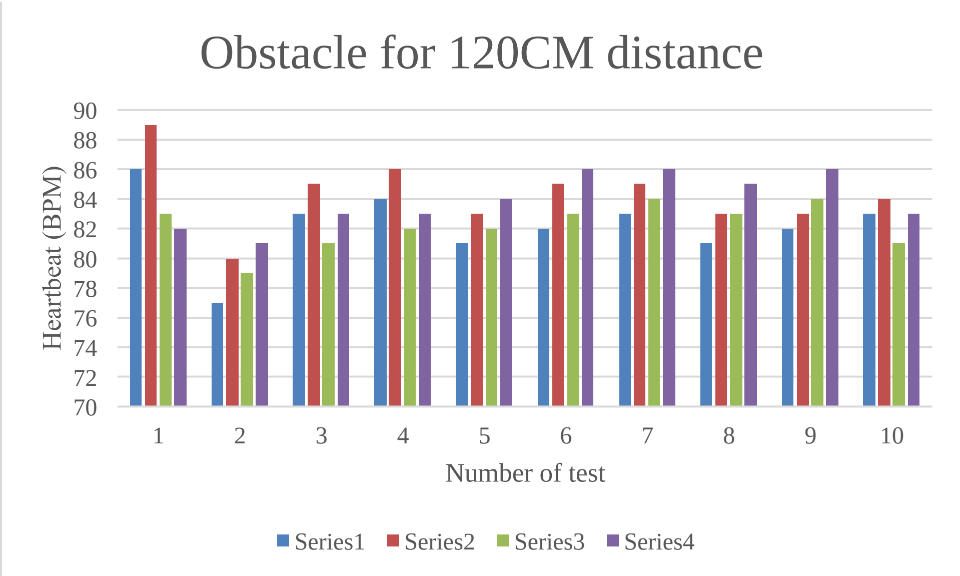


Figure 60 Result for distance of 120cm with obstacle

The result for the obstacle at a distance of 120 centimetres is as shown above. The test is carried out once more for each of the ten participants. It is now time to collect the results of the mmwave and oximeter. Because the results are viewed from the top down, this indicates that each column contains information pertaining to a single individual. The following step involves repeating each experiment twice. The average value of the points on the graph is 83.15, the median value is 83, and the most common value is also 83. The highest possible score is 89, and the lowest possible score is 77. It has been determined that the standard deviation equals 2.190304978. The number given for the standard error is 0.346317625.

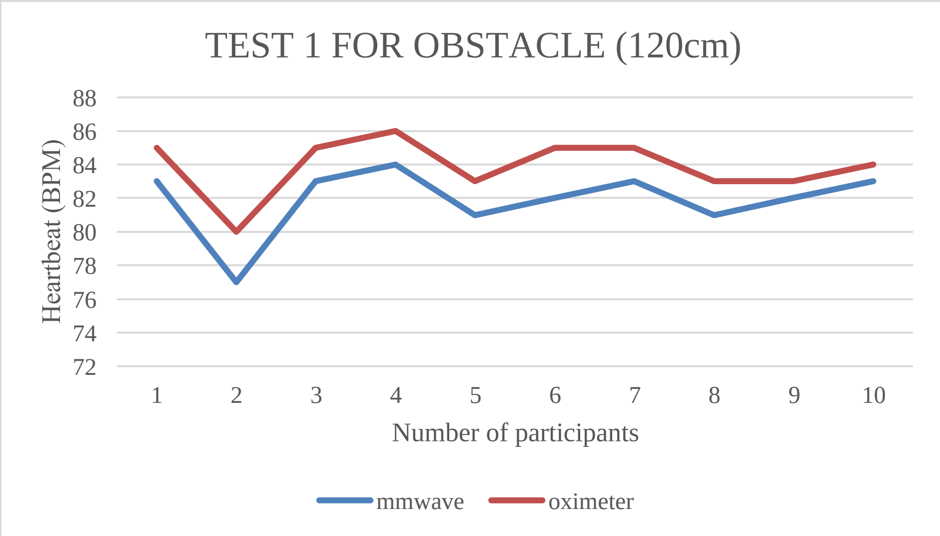


Figure 61 Waveform for Test 1 with Obstacle (120cm)

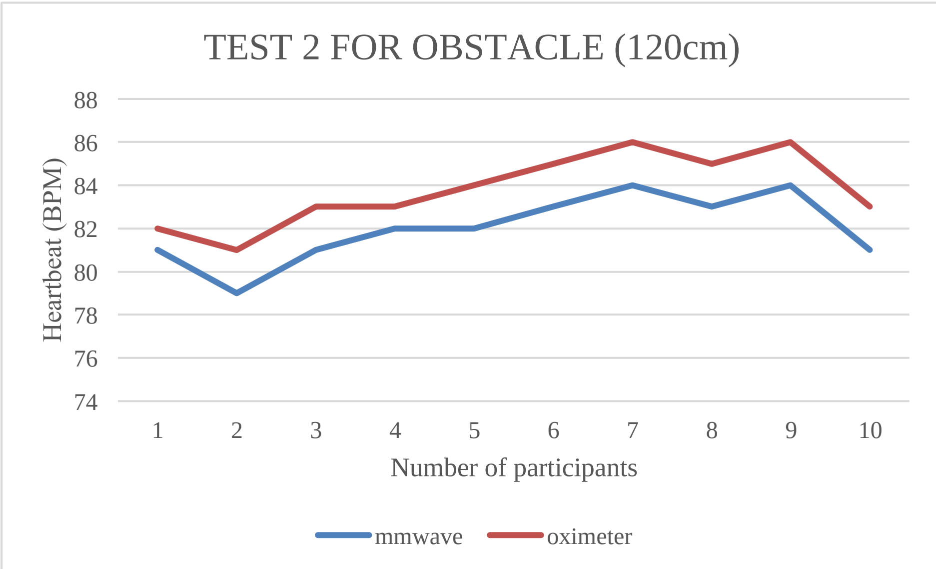


Figure 62 Waveform for Test 2 with Obstacle (120cm)

Because it provides the necessary context, the evidence that was presented earlier makes it possible to draw this conclusion as a reasonable inference. This is because it paves the way for the drawing of the conclusion. When there is an obstruction present at a distance of 120 centimetres, the waveform is not fundamentally altered in any way; the only difference is that there is an error of +-4.

4.3.5 Distance of 150cm between chest and device

Figure 63 Setup for distance 150cm with obstacle

Before beginning the experiments, the distance was determined by measuring it with one piece of measuring tape, and once that was done, another piece of measuring tape was used to mark the distance. It is important to accurately measure distances of 150 centimetres, so the back of the chair is placed on top of the measuring tape. Each person who is going to take part in the experiment is going to have to take a seat on the chair and position their backs in such a way that the back rest will support them. This is going to be a requirement in order for them to be able to participate. As soon as the participant has been seated, I will give them some time to unwind and get comfortable in order to ensure that the data that we collect is as accurate as is reasonably achievable in the circumstances. This is the anticipated outcome that will be influenced the most by the experiment that was carried out. A barrier is also placed in front of the apparatus as an additional safety measure. In order to compare the findings of the oximeter and the mmwave radar, I will first have the participant relax for a few minutes, and then I will place an oximeter on their finger. After that, I will compare the findings of the two devices. It's possible that the result won't become stable until some time has passed after the experiment has been conducted. The mmwave radar needs some time to stabilise before it can accurately determine the participant's heartbeat and breathing rate. As a direct consequence of this, there is a lag time of anywhere between ten and thirty seconds before I get the result. This is due to the fact that the mmwave radar needs some time to become stable before it can be used.

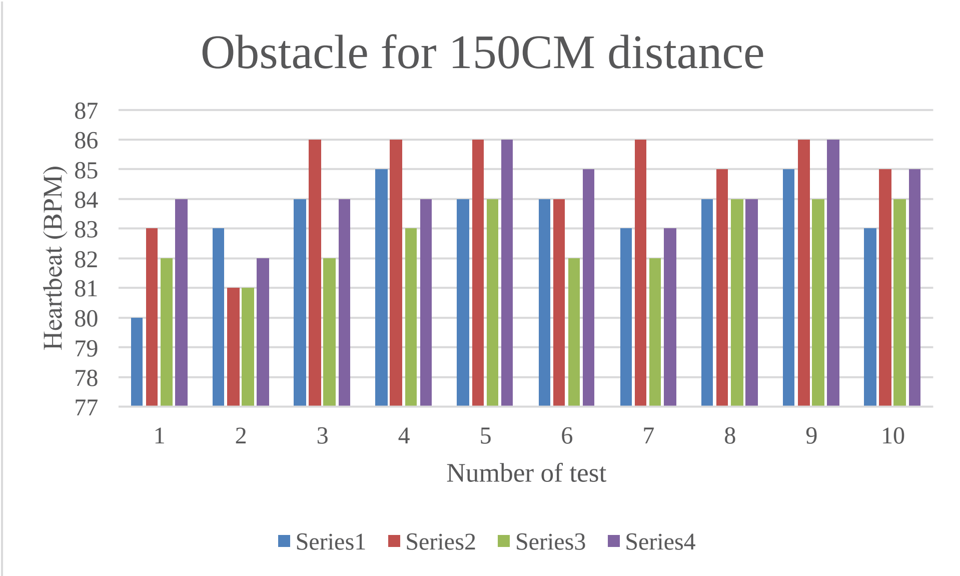


Figure 64 Result for distance of 150cm with obstacle

The result for the obstacle at a distance of 150 centimetres is as shown above. The test is carried out once more for each of the ten participants. It is now time to collect the results of the mmwave and oximeter. Because the results are viewed from the top down, this indicates that each column contains information pertaining to a single individual. The following step involves repeating each experiment twice. The average value on the graph is 83.85, the median value is 84, and the most common value is also 84. The lowest point in the range is 80, and the highest point is 86. The deviation from the mean is found to be 1.545049995. The margin of error is 0.244293854, to be exact.

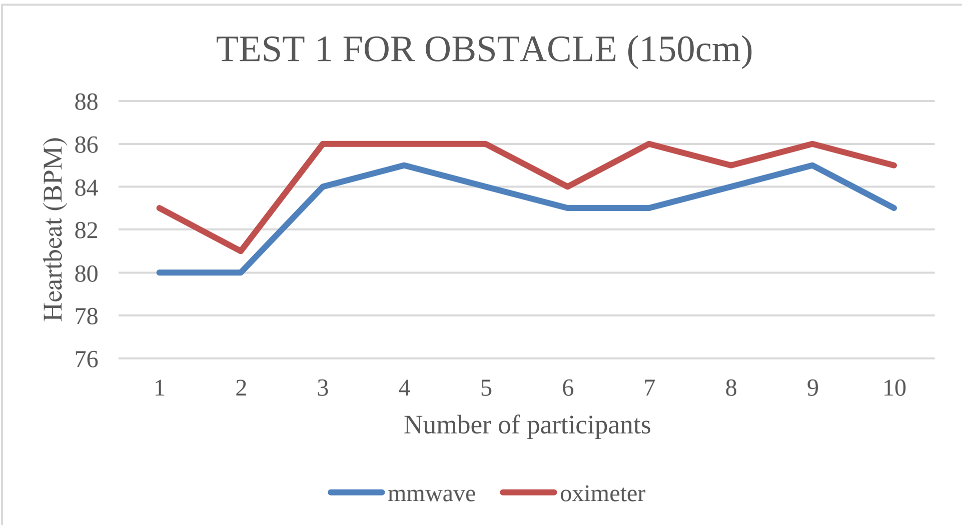


Figure 65 Waveform for Test 1 with Obstacle (150cm)

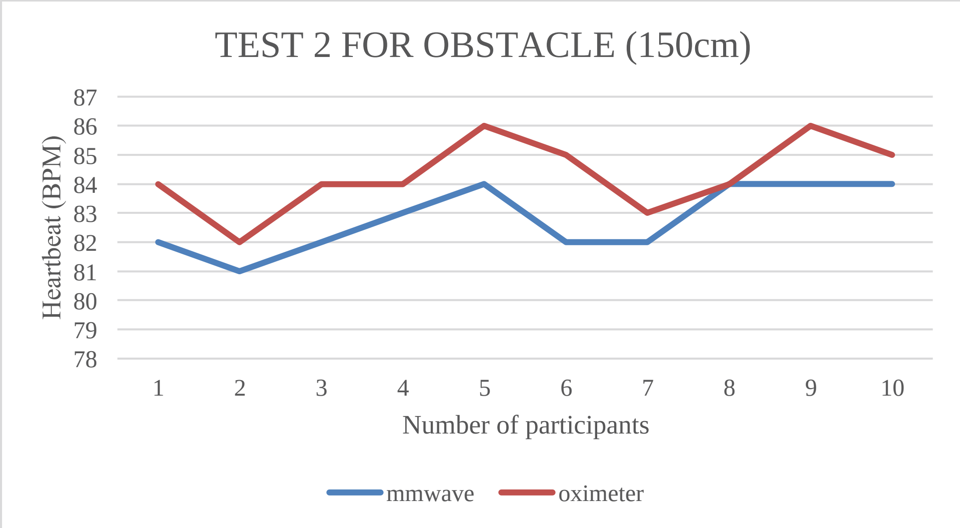


Figure 66 Waveform for Test 2 with Obstacle (150cm)

Because it provides the necessary context, the evidence that was presented earlier makes it possible to draw this conclusion as a reasonable inference. This is because it paves the way for the drawing of the conclusion. When there is an obstruction present at a distance of 150 centimetres, the waveform is not fundamentally altered in any way; the only difference is that there is an error of +-4.

4.4 Discussion

It was demonstrated that the 60GHz systems utilised in this study were capable of accurately detecting human vital signs such as the rate of breath and the heart rate. Despite this, significant additional work was required to improve the signal-to-noise ratio (SNR) for cardiac estimation, whereas the breath rate could be accurately predicted using filtering and an FFT. This has the benefit of reducing the amount of time spent computing, as well as improving estimation confidence due to the fact that all of the channels are taken into account. The results demonstrate the processing methods' capacity to generate estimates despite the presence of a time constraint. This is typically between 10 and 20 seconds on the slow-time axis scale of 20 frames per second, which corresponds to between 200 and 400 data points. Because of the higher operating frequencies at which mmwave systems function, these systems are more sensitive to random body motions. Additionally, because of the increased path loss, the system accuracy will be significantly impacted by the target distance, which restricts the applications of mmwave systems for the detection of vital signs. Due to the fact that the systems are already operating at maximum radiation power limits, there are not many hardware changes that can be made to improve this. The maximum distance at which the systems can operate and accurately report vital signs has not been determined; however, some experiments at 30, 60, 90, 120, and 150 centimetres have been conducted with mixed results and to get the most accurate result compare with all the distance is the closer the chest placements the better the accuracy for the heartbeat and breathing rate.

CHAPTER 5

CONCLUSION

5.1 Conclusion

A millimeter-wave radar monitoring system was designed and developed in this paper. In this study, a software and hardware construction of a millimetre wave sensor system was carried out. The system was then used to detect and separate respiratory and heartbeat signals by employing a method that utilised a wave transform filter. The design of the system has good penetrating ability, can pass through obstacles such as transparent plastic and bedding, is small in size, is easy to integrate, and has a higher efficiency level. At the same time, it is our goal to make use of the information and technology at our disposal in order to assist members of underprivileged communities, people who have been burned, and infants. The system that was designed in this paper has the capability of realising real-time and efficient remote monitoring of vital signs (heart rate and breathing rate) of disadvantaged groups, burn victims, and infants. This can prevent these individuals from having accidents without care, from falling through guardianship loopholes, or even from passing away. Regarding the first objective, which is to study the high frequency radio that can measure heart and breathing rate, Texas Instruments' IWR6843ISK mmwave radar is able to measure heart and breathing rate.

The heart and breathing rate monitoring device using mmwave radar was produced using a Texas Instruments IWR6843ISK 60 GHz mmwave radar. This was done in accordance with the second objective. Applications in the fields of defence, automotive, and industry have been the primary focus of mmWave radar research and development. However, recent developments in mmWave technologies are also finding applications in the medical sector, which is a sign of the sector's growing importance. It is anticipated that the improved accuracy, capabilities of high-speed signal processing, enhanced range detection, and the integration of radar into an ultra-compact chipset will significantly enable healthcare applications such as patient activity monitoring, vital signs monitoring, and other similar applications. In addition, mmWave radar has the potential to be utilised in the measurement of a person's drowsiness, stress levels, and human emotions. This has significant implications for both the field of medicine and the research and development of driver monitoring systems.

When contrasted with an oximeter, the results presented in the paper indicate that mmwave radar possesses superior levels of accuracy and dependability. It was demonstrated that the systems operating at 60GHz that were used in this investigation were capable of accurately detecting human vital signs such as the rate at which the heart beats and the rate at which the breaths are taken. However, some experiments at 30, 60, 90, 120, and 150 centimetres have been conducted with mixed results, and in order to get the most accurate result compare with all the distance is the closer the chest placements, the better the accuracy for the heartbeat and breathing rate. The maximum distance at which the systems can operate and accurately report vital signs has not been determined; however, some experiments at these distances have been conducted with mixed results. When there is a barrier in the way, the result becomes stable after a longer period of time and has an error of +4 when measured against the oximeter. When there is no obstruction in the way, the results show that the mmwave radar is accurate when compared to the oximeter with only +-2, which makes it a reliable substitute for reading heart and breathing rates.

5.2 Future works

Programming the IWR6843ISK chip for MIMO processing and modifying the GUI to receive MIMO data are all examples of additional work that would complement the work that has been provided here. Since the data are being sent to a host computer via the UART transmission at the moment, it may be more beneficial to send the data via the serial peripheral interface (SPI) to a microcontroller that has a small LCD display in order to create a system that is genuinely portable.

Beamforming the transmission and digital beamforming at the receiving end will be the most difficult tasks for the work that will be done in the future. The ability to identify many subjects' vital signs at once, which was not done in this work, is improved thanks to this method, which is one of the work's advantages. Due of the high frequencies' sensitivity to minute body motions, mmwave systems appear to require the use of beamforming for multiple subject detection. This is because of the nature of the high frequencies.

5.3 Summary

To summarise the information presented in this chapter, the IWR6843ISK from Texas Instruments is a reliable alternative that can be used for non-contact applications to measure both the heart rate and the breathing rate. When measured against an oximeter, the result was found to be accurate. The variance in error is minimal, with only a +/- error of 3-5 to contend with. The maximum distance that can be achieved is two metres, and this can be increased by utilising a focusing lens in order to pinpoint the wave that is being transmitted. The work that will be done in the future is to improve the MIMO processing and beamforming of the transmission so that it can detect multiple people all at once, which will increase its performance.

REFERENCES

1. M. Ishijima, "Cardiopulmonary monitoring by textile electrodes without subject-awareness of being monitored," Medical and Biological Engineering and Computing, vol. 35, no. 6, pp. 685–690, 1997.

2. D. A. Perednia and A. Allen, "Telemedicine technology and clinical applications," Jama, vol. 273, no. 6, pp. 483–488, 1995.

3. Z. Jia, A. Bonde, S. Li, C. Xu, J. Wang, Y. Zhang, R. E. Howard, and P. Zhang, "Monitoring a person's heart rate and respiratory rate on a shared bed using geophones," in Proceedings of the 15th ACM Conference on Embedded Network Sensor Systems, 2017.

4. S. Tulyakov, X. Alameda-Pineda, E. Ricci, L. Yin, J. F. Cohn, and N. Sebe, "Self-adaptive matrix completion for heart rate estimation from face videos under realistic conditions," in Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, 2016, pp. 2396–2404.

5. F. Adib, H. Mao, Z. Kabelac, D. Katabi, and R. C. Miller, "Smart homes that monitor breathing and heart rate," in Proceedings of the 33rd annual ACM conference on human factors in computing systems. ACM, 2015, pp. 837–846.

6. M. Zhao, F. Adib, and D. Katabi, "Emotion recognition using wireless signals," in Proceedings of the 22nd Annual International Conference on Mobile Computing and Networking. ACM, 2016, pp. 95–108.

7. H. Wang, D. Zhang, J. Ma, Y. Wang, Y. Wang, D. Wu, T. Gu, and B. Xie, "Human respiration detection with commodity wifi devices: do user location and body orientation matter?" in Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing. ACM, 2016, pp. 25–36.

8. M. Barsaiyan and P. P. Bansod, "Protection circuit design for Electrocardiograph (ECG) with input filtering," 2017 8th International Conference on Computing, Communication and Networking Technologies (ICCCNT), 2017, pp. 1-4, doi: 10.1109/ICCCNT.2017.8204168.

9. A simple device to illustrate the Einthoven Triangle. (n.d.). Retrieved June 4, 2022, from https://journals.physiology.org/doi/epdf/10.1152/advan.00029.2012
10. H. Aghasi and P. Heydari, "Millimeter-Wave Radars-on-Chip Enabling NextGeneration Cyberphysical Infrastructures," in IEEE Communications Magazine, vol. 58, no. 12, pp. 70-76, December 2020, doi: 10.1109/MCOM.001.2000544.

11. Dev.ti.com. (2022), from https://dev.ti.com/tirex/explore/node?a=VLyFKFf__3.6.2&a=VLyFKFf__4.2.1&node=AKU0Y-htBc6mwPY1fsOUvw__VLyFKFf__LATEST.

12. Mdar.mda.gov.my. (2022). Retrieved 3 June 2022, from https://mdar.mda.gov.my/frontend/web/index.php?r=carian%2Fview&id=2 3502.

13. (2022). Retrieved 3 June 2022, from https://www.ti.com/product/IWR6843#features.

14. W. Lee, S. Nagubadi, M. Kryger and B. Mokhlesi, "Epidemiology of obstructive sleep apnea: a population-based perspective", *Expert Rev Respir. Med.*, pp. 349-364, June 2008.

.