Final Year Project A3148-201

# RADAR SENSORS IN ASSISTED LIVING


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A final year project report presented to the Nanyang Technological University
in partial fulfilment of the requirements of the degree of
Bachelor of Engineering

**April 2021**

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# Abstract

Assisted living facilities provide assistance to elderlies with their daily needs, however, due to the exponential growth of elderlies in Singapore [1], these facilities are unable to meet the demands of the aging population [2].

The development and growth of mmWave radar sensors today, provides vast opportunities in the telecommunication and healthcare markets. This promising technology offers several benefits over the traditional infra-red and ultrasonic sensors such as improved performance and more precise measurements [3]. Hence to tackle this issue, Millimeter Wave (mmWave) radar was utilised to minimise cost and relocation of seniors.

This project aims to study the different sleep movements of elderlies and compare the results to prove the capability and potential of mmWave radars. This is done by integrating the use of the Acconeer XM112 radar sensor and MATLAB to obtain measurements and study the various types of graphs such as fast time, slow time, range and signal power fluctuation graph.

# Acknowledgements

This Final Year Project (FYP) experience has been enriching and rewarding. It has allowed me to enhance my knowledge and skills while stepping out of my comfort zone, and building up my self-confidence. Furthermore, I learned to adapt and be flexible when faced with challenges and this enabled me to solve problems effectively.

I would like to express my deep appreciation to Professor Lu Yilong for giving me the opportunity to be involved in this meaningful project. His guidance and constructive feedback have been valuable in helping me achieve successful results. I appreciate his encouragement, patience and support throughout this past year which made my learning experience memorable.

Next, I would like to thank my family and friends who supported me from the initial phase of researching to the execution of this project. With their encouragement and solace, I am able to resolve difficulties and advance.

# Acronyms

| | |
|---|---|
| CW | Continuous Wave |
| FMWC | Frequency-Modulated Continuous-Wave Radar |
| FFT | Fast Fourier Transform |
| EVK | Evaluation Kit |
| MCU | Microcontroller Unit |
| RSS | Radar System Software |
| PCR | Pulse Coherent Radar |
| SPI | Serial Peripheral Interface |
| USB | Universal Serial Bus |
| BPM | Breathing Rate Per Minute |
| SNR | Signal-to-Noise Ratio |

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# Chapter 1

# Introduction

## 1.1 Background

Assisted living facilities are specialized residences for individuals aged 65 and above. These facilities provide aid with daily living activities and significantly improve the quality of life for elderlies by meeting specific needs and encouraging independence in daily living [4], [5].

Being an aging society, the population of elderlies has been projected to increase to 83,000 in 2030 from 52,800 in 2017 and 25,900 in 2009 [1], [6]. Based on current intakes available, such facilities are unable to catch up with the exponential growth of elderlies. Moreover, the cost of accommodation ranges from $4,000 to $5,000 per month becomes the main deterrence for elderlies without financial stability [2].

Despite the expansion of services and facilities in Singapore, 78% of elderlies are unwilling to relocate from their own homes, which bring risks and difficulties such as falls, mobility limitations, showering, and dressing [7]. This impacts the well-being and health of elderlies as it results in severe complications if issues are not reported and accounted for [8].

## 1.2 Motivations

Current technology for radio wave sensors (radar) are great at detecting, tracking, locating and recognizing objects at a great distance. Furthermore, it is capable of determine the location, velocity, shape, and size of the object even under adverse weather conditions [9]. In particular, Millimeter wave (mmWave) radar proves to be a promising solution. Being an emerging technology, it is widely used in various applications such as ambient assisted living. With comparison to traditional radar, benefits exclusive to mmWave radar as it transmits shorter wavelength signals in the millimetre range includes accuracy, capability of detecting small movements and compact component size [10].

Some existing products in the market consist of wearable devices, smart clothes, and motion sensors that lacks precision, reliability, maintainability, and face privacy issues [11]. A study [12] mentions the several drawbacks of these devices such as discomfort, trouble of remembering to wear them, and limited battery life. Besides the studies conducted on ambient living, human vital signs, and fall detection, there are other possible fields of development.

As this technology proves to be promising, there is a potential for it to be exploited further by developing a smart product that fully unlocks the precision of radar and autonomy of artificial intelligence.

## 1.3 Objectives and Scope

This project aims to study the sleep movement of elderlies to prevent potential catastrophes and is done through a combination of both hardware and software applications such as the Acconeer XM112 radar sensor and MATLAB. This validates the performance and accuracy of mmWave radar sensors that have the potential to expand into homes to improve the standard of living for elderlies.

It is important to understand how Acconeer XM112 and MATLAB are integrated together to simulate, calibrate and functionalise radar sensors. Firstly, the mmWave radar sensor deployed will generate data from movements, vital organs in its proximity under different scenarios, and radar settings such as frequency and distance. Subsequently, raw data will be collated and analysed to extrapolate possible movements and vital signs to ensure accuracy and eradicate false data. Followed by processing these raw data using MATLAB to achieve various types of graphs such as range and signal power fluctuation which will be studied further. Being fully autonomous, the issue of privacy intrusion will be eradicated.

## 1.4 Organisation

This section will explain the content and expectations in each chapter. Throughout this report, clear and relevant information will be provided to give a better understanding on the execution of the project.

The report first starts with the introduction that covers the background, motivation, objective and scope and organisation. In this chapter, it describes the problems faced by elderlies who are unable to move into assisted living facilities and how this issue can be overcome through mmWave radar sensors.

Following that is a literature review which gives an introduction of radar wave principles, modulation, doppler effect, Fast Fourier Transform (FFT) and I/Q signals. As well as supporting these theory concepts with formulas.

Next, an exploration of the Materials and Methods used that specifies the different hardware and software applications. Embedded in it contains an explanation of the setup process and configuration of the applications.

Subsequently, the test conducted and results are displayed along with the methodology. Thereafter, results were studied and compared to come to a conclusion of both the Acconeer XM112 radar sensor and sleep movements.

The final chapter concludes this project with the observation made from the experimentations, learning points, and recommendation on how this can be explored further for future work.

# Chapter 2

# Literature Review

## 2.1 Continuous Wave Radar Principles

The Continuous Wave (CW) transmits continuous signals using two antennas: transmitting and receiving signals. This is commonly used in radar sensors when velocity is prioritized over the actual range. Some benefits of CW includes; the ability to detect stationary objects without affecting its performance and usage of a relatively low power transmitter.

As CW focuses on velocity measurement with the usage of Doppler Shift, it allows differentiated transmitted signals from received signals by the shifting in frequency of the movement in object [13]. Hence, it has the ability to measure the relative speed of the illuminated target. However, they are considered as unmodulated continuous waves. Without frequency modulation, it only recognises moving objects as stationary objects. This is due to the transmitted signals that covers up the reflected signals from the objects.

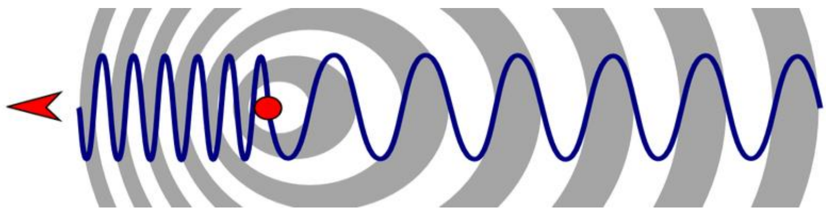


Figure 2.1 Change of wavelength caused by the source [14]

Moreover, transmitted signals need to be identified on the time axis for a CW radar to measure the distance. This is implemented by frequency modulation which separates the target reflected signal from the received signal. Resulting in the measurement of frequency of the received signal, time delay and range measurement. Hence, the range is calculated in (2.01) from the frequency of the received signal measured [15]:

$$R = C\frac{T}{2}\frac{\Delta f}{f2 - f1} \qquad (2.01)$$

Where $c = 3 \times 10^8\ m/s$ is the speed of light, $f_1$is the minimum transmitted signal, $f_2$ is the maximum transmitted signal.

While the phase difference $\varphi$ between the transmitted signal and received signal is calculated by the following equation (2.2):

$$\varphi = -2\pi\frac{2r}{\lambda} \qquad (2.02)$$

Where r is the distance between the reflector and antenna.

## 2.2 Frequency Modulated Continuous Wave (FMCW) Radar Principle

Frequency Modulated Continuous Wave (FMCW) radar has the capability of measuring distance. Similar to a CW radar where it transmits continuous transmission power and has two antennas. It also has the ability to change its operating frequency during measurements when the transmission signal is modulated. In comparison to the CW radar, FMCW radar has better performance with the advantage of determining the target range and recording phase or frequency measurements. Some key features of FMCW are the ability to measure small ranges, measuring target range and velocity simultaneously, and having high accuracy of range measurement. The distance R is calculated with in (2.03):

$$R = \frac{c\ |\Delta t|}{2} = \frac{c\ |\Delta f|}{2\left(\frac{d(f)}{d(t)}\right)} \qquad (2.03)$$

Where $c = 3 \times 10^8\ m/s$ is the speed of light, $\frac{\mathrm{d(f)}}{\mathrm{d(t)}}$ is the frequency shift per time.

When an object is stationary, the frequency difference, $\Delta f$ caused by the period and is proportional to the distance, R. As $\Delta f$ only calculates absolute value, the increase in frequency and decrease in frequency are equivalent. Whereas, for a moving object, an additional doppler frequency, $f_D$ is applied which is caused by speed.

Figure 2.2 is a basic FMCW block diagram where the low-pass filter removes mixed frequencies acquired from the transmitted and received signals obtained. Before post processing and detection, the Analog-to-Digital Converter (ADC) digitizes the signal [16].

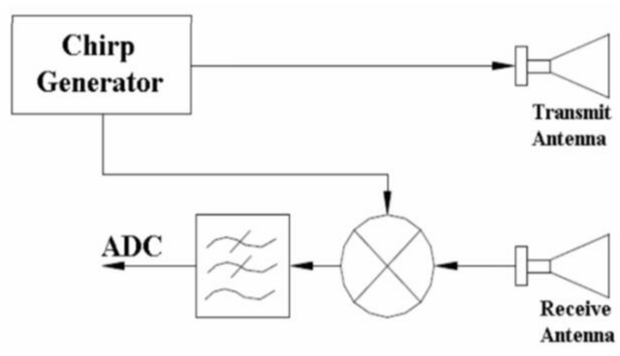



Figure 2.2 FMCW Block diagram [16]

Figure 2.3 illustrates the range measurement technique using FMCW. Between the transmitted and received signal, the time delay is represented by, $\Delta t$. As the signal is continuously running through the frequency band, the frequency difference is known to be the beat frequency, $f_b$.

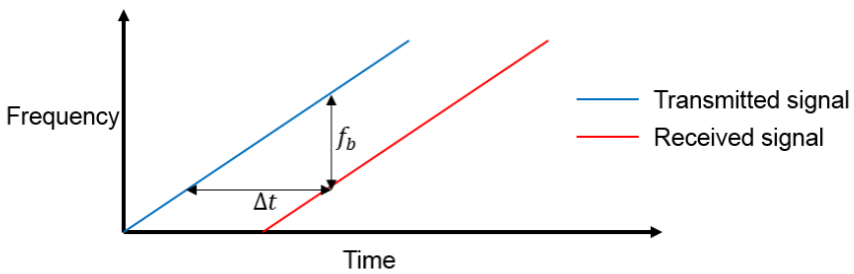



Figure 2.3 FMCW range measurement [17]

## 2.3 Types of Frequency Modulation (FM) pattern

Frequency Modulation (FM) refers to the change in frequency of the carrier wave, while the amplitude of the modulating signal remains constant. The input signal modulates the carrier signal and information is transmitted once it has been converted into an electronic signal. If the amplitude of the wave increases, the frequency change increases. FM allows transmitted signals to measure distance of stationary objects by separating the reflected signals from the received signals.

Figure 2.4 shows the common modulation patterns: Sine, square, triangle and sawtooth. With each pattern being unique as it is used under different conditions.

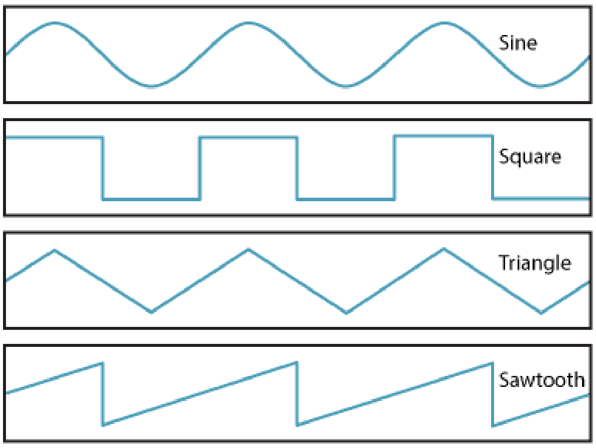



Figure 2.4 Waveform modulation patterns [18]

First the sinusoidal modulation is used for complex objects that require both the range and velocity measurements. Being a continuous modulation waveform with no impulse modulation, the receiver never stops processing incoming signals. The time domain and time delay are represented by the following formulas respectively, (2.04) and (2.05).

$$y(t) = cos\{2\pi[f_c + Bcos(2\pi f_m t]\} \qquad (2.04)$$

Where B = $\frac{f\Delta}{fm}$ (Modulation index)

$$y(t) = \cos\{2\pi[f_c + Bcos(2\pi f_m(t + \delta t))(t + \delta t)]\} \qquad (2.05)$$

Where δt is the time delay

Whereas the square modulation is used for accurate distance measurement at close range by comparing two signal frequencies. However, the echo signals cannot be separated which is a drawback as this process recognises a small measuring range.

Next, the triangle waveform has an advantage as it allows easy separation of different frequency of both $\Delta f$ and doppler frequency, $f_D$. Without doppler frequency, the change in frequency difference for both rising and falling edge are equal. However, the doppler frequency causes a shift in the received signal.

Finally, the sawtooth modulation is commonly used for large distance measurement and objects lacking rotating parts. This modulation is able to identify velocity and capture it in one radar set together with the range.

## 2.4 Doppler and Micro doppler effects

Doppler effect is the shift in frequency produced by a moving source as explained in figure 2.5. As the ambulance with the siren on is approaching the target, the waveform gets shorter, resulting in a higher pitch siren corresponding to a higher frequency. However, when the ambulance passes the target, the waveform gets spaced out, causing the pitch of the siren to drop and lower frequency.

On the contrary, when the ambulance is stationary, the waves emitted in all directions have a constant frequency. This is due to the evenly spaced wave, so any target located near the ambulance will observe the same frequency.

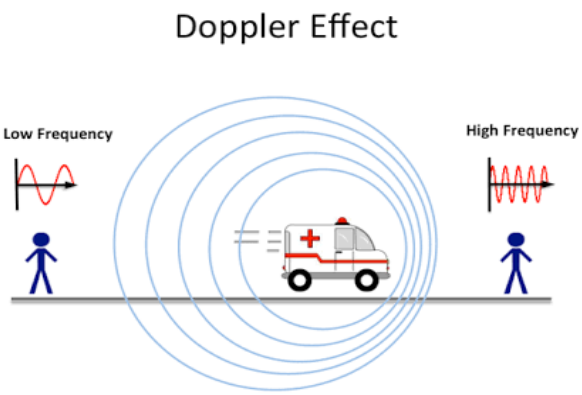



Figure 2.5 Doppler effect [19]

When a radar transmits an electromagnetic signal to a target, the signal makes a round trip by hitting the target and returning back to the radar. Doppler effect is the carrier frequency of which the returned signal is shifted when the target moves at a constant velocity. The change in properties of the returned signal shows the characteristics of the target. The doppler frequency shift is measured by the electromagnetic wavelength and relative velocity between the radar and the target and is given by (2.06):

$$f_D = -2\lambda V \tag{2.06}$$

Where $\lambda = \frac{c}{f}$, $c = 3 \times 10^8\ m/s$ is the speed of light.

When the radar sensor is stationary, the relative velocity V is equivalent to the radial velocity known as the velocity of the target which is visible along the Line Of Sight (LOS). However, if the target moves, the velocity becomes positive which results in a negative doppler shift.

Micro-Doppler effect occurs when a target has mechanical vibration or oscillatory motion which leads to a frequency modulation on the reflected signal that generates the target's doppler frequency shift. Due to micro-motion dynamics, additional doppler change will be produced to the constant doppler shift. This aids with determining the kinetic properties of the target and provides additional features on current existing methods. For instance, the micro-doppler effect helps to identify specific types of vehicles, movements and speed of engines by measuring the surface vibration. This allows it to recognise the engine and differentiate between a gas turbine engine of a tank of diesel engine of a bus [17].

## 2.5 Fast Fourier Transform (FFT)

The Fast Fourier Transform (FFT) is a computer algorithm and requires less computational effort as compared to the past. This tool is known to be one of the most useful too and is commonly used for signal processing. The algorithm organises the computations by eliminating the redundant data in an efficient manner by using the Fourier matrix. Furthermore, breaking down complex signals into smaller signals.

FFT method is used to compute the Discrete Fourier Transform (DFT) of a time series (discrete data samples). The DFT is a transform of the Fourier integral transform of the continuous waveform from taken samples that form a time series. DFT is useful in analysing the power spectrum and filter simulation on digital computers. DFT is defined by (2.07):

$$x[k] = \sum_{K=0}^{N-1} [x_n] \exp\left(\frac{-j2\pi kn}{N}\right) \tag{2.07}$$

Where r = 0, …., N-1, N is the size of the domain

In DFT, the size of the problem is represented as $O(N^2)$ and the FFT reduces the number of computation to $O(NlogN)$. For example, when $\mathrm{N} = 10^9$, FFT will take about 30 seconds to compute while the DFT will take much longer.

The Fourier transformation is represented by (2.08):

$$\begin{cases} n = 2r & if\ even \\ n = 2r + 1 & if\ odd \end{cases} \tag{2.08}$$

From algebra calculation, the sum of both equations are expressed in (2.09):

$$x[k] = x_{even}[k] + exp\left(\frac{-j2\pi kn}{N}\right) \times x_{odd}[k] \tag{2.09}$$

Both odd and even components can be easily calculated and concurrently.

Not only does FFT reduce computation time and reduces round-off errors, it also computes the DFT of a time series. It is an algorithm that determines the DFT by combining the sum of data samples produced, saving computational time which significantly increases overall efficiency.

## 2.6 In phase (I) and Quadrature (Q) signal

In phase (I) and Quadrature (Q), signals are represented by two sinusoidal waves with the same frequency having a phase difference of 90°. I signal is represented by a cosine wave while the Q signal is represented by a sine wave. I/Q data often refers to time domain signals. I/Q modulation helps to transfer information in digital formats and creates amplitude modulation (AM), frequency modulation (FM) and phase modulation (PM). Through simple modulation, the resulting sum from a complex modulation is created. Likewise, complex data from a demodulated IQ signal can be retrieved [21].

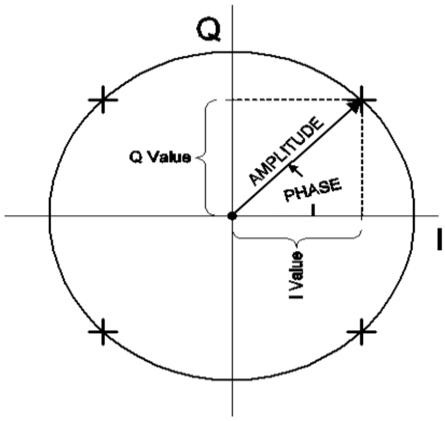



Figure 2.6 Phase and amplitude [22]

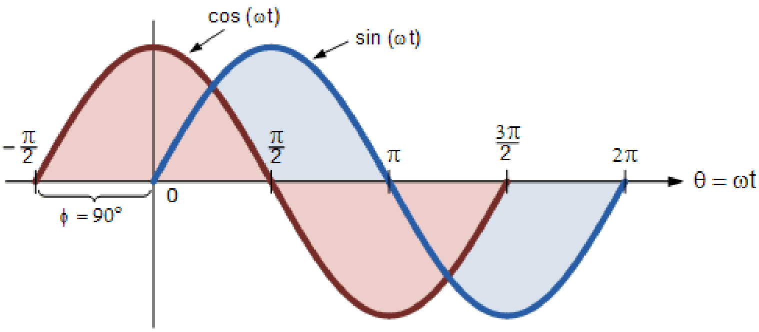



Figure 2.7 Phase difference [23]

The waveform, amplitude, phase and frequency of the IQ signal is represented by the following equations (2.10), (2.11), (2.12) and (2.13) respectively.

$$x(t) = I(t) + jQ(t) \tag{2.10}$$

Where x(t) is a vector with magnitude and phase angle

$$A(t) = \sqrt{I^2(t) + Q^2(t)} \tag{2.11}$$

$$\phi(t) = \tan^{-1}\left(\frac{Q(t)}{I(t)}\right) \tag{2.12}$$

$$f(t) = \frac{\partial\phi(t)}{\phi t} \tag{2.13}$$

# Chapter 3

# Materials and Methods

This chapter explains the hardware, software and construction of the application. Both Acconeer radar sensors were purchased from Digi-Key Electronics (Thief River Falls, Minnesota) and shipped directly from their headquarters.

## 3.1 Acconeer XM112 Module Evaluation Kit (EVK)

Acconeer XM112 is a radar Module Evaluation Kit (EVK) with 60GHz operating frequency. This is an advanced module integrated with Acconeer A111 radar sensor and Atmel SAME70 Microcontroller Unit (MCU) which enables advanced signal processing. The EVK consists of two components to run the module: XM112 module and XB112 breakout board which allows users to easily evaluate and develop their own application [24]. Several benefits are the ability to track fast and small movements with high precision, and its robustness to perform in any condition. This module is suitable for a wide range of applications such as automotive, robotics, healthcare, wearable etc.

The four main services supported by the radar sensors are envelope service, power bin service, IQ data service and sparse service. On top of these services, detectors have also been built based on different services and produce different results for different applications. This gives users an advantage in selecting either the provided detector or to develop their own detector.

Therefore, Acconner XM112 was selected based on the flexibility, features and functionality of the relevant services and detectors provided which is beneficial for this FYP project.

## 3.2 Acconeer XM112 Module

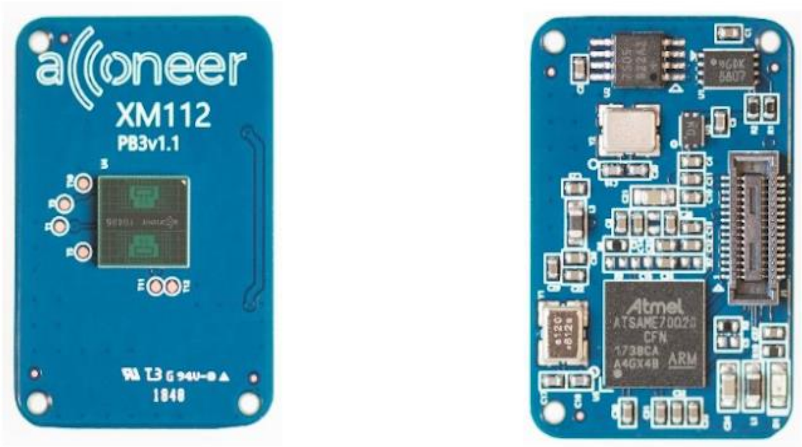



Figure 3.1 Front (left) and back (right) view of XM112 board [24]

Acconeer XM112 is a reference module that is intended for commercial use, evaluation and development of an application that encourages creativity and innovation.

Being a high performance radar sensor module that is user friendly and gives users the flexibility of developing their own application on top of the Acconeer RSS (Radar System Software) [25]. This enables users to integrate their own application on top of the Acconeer software provided. Furthermore, this module gives the options of either being a stand-alone module, where there is no dependency on external controllers, or, a controlled module, where an external controller is connected to run an external application respectively.

The key feature is the high precision measurement of movements, distance, and materials that reaches up to 2m without the need for physical aperture. This gives an advantage in data collection as measurements are recorded in the micrometre range. Also, having the benefit of being integrated behind glass or plastic materials without any visible aperture [25].

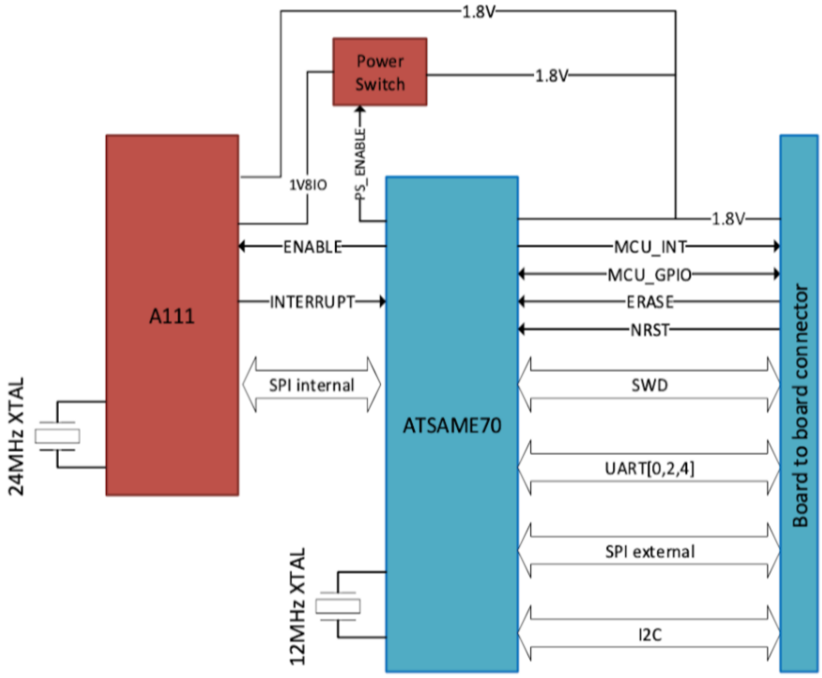



Figure 3.2 XM112 block diagram [25]

Figure 3.2 shows the block diagram connections of Acconeer XM112. The ATSAME70Q20A microcontroller with 32 bits which operates at up to 300MHz, is connected to both the A111 60GHz Pulse Coherent Radar (PCR) and the 30 pin board to board connector. The pin connector enables easy accessibility to the MCU external interface which includes the 1.8V voltage supply [25].

The Acconeer XM112 module allows an external power supply of 1.8V. The UART (0,2,4), SPI and I2C are used for external serial interfaces and serial communication that are controlled by an external host. Also, UART0 is applicable for software flashing. Moreover, there are two General Purpose IOs (GPIOs): MCU_INT and MCU_GPIO. The MCU_INT is optional to be used while the MCU_GPIO is used for general purpose IO pin.

## 3.3 Acconeer XB112 breakout board

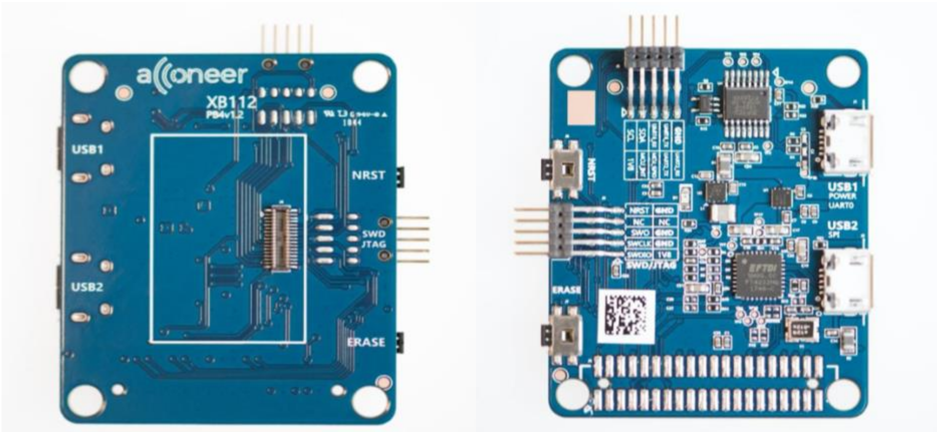



Figure 3.3 Front (left) and back view (right) of XB112 board [26]

Acconeer XB112 is a breakout board for the XM112 radar module and enables connection to external devices. Furthermore, this is designed to provide power supply and easy accessibility for flashing and debugging. The radar sensor is connected by placing the XM112 module on top of the XB112 breakout board, through the board to board connector [26]. Followed by connecting a micro USB cable from USB1 to the computer port. After doing so, the LED on the XB112 will light up which indicates that the XM112 module is ready to be used.

The main connection includes two USB connectors named USB1 which supplies 5V to the module and USB2 that sends high speed data output from the Serial Peripheral Interface (SPI) data [25]. Two buttons are used for flashing controls, the “Erase” and “NRST” on the MCU [26].

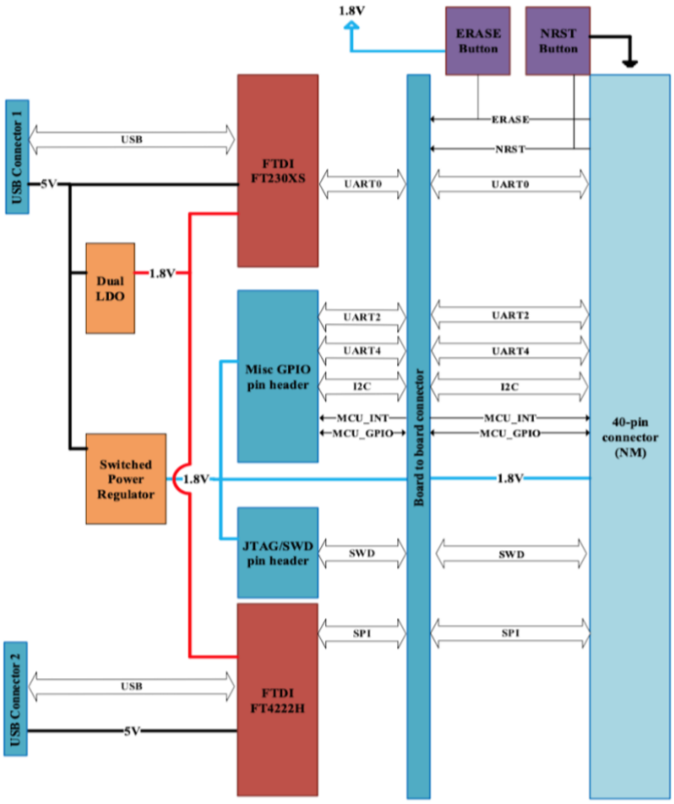



Figure 3.4 XB112 block diagram [26]

Figure 3.4 consists of two Universal Serial Bus (USB) connectors, two 2x5 pin headers, one unmounted 2x20 pin header and two buttons. These components are identified from J1 to J8 accordingly.

Firstly, the USB connectors are known as USB1 (J1) and USB2 (J2). USB1 acts as a power supply for the module and also supplies 5V to the USB-UART chip (U4) and the XM112. While USB2 powers up the USB-SPI chip (U5) and is used for high speed data output from the Serial Peripheral Interface (SPI) data. However, USB2 is unnecessary if SPI data is not required but USB1 must be connected.

Subsequently, the 2x20 pin header (J3), 30 pin board-to-board connector (J4), two 2x5 pin header (J5, J6). 2x20 pin header is for Acconeer internal use while the 30 pin board-to-board is a connector for both XM112 and XB112. The first 2x5 pin header carries signal needed for flashing while the second 2x5 pin header carries miscellaneous 1.8V from the module.

Lastly, the two buttons located on the right hand side of the board, “ERASE” and “NRST”, J7 and J8 respectively control the signal.

## 3.4 H5 Files Format

The data saved in the GUI are saved as Hierarchical Data Format version 5 (.H5) which is an open source that stores large and complex data. A H5 file gives users the advantage of storing similar sets of data that are organized in the same way based on their preference. H5 files format consist of both groups and datasets; groups refers to a folder within the H5 file that contains datasets that are actual data contained in the H5 file. Being a self-describing format as shown in figure 3.5, an associated metadata that provides information of other data is included in the group and dataset. This enables information to be identified easily and be processed [27]. Key features of H5 file structure includes storing large datasets, storing different types of data, and data slicing.

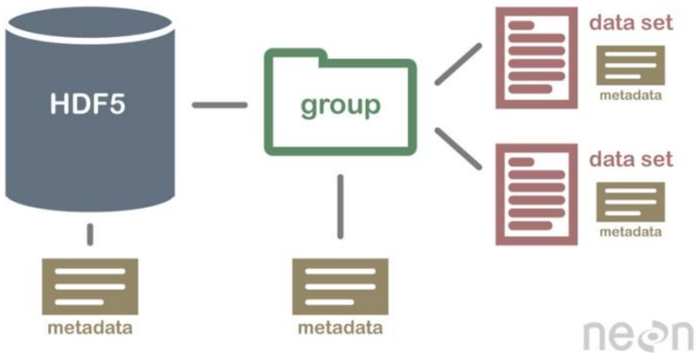



Figure 3.5 Each files contains metadata [27]

Improvements have been made to develop an improved H5 version from previous versions. Previously files could not store more than 20,000 complex objects and parallel I/O was not supported. Hence, data types and data models were consistent and restricted which did not perform well. The new improvements are made to support larger files and multidimensional arrays that strengthen the latest version to be more comprehensive and functional [28].

Also, H5 files is a standardized format that supports most coding languages which makes it accessible to be shared through external platforms such as MATLAB and Python. H5 files functions similar to Python files and is error free which is well supported and requires minimal technical support. This file format is readily available on Windows, Mac and Linux. This increases the operability and brings convenience to other individuals who wish to access and read data.

Most importantly, to execute H5 files, NumPy is required to be installed and basic understanding of NumPy is essential in understanding and writing the codes.

## 3.5 Configuration of XM112 Radar Module

The following steps were carried out to configure the XM112 radar module [29].

a. Assembling the hardware
    i. Connect the XM112 module and XB112 breakout board via the board-to-board connector
    ii. Connect a micro USB cable from USB1 (XB112) to the computer port
b. Booting the XM112 radar module
    i. Pressing down the “Erase” button, followed by the “NRST” button and releasing it one by one
c. Downloading the following software to complete the installation
    i. Acconeer module software image used for evaluation
    ii. Acconeer exploration tool that runs python scripts via GUI
    iii. Bossa a simplified software for flashing programming utility for microcontroller
    iv. Python application that runs the codes
d. Install the exploration tool to display the data
    i. Unzip file in cii

ii. Run command prompt to run mandatory commands

e. Reboot the module

i. Press the “NRST” button

ii. Enter and run mandatory commands

f. Output data is displayed

After the above steps have been completed and GUI is executed, the radar sensor was ready to be used. As different computers function differently, it was necessary to check the computer port under the device manager to ensure correct port connection. Figure 3.6 is the overview image of one service available on the GUI, the IQ service was used as an example. The graph measurements are located on the left side of the GUI while the variable options are located on the right.

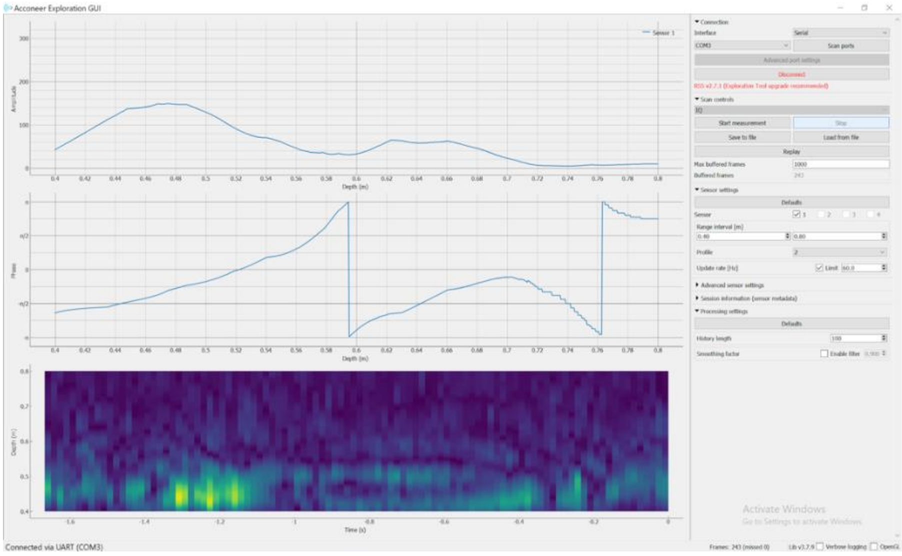


Figure 3.6 Overview image on GUI

As the XM112 radar sensor provides flexibility, various settings can be adjusted to suit one’s preference such as the sensor range interval, profile and frequency. Five profiles are offered by this radar sensor and each profile is recommended for different services as it is designed for different purpose. It varies in the distance of the radar pulse and how the incoming pulse is sampled. These profiles are numbered from 1 to 5 profile 1 uses the shortest pulses in the range of less than 20cm while profile 5 uses the longest pulse with the range of more than 20cm.

The buffered frames set on the GUI determine the number of frames recorded and saved. For example, if the buffered frame was set at 1000, only the first 1000 frames in the measurement will be saved, otherwise the recording will discontinue. Nevertheless, measurements will not cease with recordings. As frequency is inversely proportional to the period shown in (3.01), for instance at a lower frequency of 20Hz, the period increases and more data points will be captured. Whereas, when the frequency increases, the time taken to reach 1000 buffered frames becomes faster and more data frames will be omitted and not captured.

$$T = \frac{1}{f} \tag{3.01}$$

# 3.6 Applications on Acconeer XM112

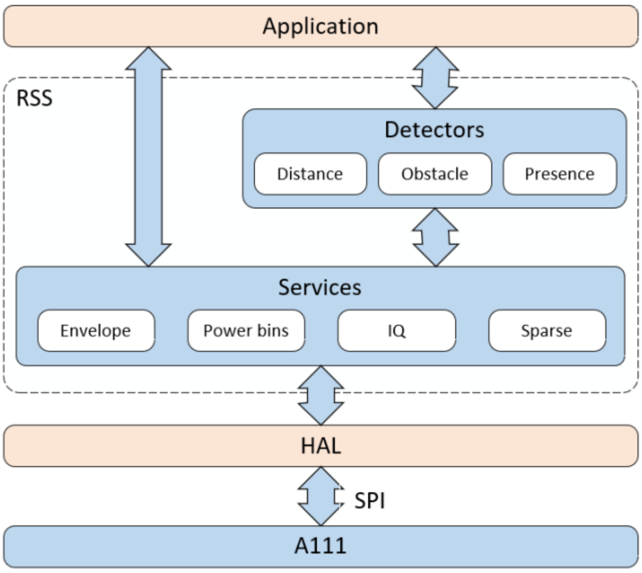



Figure 3.7 Available applications on Acconeer XM112 [30]

The two levels of output provided are services and detectors. The output data of the services are represented as a function of distance. While the output of the detectors are represented by distance, angle, presence and etc. Each service and detectors are applicable for different applications and produce different output [30]. The four services are used in the following cases:

(i) Envelope service: Commonly used for distance measurement and detecting stationary targets

(ii) Power Bins service: Purposed for low power application of large objects measuring short distances, e.g., parking sensors

(iii) IQ service: Capable of detecting micro movements, such as breathing rate and obstacles

(iv) Sparse service: Designed to detect presence and hand gestures

Considering the focus of this FYP, the IQ service and Envelope Service were selected based on its relevance and appropriateness to access the accuracy of distance measurement and breathing rate. Apart from the services, breathing and sleep breathing detectors were be included to evaluate the performance of the XM112 radar sensor.

### 3.6.1 IQ Service

IQ service uses cartesian data that transforms to polar data by providing amplitude and phase of the signal. The phase signals allow the radar to perform a more accurate measurement by detecting micro motions. With the high processing power and memory allocation, it is commonly used for breathing rate or obstacle detection [30], [31].

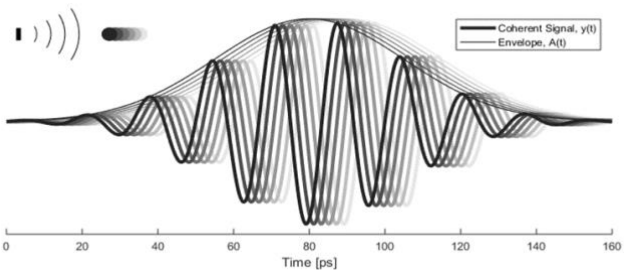



Figure 3.8 Amplitude and phase output signal for a moving object [30]

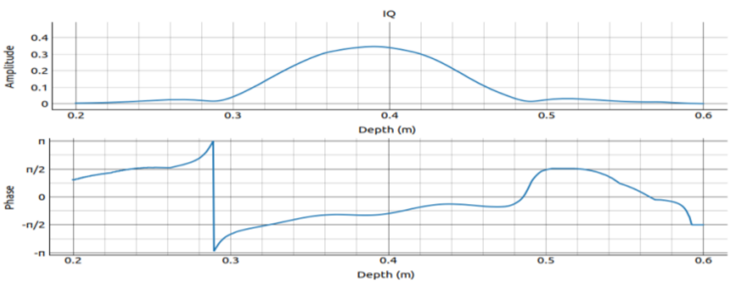



Figure 3.9 Amplitude and phase signals on GUI [32]

The sleep breathing detector is built on top of the IQ service and is used to detect a still target through his breathing motions from the target's chest to the radar sensor. This algorithm comprises three parts: (i) extracting breathing motion, (ii) performing Fourier transform for oscillation and (iii) detecting respiration rate from the spectra [32].

To obtain (i), the radar does a sweep of the distance measurement range at 0.5mm and 100Hz, followed by down sampling the data and using a low pass filter to reduce noise. Finally using a high pass filter to unwrap phase of the IQ samples.

Next for (ii), the data obtained from above will be seen as oscillation and Fourier transform will be performed to search for peaks in the autocorrelation function. Using low pass filters to down sample in time and increasing the frequency resolution.

Finally (iii) is carried out by identifying if the peak in the spectra is higher than the noise spectra. Hence, breathing motion is detected when the peak is higher than the threshold times the noise level [18].

### 3.6.2 Envelope Service

Envelope service provides data received at different distances from the radar sensor to the target. This service is commonly used for distance measurements and targeting stationary positions. It is achieved by emitting radar pulses and measuring the energy from the returning echoes over a duration of time delays [33]. The Envelope service in figure 3.10 outputs the amplitude of received signal against the distance.

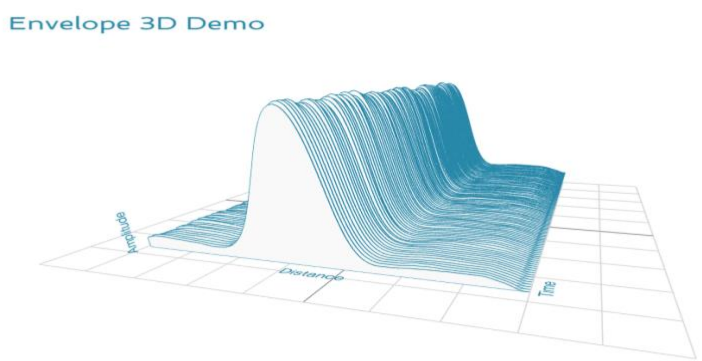



Figure 3.10 Envelope service output [30]

The data is a set of real valued samples represented by $[x]d$, $d$ is the delay sample index and the amplitude of each sample is known as $[x]d = A_d$. The sweeps in this service can be filtered to increase the Signal-to-Noise Ratio (SNR) and stabilise the signal by adjusting the settings of the average factor between 0 and 1, where more filtering is performed at a factor of 1. This filtering utilises a low-pass filter and at low frequency of a few hertz, static moving objects remains in the sweep [33].

The profile configured for the Envelope service is set at profile 2 with a recommended distance of 0.2m to 1m and was included to determine the accuracy of the distance measured.

## 3.7 Developing a Detector

The initial stage of this FYP is to understand the two individual applications - Acconeer XM112 sensor and MATLAB in order to integrate them together in the later stage. However, the Acconeer XM112 module provides its own set of python scripts and runs independently on GUI. Python provides several advantages such as codes are more readable in python language and more versatile. Hence, there was a shift in progress to understand how python works and how an application can be developed.

Through experimentation, figure 3.10 data captured is observed to be stabilised when radar is aimed at the chest. Conversely, when the radar module was not aimed at the chest, the data showed the instability and the fluctuation in readings. The recorded reading shows accuracy as the Breathing Rate per Minute (BPM) for 12 years and older should range between 12 to 20 BPM [19].

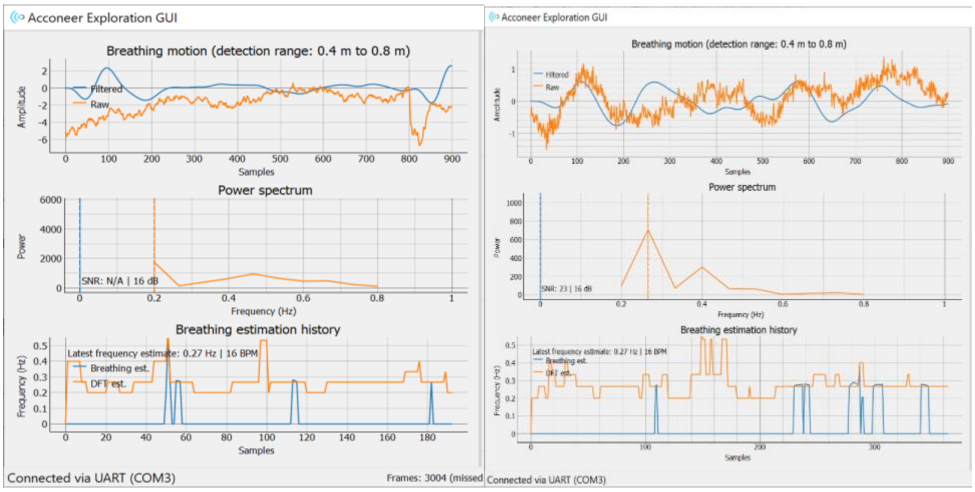



Figure 3.11 Radar aimed at chest (left) and radar not aimed at chest (right)

Initially, the two detectors commonly used were the sleep breathing detector and breathing detector, both detectors have similar traits and are built on top of the IQ service. Figure 3.11 (left) shows the sleep breathing detector that provides the breathing motion, power spectrum and breathing estimation history. Whereas the breathing detector shown in figure 3.11 (right) provides the amplitude of IQ data and change, phase of IQ at peak, relative movement and breathing movement.

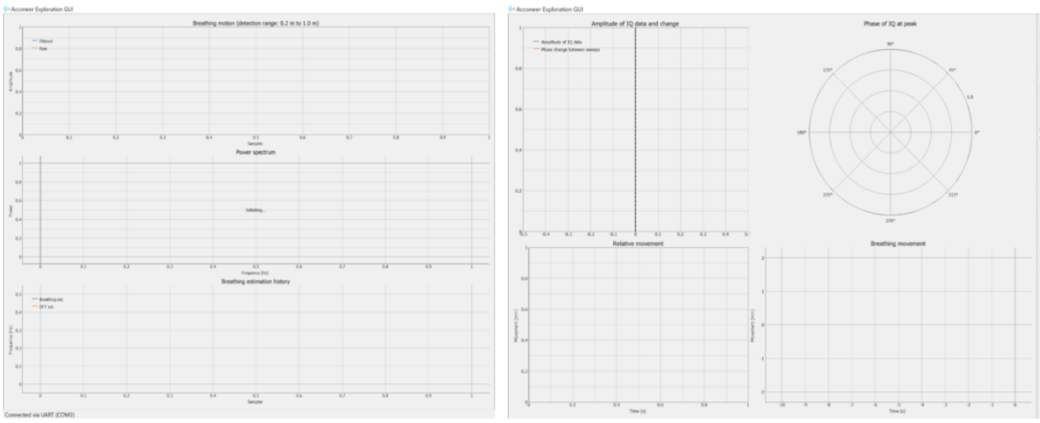


Figure 3.12 Sleep breathing graph (left) and breathing graph (right)

Subsequently, it was noticed that the breathing detector provided additional data such as IQ data which uses raw data, while this project focuses on the processed data. Hence, the IQ data was excluded in the revised detector to alleviate any complications. This was carried out in the following steps:

a. Creating a new python file “my_new_detector” from an existing detector file
b. Modifying the module python file which defines the services and detectors on the GUI
c. Importing the new detector into the GUI
d. Modifying the python code to suit this project

Figure 3.12 shows the revised detector that consists of both relative movement and breathing movement graphs.

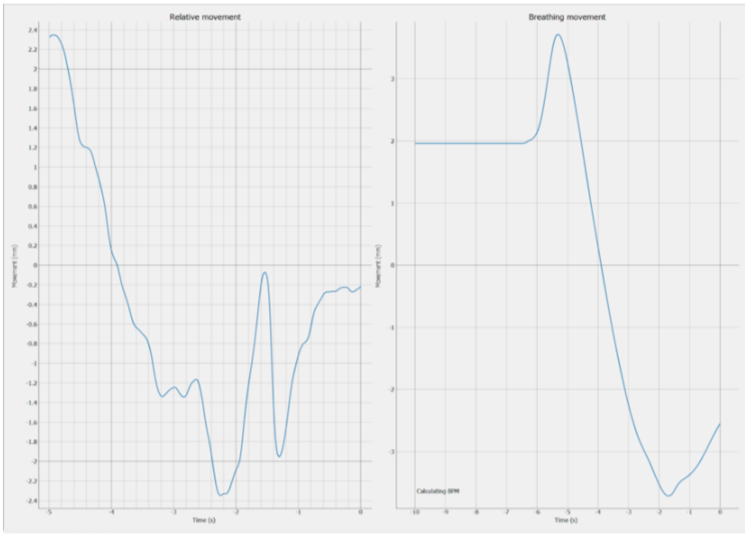



Figure 3.13 The new developed detector

A total of three detectors named sleep breathing, breathing and revised detector were evaluated and explored for this project. Recognising that these detectors were built on top of the IQ service, it was important to include the IQ service to understand how it functions. Consequently, it will be easier to apprehend and conclude the effectiveness of each detector and service and how it can be improved for future works.

## 3.8 Radar Sensor Encasement

Apart from focusing on the experiments, protection of the radar sensor was equally important to help minimise the risk of hardware damage. As the components on the radar sensors are exposed, it can be easily damaged without proper care and handling.

The guidelines to follow when designing the cover were no sharp edges that can injure elderlies or wire connections should not be hindered.

A temporary cover was built based on the available materials at that point in time: an airtight mini container and four steel PCB stands. Since all measurements were recorded from the top surface of the radar sensor, anything on the bottom surface will not affect its performance, especially steel screws. Thereafter, a camera stand holder was added onto the mini container for the container to stand in place during measurements.

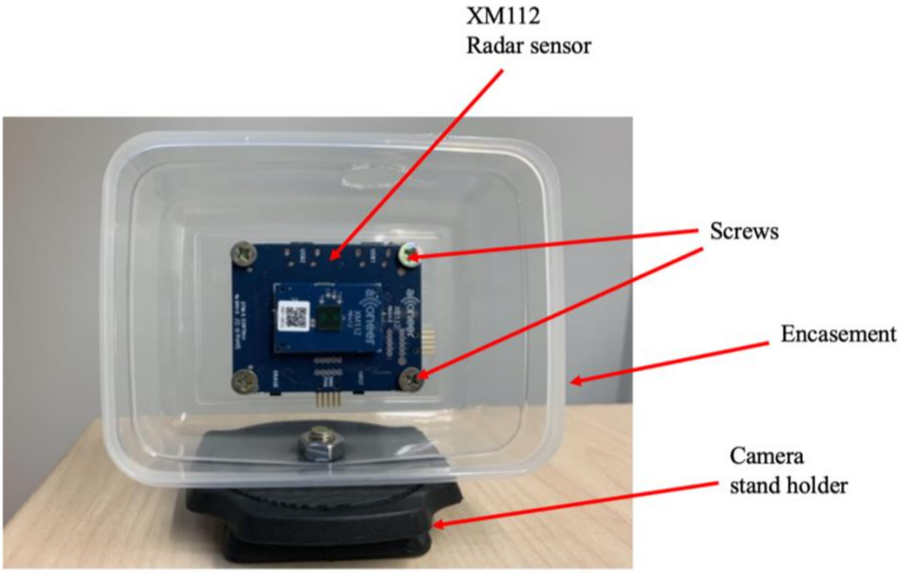



Figure 3.14 Front view of the encasement

Figure 3.15 Back view of radar sensor encasement

Figure 3.16 Side view of cover to plug in wire

Figure 3.17 Overall view with wire connected

# Chapter 4

# Test and Results

## 4.1 Experimental Overview

The following procedures were carried out during the experimentational phase:

a. Recording data from the GUI
    i. Under different scenarios
    ii. Low frequency (20Hz)
    iii. Mid frequency (60Hz)
    iv. High frequency (100Hz)
    v. Range interval between radar sensor and target (0.2m to 1.0m)
    vi. 1000 buffered frames
b. Extracting data from MATLAB
    i. Load .H5 files
    ii. Obtain raw data
    iii. Process raw data
c. Compare and study results

The H5 file advantages are the ability to store and organise large data files in different ways. Being a relatively new file format, users are unfamiliar and are not trained in this particular area. Besides that, one main disadvantage was that recorded measurements could only be accessed when the radar sensor is connected and GUI is opened. This caused inconvenience to those without the radar sensor as it required the necessary software to view the data. Hence, MATLAB was introduced to load H5 files before extracting and obtaining data out of GUI.

## 4.2 Data Processing Overview

The results in this chapter shows a comparison of the 3 detectors and 2 services in the following order:

(i) IQ service

(ii) Envelope service

(iii) Breathing detector

(iv) Revised detector

(v) Sleep Breathing detector

Above-mentioned that only the specified buffered frames will be saved in the recording and the frames setting for all the obtained data below was fixed at 1000. Hence, the only variables adjusted were the distance and frequency.

The raw data processed using MATLAB was able to obtain both fast time and slow time data. From the fast time axis, the range measurement of the distance of the target can be obtained. Whereas, doppler information or signal power fluctuation can be retrieved from the slow time axis. The figures shown in the various studies provides better information and visualization of both the XM112 radar sensor and target.

### 4.2.1 Study 1: Results for IQ service

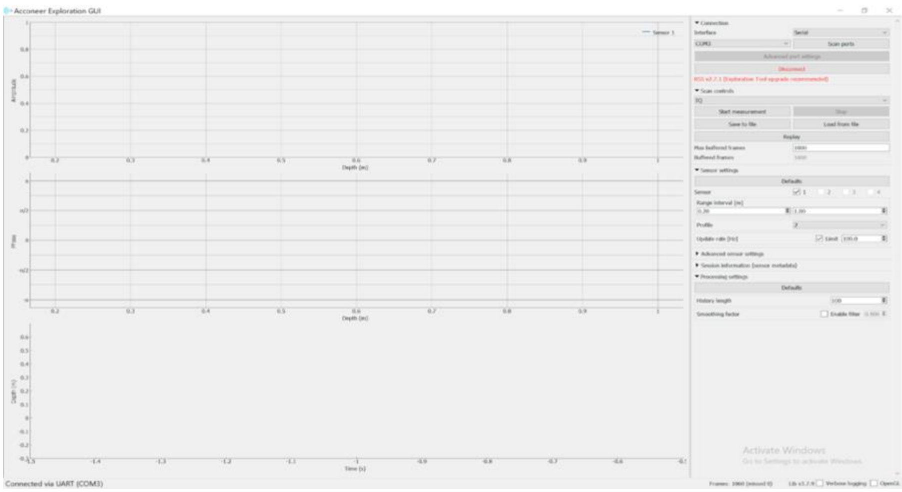


Figure 4.1 IQ service on GUI

In figure 4.1, IQ service produces the IQ components that can detect small movements made by the target. This service provides the range of the target and does not detect any breathing movements. The frequency for this study was set over three different range of frequencies: low, mid and high of 20Hz, 60Hz and 100Hz respectively. The obtained data are represented in the following graphs:

(i) Range vs Frame

(ii) Range vs Time

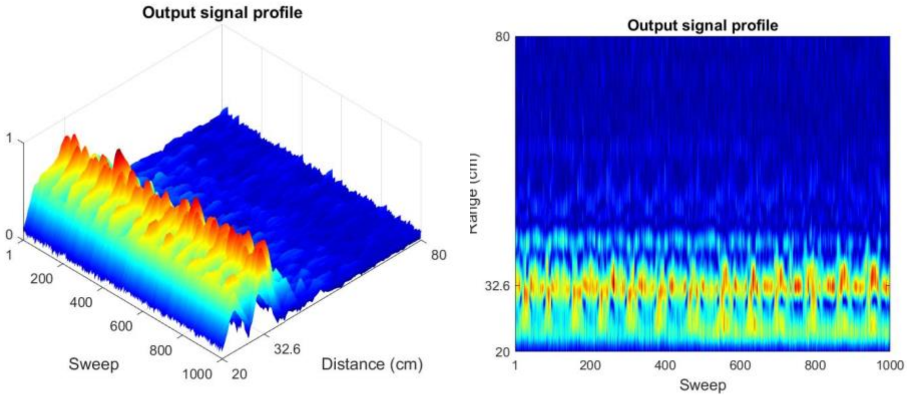



Figure 4.2 20Hz Range vs Frame (left) and 20Hz Range vs Time (Right)

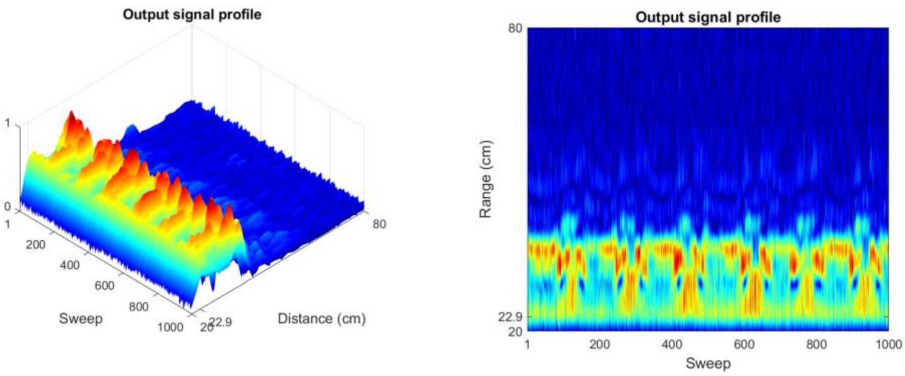



Figure 4.3 60Hz Range vs Frame (left) and 60Hz Range vs Time (Right)

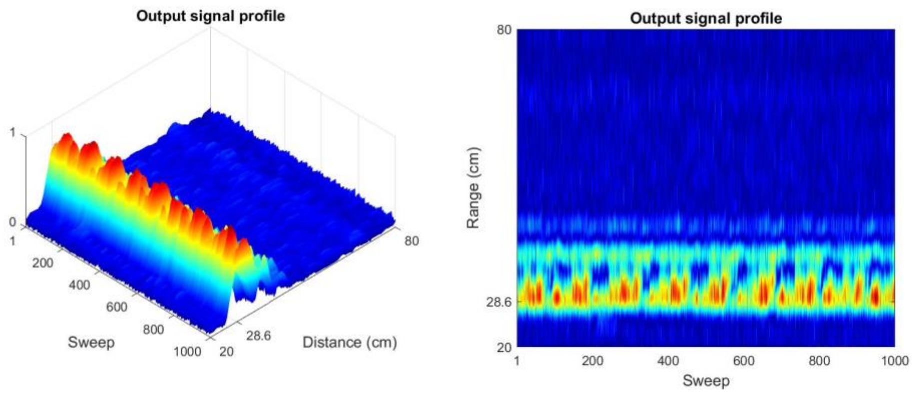



Figure 4.4 100Hz Range vs Frame (left) and 100Hz Range vs Time (Right)

The (i) graphs placed on the left are obtained from MATLAB using the surface plot function that creates a three-dimensional plot, also, indicating the distance of the target from the radar sensor. Whereas (ii) placed on the right of figures 4.2, 4.3 and 4.4 shows the same data as (i), but in a different view of the detected range of the target using the imagesc function on MATLAB.

Comparing figures 4.2, 4.3 and 4.4, it can be seen that at lower frequency of 20Hz, the radar sensor captured more point. By applying (3.01), at lower frequency, the period taken for the recording lasts longer and it was able record more data points. Likewise, when the frequency increased to 100Hz in figure 4.4, the lesser data points are captured and points are less saturated.

On top of that, the distance of the radar sensor to the target is recorded and indicated on the y-axis. Figure 4.2 shows the target distance at 32.6cm and in figure 4.4 the target is positioned 28.6cm away from the radar sensor.

Despite the change in frequencies, the plotted graphs provided sufficient information of the target range and distance of the target which is helpful in detecting the necessary details.

### 4.2.2 Study 2: XM112 Calibration

This case study will calibrate the accuracy of distance measurement between the radar sensor and object by employing the Envelop service which is commonly used for distance measurement. Prior to the experiment, the GUI was set to profile 2 with a range interval of 0.2m to 0.8m and a fixed frequency of 30Hz. Figure 4.4 shows the set-up for this study where it was carried out by placing the XM112 radar sensor at different marked points on the ground to measure the distance from the radar sensor to the upright surface.

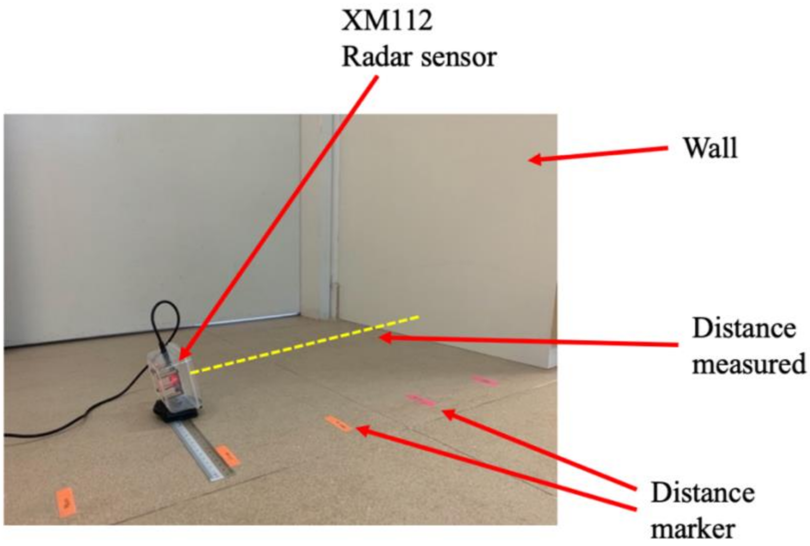



Figure 4.5 Calibration set-up

Figure 4.6 Sideview of the set-up

An error could be present in the obtained results which could be cause by physical, software or hardware calibration. For this reason, the confidence level was set at 5% to determine if it is within the acceptable error range. In this study, errors might be present in the obtained results which could be caused by the radar sensor or the set up error. Henceforth, to ensure the obtained results stays within the $\pm 5\%$ tolerance rate, calculation from (4.01) is used to determine the chi value:

$$\frac{O_i - E_i}{E_i} \qquad (4.01)$$

Where $O_i$ is the obtained value, $E_i$ is the expected value.

The recorded data was processed using MATLAB to obtain the following three graphs:

(i) Range vs Frame

(ii) Range vs Time

(iii) Signal vs Range

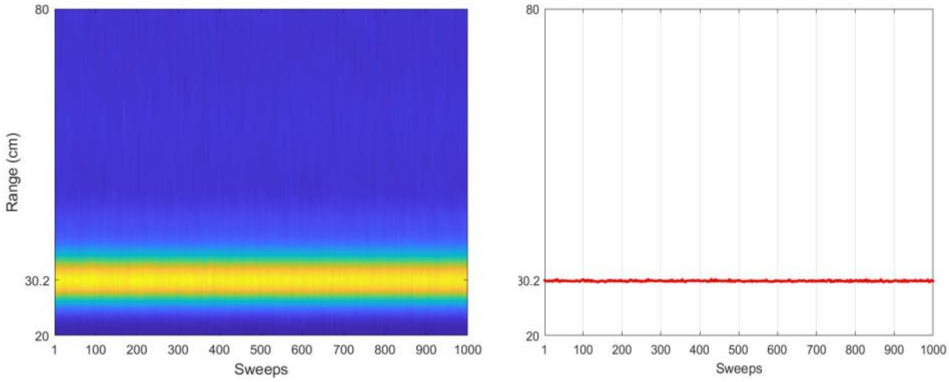



Figure 4.7 30cm Range vs Sweep (left) and 30cm Profile vs Sweep (right)

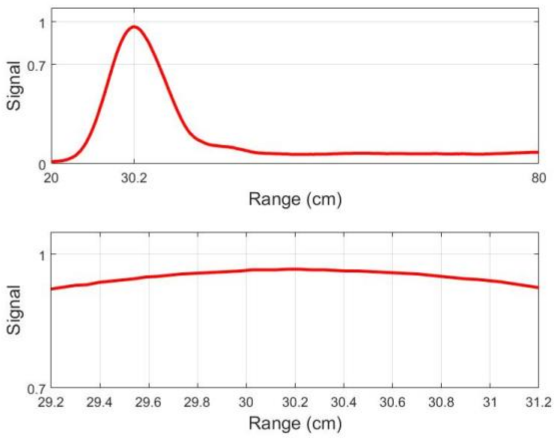



Figure 4.8 30cm Signal vs Range

(i) and (ii) are represented by figure 4.7 and (iii) is represented by figure 4.8. The first experiment conducted measured a distance of 30cm from an upright surface target. Both figures in figure 4.7 shows the distance of the wall from the radar sensor and the value recorded was 30.2cm.

Figure 4.8 displays two signal vs range graphs where the latter graph is the enlarged version. It was observed that the signal increased to its peak value only at its detected range of 30.2cm and decreased back to almost 0. The zoomed in plot in figure 4.8, shows a close up of the signal increasing to its peak before decreasing after 30.2cm.

A 0.2cm error was observed in this data and using (4.01) the calculated error is 0.667% which is below 5%, within the acceptable range. This error could either be caused by the physical limitations of the set-up or hardware limitations of the radar sensor, hence, the successive data will determine the underlying cause of this error and performance of XM112 radar sensor.

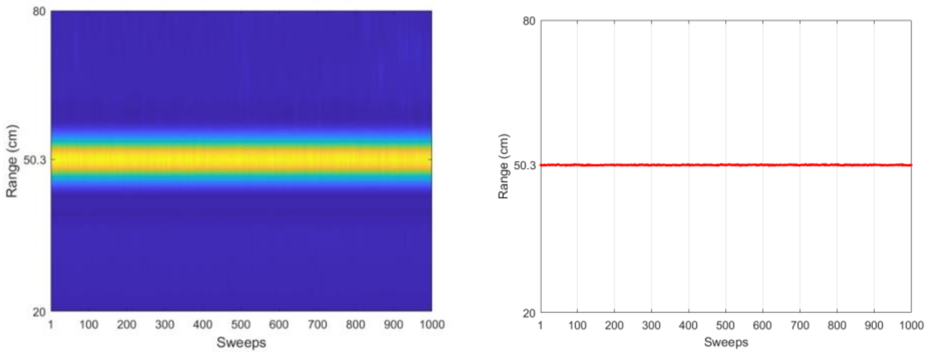



Figure 4.9 50cm Range vs Sweep (left) and 50cm Profile vs Sweep (right)

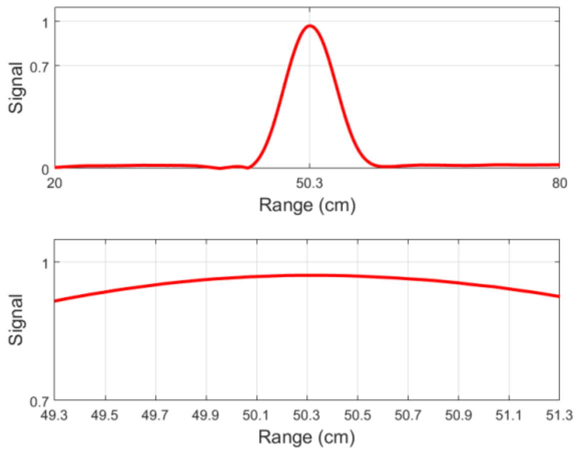
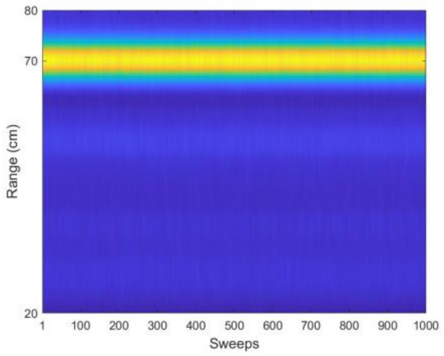



Figure 4.10 50cm Signal vs Range

(i) and (ii) is represented by figure 4.9 where the radar sensor detects the distance of where the object was positioned. This experiment measured a distance of 50cm from the radar sensor to the upright surface, however, the detected range was 50.3cm

Figure 4.10 represents (iii), where it shows the peak signal received over the range. As seen the received signal rises up to almost 1 at the detected range of 50.3m. The close up graph shows the individual range points when the signal increased and decreased at its peak.

From the obtained data a distance of 50.3cm was observed instead of 50cm and applying (4.01), the error of 0.3cm corresponds to 0.6%. This percentage error is kept within the tolerance level of 5% and the results is still acceptable.



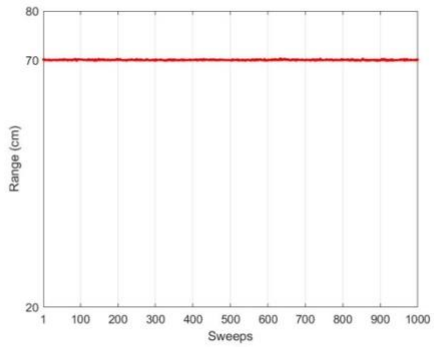




Figure 4.11 70cm Range vs Sweep (left) and 70cm Profile vs Sweep (right)

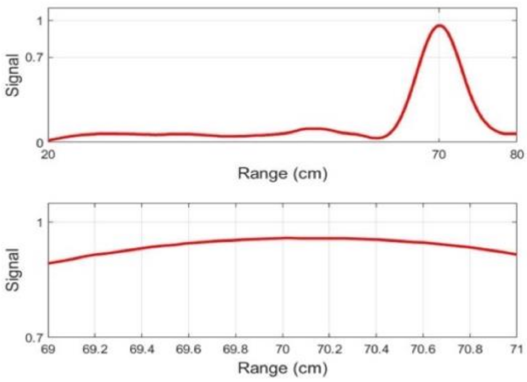



Figure 4.12 70cm Signal vs Range

The next experiment measured a distance of 70cm between the radar sensor and object. Figure 4.11 indicates the distance of where the object is located and the obtained value for this measurement was situated at 70cm from the radar sensor.

Figure 4.12 shows how the signal changes at its detected range of 70cm. It can be seen that at 70cm, the received signal increased up to its peak value of almost 1 and decreased after 70cm. Also showing the specific range values as the signal increased to its peak as shown in the zoomed version.

Hence, there was no error detected for this experiment as the obtained data matched with the measured distance of 70cm prior to the recording.

As mentioned above, the previous experiments had the range setting of 0.2m to 0.8m but in the following experiments the range will be increased to 1m. This was carried out as profile 2 has the capability of operating up to 1m and this will determine the effectiveness and usefulness of the radar sensor when it is set to its maximum distance.

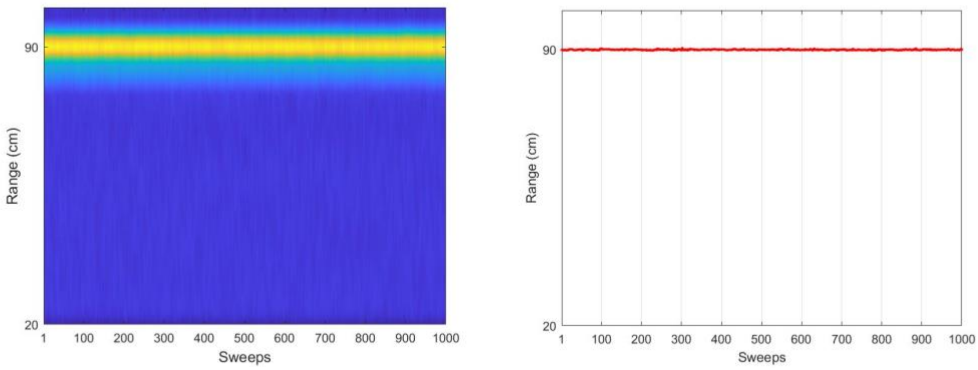



Figure 4.13 90cm Range vs Sweep (left) and 90cm Profile vs Sweep (right)

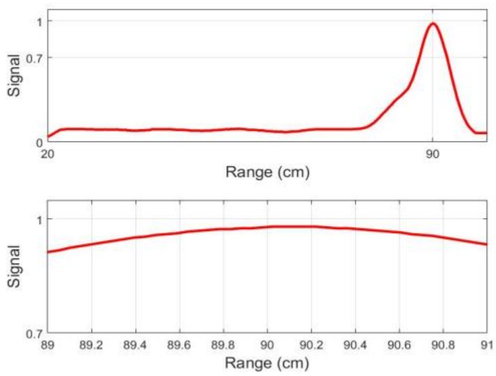



Figure 4.14 90cm Signal vs Range

The distance in this experiment was measured at 90cm from the radar sensor to the object. In the plotted graph of figure 4.13 it represents (i) and (ii) where the detected range is marked at 90cm.

Figure 4.14 shows how the signal against range with a close up version. As observed, the signal reached its peak value at its detected range of 90cm and the signal returned close to its initial value.

There was no error detected in this experiment as the target is situated at 90cm, meaning the distance measured before recording matches with the obtained data.

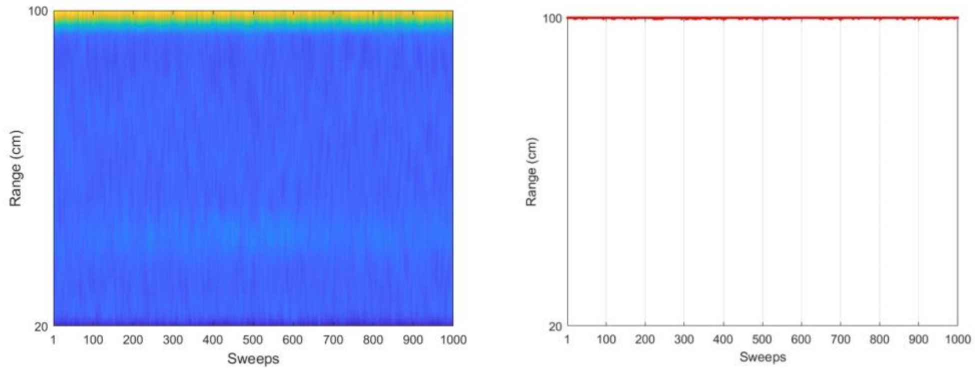



Figure 4.15 100cm Range vs Sweep (left) and 100cm Profile vs Sweep (right)

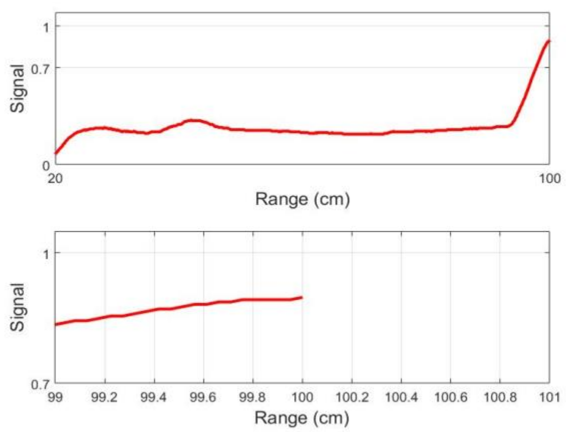



Figure 4.16 100cm Signal vs Range

The last experiment was measuring the distance at its maximum of 100cm and testing if the radar sensor was able to measure beyond its maximum distance.

Figure 4.15 represents (i) and shows the distance of where the target is located. The distance of the target from the radar sensor was measured at 100cm without any error detected. In addition, figure 4.16 shows that the signal increased up its peak value when the range was situated at 100cm. However, the signal does not return to its initial point and terminated at the range of 100cm. This implied that the radar sensor was unable to detect any points beyond the maximum range of 100cm and the obtained results will be imprecise and rejected. Ensuring the distance was kept between 0.2m to 1m, the radar sensor was valid in detecting up to its maximum distance and does not affect its performance.

Based on the experiments conducted over the range of 0.2m to 1m, errors have been present in some results, yet these errors are kept within the tolerance level of $\pm 5\%$. As more than half of the results prove to be accurate, the underlying cause could be the inaccurate distance position prior to the actual measurement. As the radar sensor encasement was mounted on top of a camera stand holder shown in figure 4.16, the radar was slanted at an angle which could result in the imprecise distance measurement. Taking the miscalculated setting and parallax error into account, the error occurred owing to the set up.

Figure 4.17 Side view of encasement

In consideration of the physical limitations, the Envelope service is appropriate and applicable in measuring distances when the measurements are kept within its limits.

### 4.2.3 Study 3: Results for breathing detector

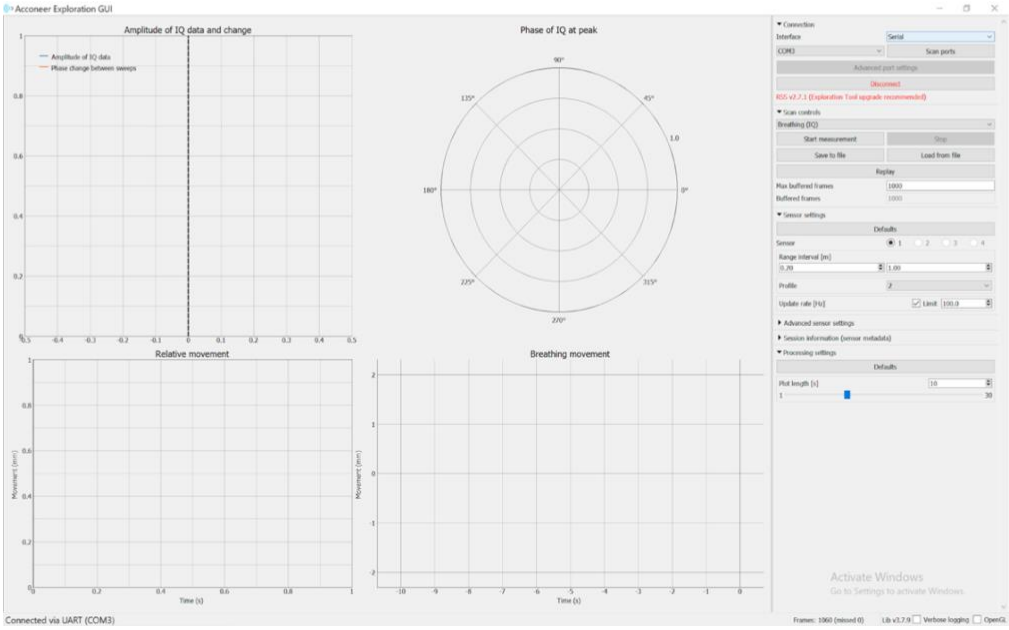



Figure 4.18 Breathing detector on GUI

In figure 4.18, the breathing detector consists of the Amplitude of IQ data and change, Phase of IQ at peak, Relative movement and Breathing movement. This detector is built on top of the IQ service in study 1. The raw data recorded was processed using MATLAB to obtain three graphs:

(i) Range vs Frame

(ii) Range vs Time

(iii) Mean signal of Range

(iii) represents the signal power around the target and the total number of peaks corresponds to the chest movement of the target. Moreover displaying two graphs; (iiia) represents the actual data while (iiib) is the smooth curved obtained using the Savitzky-Golay filtering on MATLAB. The figures below shows the different frequency range of 20Hz, 60Hz and 100Hz.

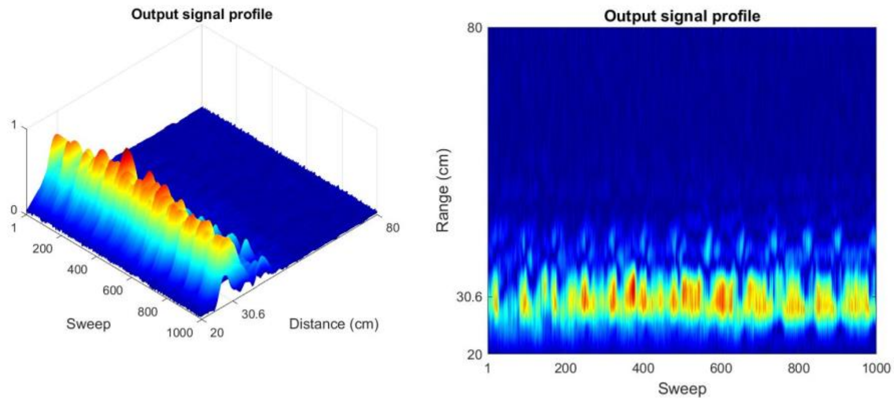



Figure 4.19 20Hz Range vs Frame (left) and Range vs Time (Right)

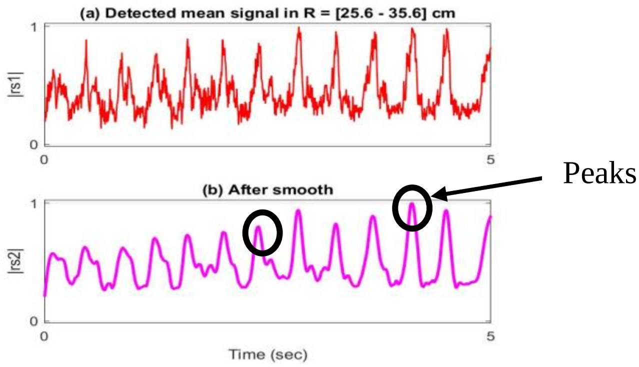



Figure 4.20 20Hz Mean signal in range

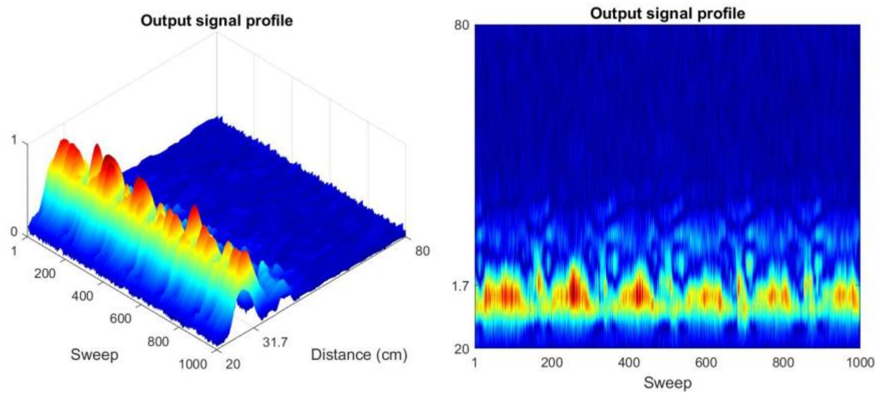



Figure 4.21 60Hz Range vs Frame (left) and Range vs Time (Right)

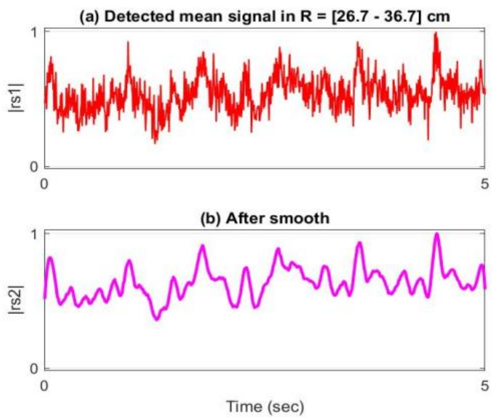



Figure 4.22 60Hz Mean signal in range

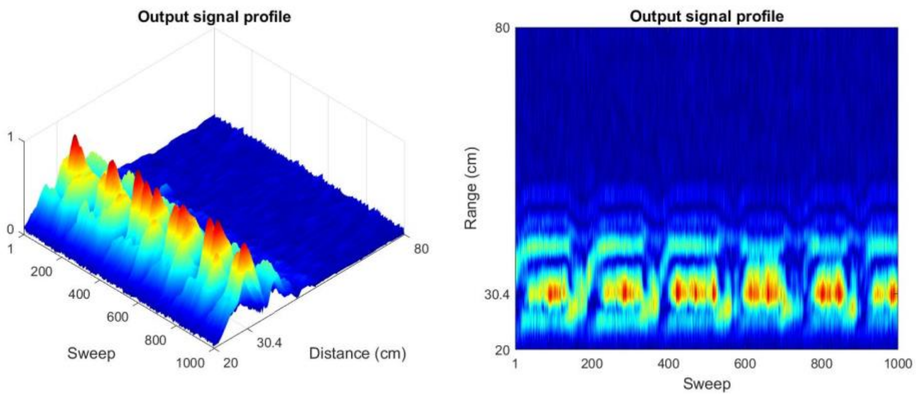



Figure 4.23 100Hz Range vs Frame (left) and Range vs Time (Right)

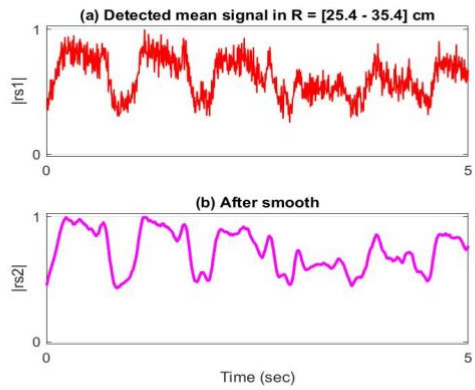



Figure 4.24 100Hz Mean signal in range

Figure 4.19 shows the obtained graph measured at lower frequency where the graph is more concentrated, and the target is 30.6cm away from the radar sensor. As mentioned above in (3.01), frequency is inversely proportional to the period taken and over a longer duration, more points will be captured by the radar sensor. Likewise, in figure 4.23 the frequency was set to 100Hz there were less data points detected in the graph and the target was positioned 30.4cm away from the radar sensor.

Figure 4.19, 4.21 and 4.23 represent (iii), where the peaks on the graph corresponds to the movement of the chest. The total number of peaks was equivalent to the number of breath taken over the period. However as seen in figure 4.20, at lower frequency and there were a total of 12 peaks observed shown in the black circle indicates the target's chest movement, but results might be inaccurate as 12 breaths were too extreme over the given period. One possible reason for this cause was at lower frequency the signals have better penetration and signals had the capability of passing through objects, for example the wall. Another possibility was the false and missed detection due to the configuration of the radar sensor [32]. Furthermore, the frame rate on the code was 200 which was considered high which resulted in a 5 second recorded time shown in figure 4.20. In contrast, figure 4.24 shows a large interval between the breath movements, meaning the target took a longer time to breath. It was also noticed that the mean signals over three frequencies were similar at approximately 25cm to 36cm. Hence, the Breathing detector provide necessary information of the target distance and the breaths taken over a period.

### 4.2.4 Study 4: Results for revised detector

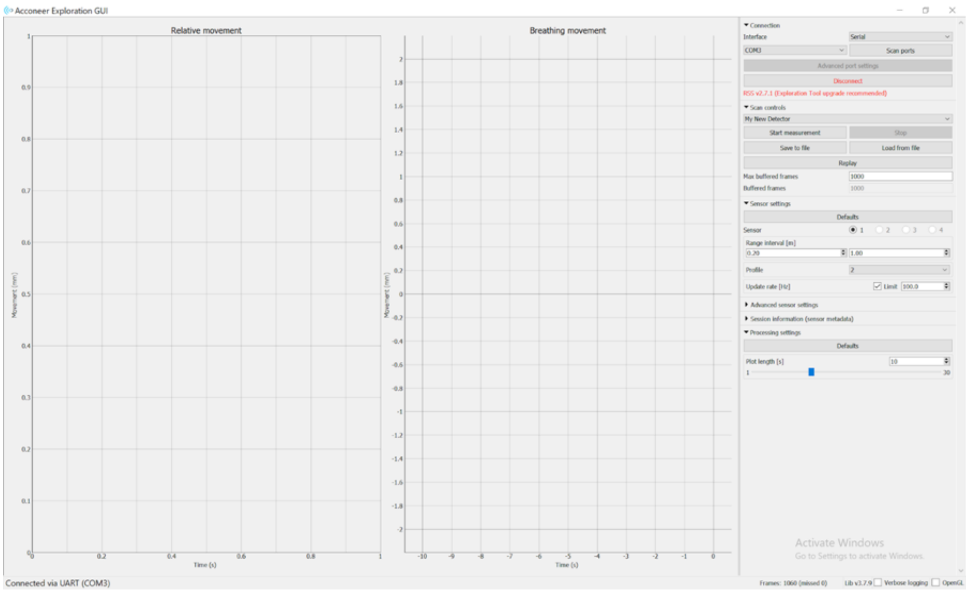



Figure 4.25 New developed detector on GUI

In figure 4.25 shows the measurements included for the new developed detectors which includes the relative movement and breathing movement. Unlike the other detectors, this detector places emphasis on only the breathing movements without the raw data from IQ signal. This detector was modified from the Breathing detector used in study 3. The raw data recorded was processed using MATLAB to obtain three graphs:

(i) Range vs Frame

(ii) Range vs Time

(iii) Mean signal of Range

(iii) shows the total number of peaks on the graph represents the chest movement of the target. The figure displays two graphs where (iiib) is the smoothen curve obtained using (iiia). The figures below shows the different frequency range of 20Hz, 60Hz and 100Hz.

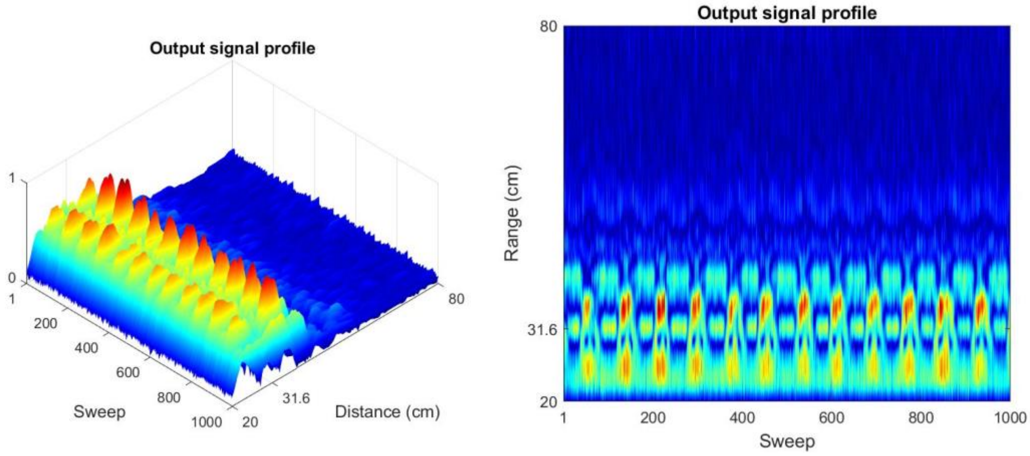



Figure 4.26 20Hz Range vs Frame (left) and 20Hz Range vs Time (Right)

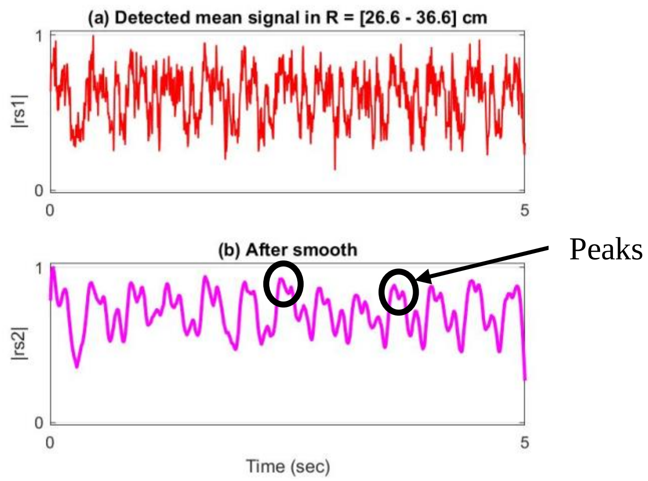



Figure 4.27 20Hz Mean signal in range

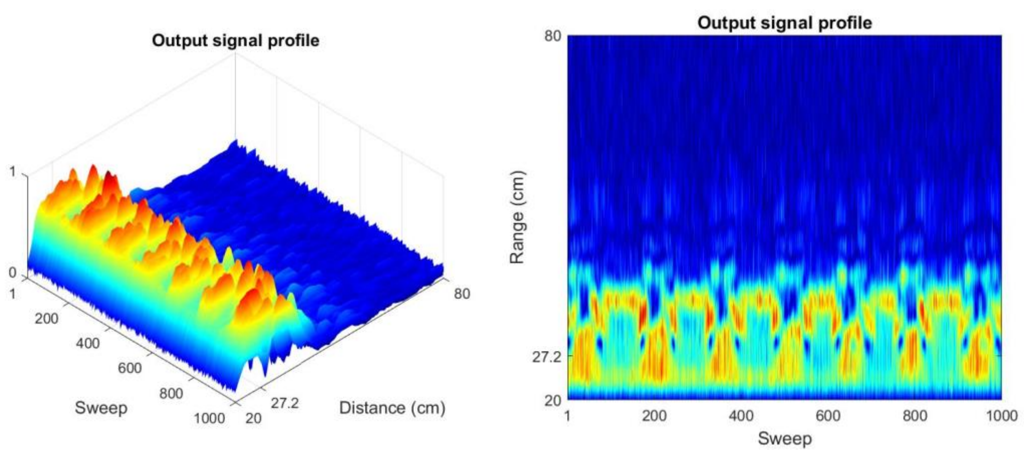


Figure 4.28 60Hz Range vs Frame (left) and 60Hz Range vs Time (Right)

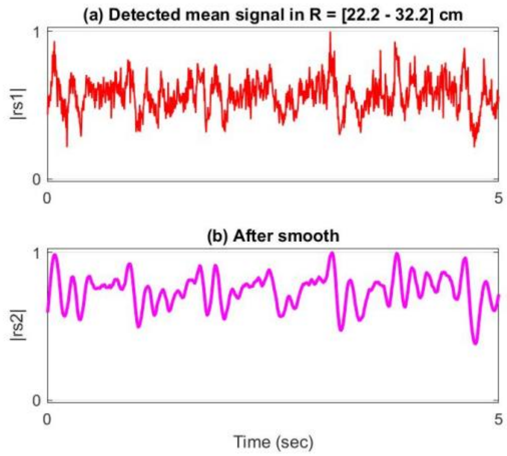



Figure 4.29 60Hz Mean signal in range

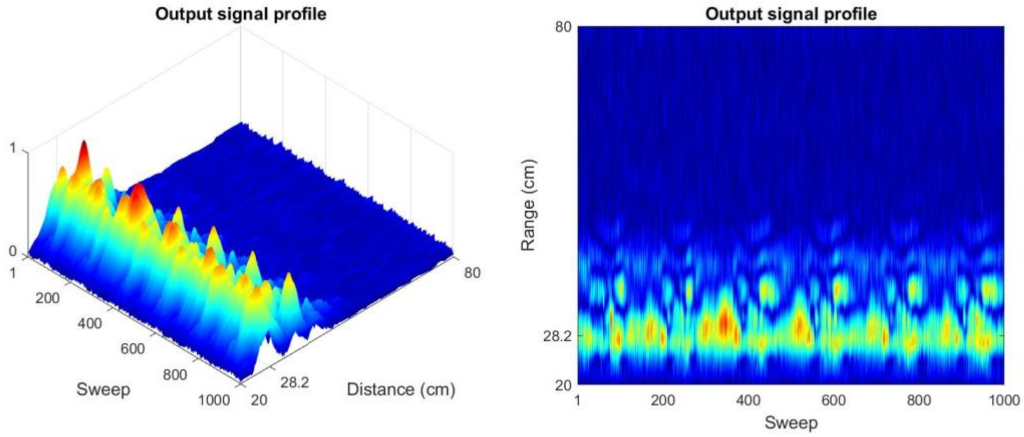



Figure 4.30 100Hz Range vs Frame (left) and 100Hz Range vs Time (Right)

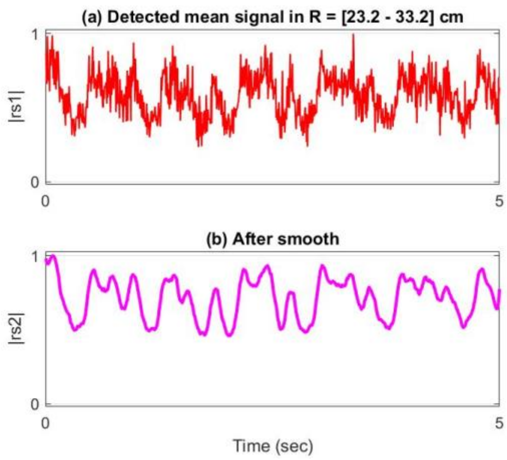



Figure 4.31 100Hz Mean signal in range

Figure 4.26, 4.28 and 4.30 shows the range of where the target was located with the indicated values on the y-axis. Figure 4.26 records the measurement at a lower frequency of 20Hz and the detected distance of the target is 31.6cm. The points captured revealed more information of target such as the minimal movements made. With contrast in figure 4.31, the frequency was set to 100Hz which was considerably high for this project and it can be observed that lesser points are captures as the period completes faster.

Figure 4.27, 4.29 and 4.31 shows the total number of peaks that corresponds to the chest movement of the target. Figure 4.27 had the most number of peaks detected but as mentioned earlier in case 4 this could happen at lower frequency due to the signal penetrating through the walls. As well as the missed detection from the settings of the radar sensor and the high frame rate of the radar sensor. On the other hand, in figure 4.29 and 4.31, the number of peaks were lowered to approximately five breaths and the interval between each chest movement is longer too. Moreover, the mean signal for all three frequencies were similar between 23cm to 35cm. Comparing the graphs between study 3 and 4, both detectors are alike and it seems that an ideal frequency setting should be approximately 60Hz to detect a more accurate breathing movement of the target.

### 4.2.5 Study 5: Results for sleep breathing detector

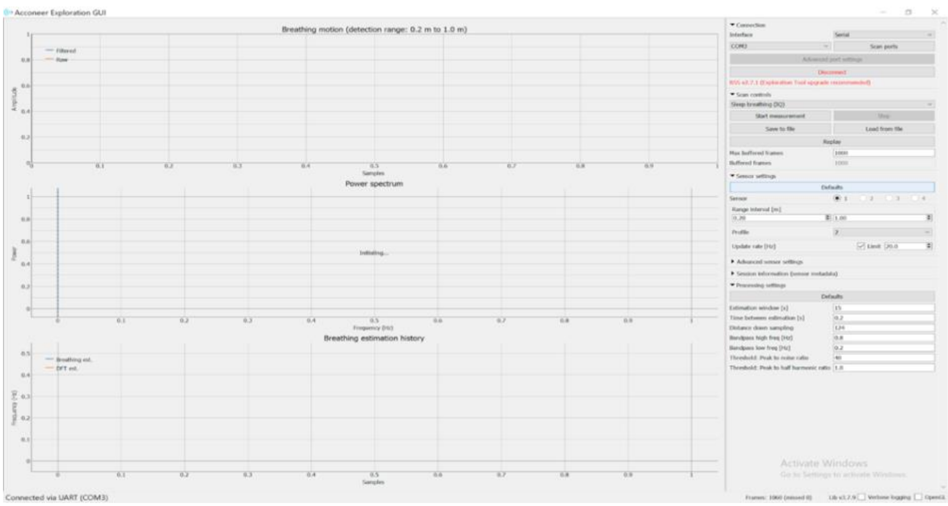



Figure 4.32 Sleep breathing detector on GUI

As seen in figure 4.32, the sleep breathing detector consists of the breathing motion, power spectrum and breathing estimation history. When the measurement began, the breathing motion starts off first while the power spectrum and breathing estimation history initiates up to 100%. In addition, this detector is built on top of the IQ service in study 1. The raw data recorded was processed using MATLAB to obtain three graphs:

(i) Range vs Frame

(ii) Range vs Time

(iii) Mean signal of Range

Where (iii) represents the total number of peaks on the graph represents the chest movement of the target. (iiib) is the smoothen curve obtained using the Savitzky-Golay filtering on MATLAB. The figures below shows the different frequency range of 20Hz, 60Hz and 100Hz.

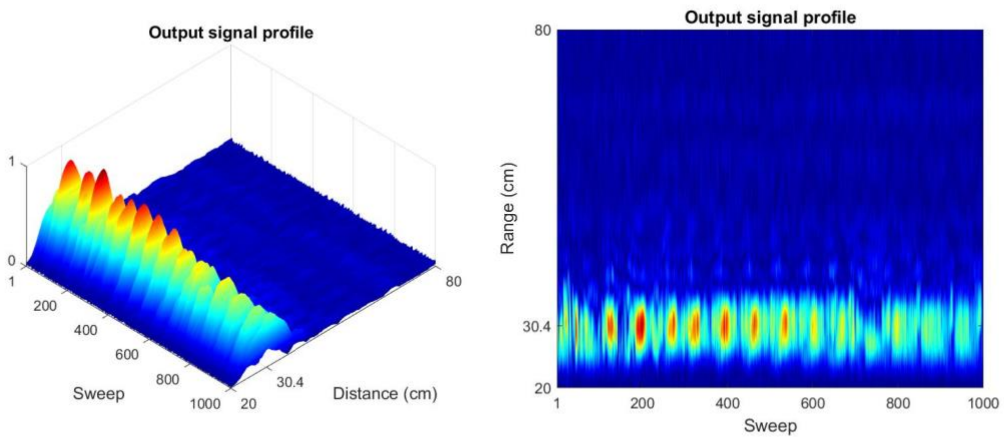



Figure 4.33 20Hz Range vs Frame (left) and Range vs Time (Right)

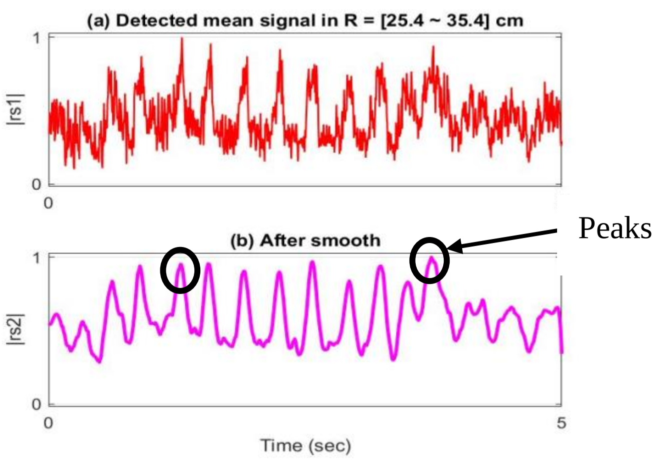


Figure 4.34 20Hz Mean signal in range

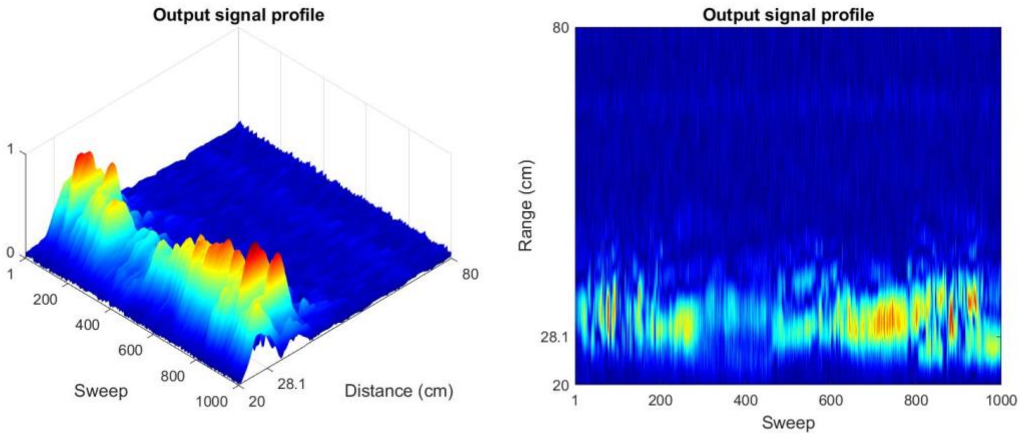



Figure 4.35 60Hz Range vs Frame (left) and Range vs Time (Right)

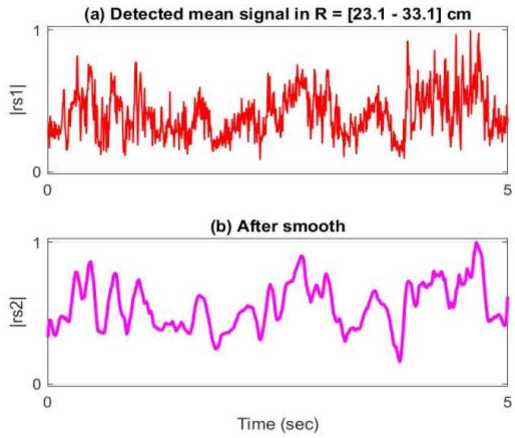



Figure 4.36 60Hz Mean signal in range

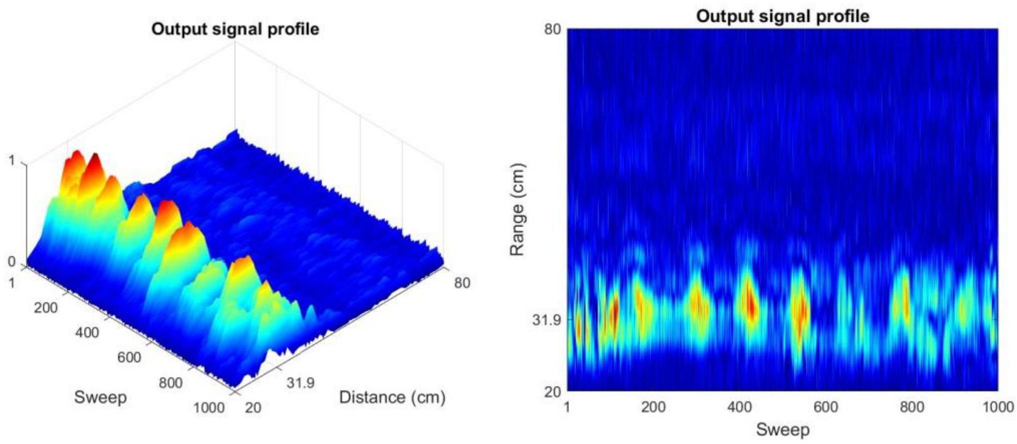



Figure 4.37 100Hz Range vs Frame (left) and Range vs Time (Right)

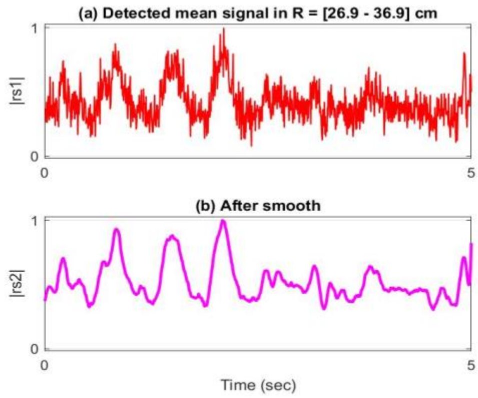



Figure 4.38 100Hz Mean signal in range

Figure 4.33, 4.35 and 4.37 shows that target induced movements while sleeping which resulted in the fluctuation on the detected range. Despite this, the Sleep Breathing detector was capable of detecting sufficient movements for MATLAB to process a detailed graph. Figure 4.33 is the obtained data for a frequency of 20Hz and as observed more data points were captured as compared to figure 4.37 at 100Hz. As mentioned above, the difference occurred due to (3.01) where the period taken is longer, hence detecting more data points.

Figure 4.34, 4.36 and 4.38 represents the breaths taken by the target over a period of time, the each peak observed equals to the chest movement. However in figure 4.34, a total of approximately 11 peaks were identified and as mentioned earlier the possible cause could be at lower frequency the signal penetrated better and passed through the surrounding objects such as the wall. Besides that, the configured settings on the radar sensor was not set to its optimal values for the experiment and the frame rate were too high. In figure 4.36 and 4.38 there were approximately 6 peaks which was reasonable and possible.

Therefore, it is preferable for the frequency setting to be adjusted to a mid-range frequency for a more accurate and reliable data.

### 4.2.6 Study 6: Near and far range

This study shows a comparison between the near and far range of the target from the radar sensor. The sleep breathing detector was used in this study.

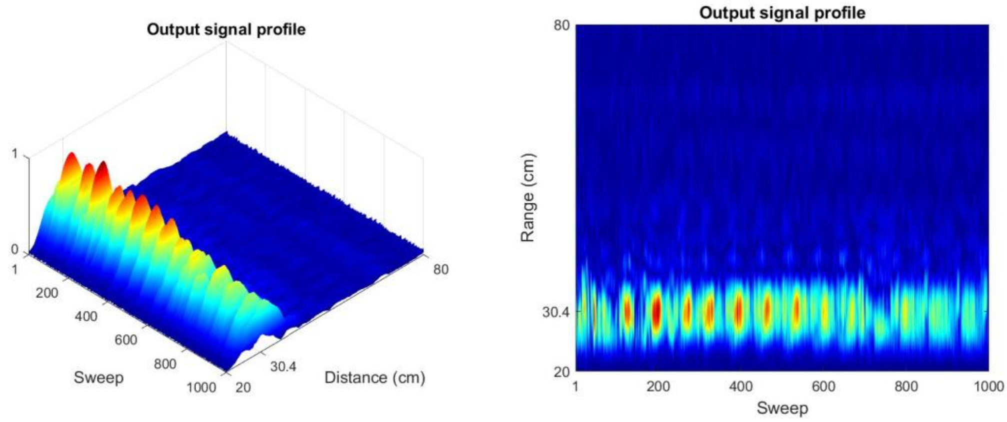



Figure 4.39 Far range: 20Hz Range vs Frame (left) and Range vs Time (right)

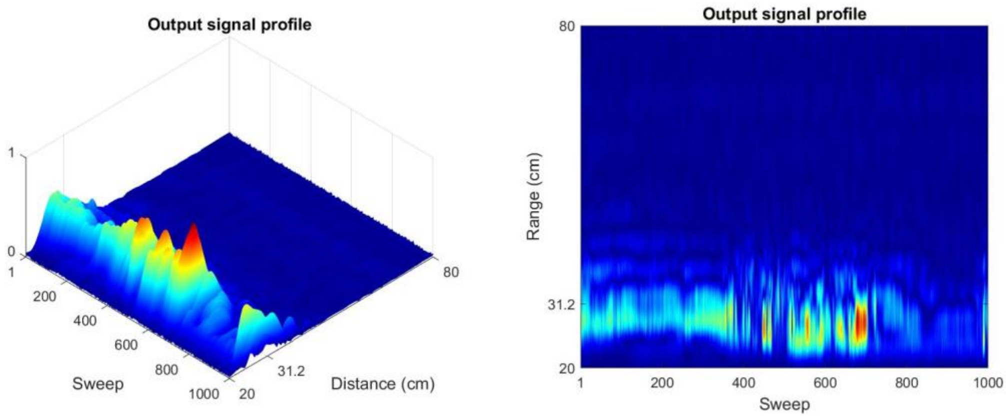



Figure 4.40 Near range: 40Hz Range vs Frame (left) and Range vs Time (right)

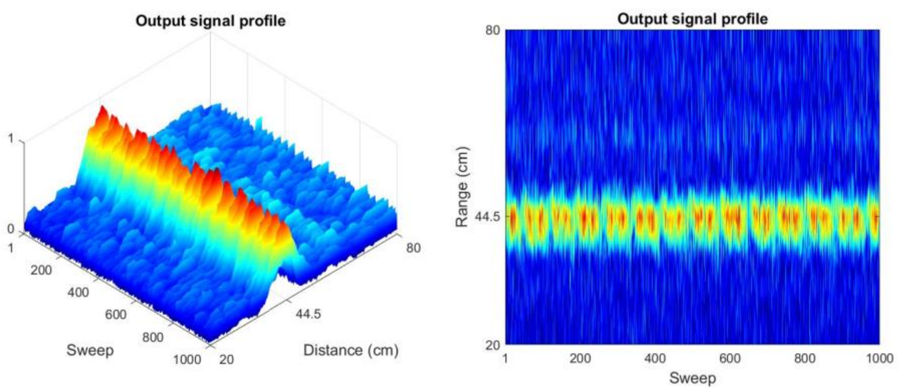



Figure 4.41 Far range: 20Hz Range vs Frame (left) and Range vs Time (right)

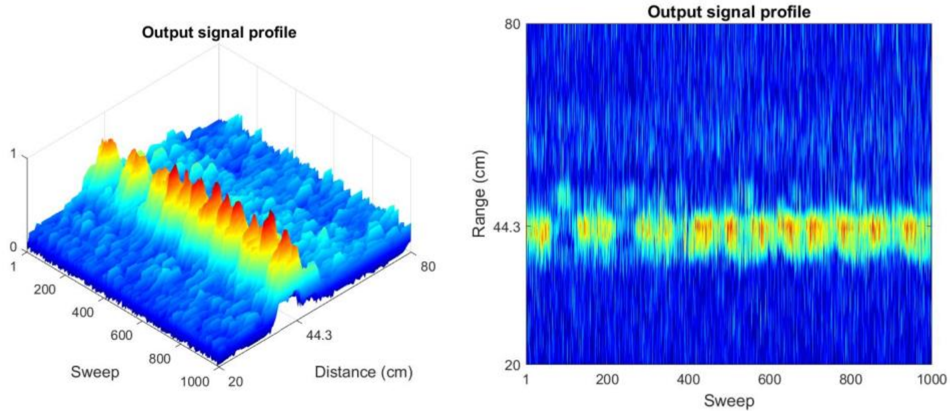



Figure 4.42 Far range: 40Hz Range vs Frame (left) and Range vs Time (right)

Figure 4.39 and 4.40 represents the near range of 30cm while figure 4.41 and 4.42 represents the far range of 44cm. It was observed in figure 4.41 and 4.42, the background contained more noises and interference seen on the grainy background as compared to figure 4.39 and 4.40. At a closer range, the background contained lesser interference and focused better on the target. Previously, it was stated that at lower frequency, the obtained graph will be more concentrated with the data points being more specific that provides more details of the measurement. At high frequency, the graph showed the opposite.

In spite of the distance and frequency, the Sleep Breathing detector is proven to accurately detect the range of the target.

## 4.3 Concluding Observations

These studies were conducted to identify which detector was more applicable for this project and determined its overall capability and performance. Two services (IQ and Envelope) and three detectors (Breathing, Newly developed, Sleep Breathing) were utilized and measurements were recorded over different frequencies.

The IQ service focuses on detecting small movements made by target while the Envelope service prioritises accurate distance measurements. As observed in the studies above, both IQ and Envelope services have fulfilled its objectives and provided adequate data and information.

Subsequently, the three detectors were used to measure the range of the target and breathing movements. Although the GUI for the detectors have different functions, the obtained data and processed data showed that they operate and function alike. Although the distance of the target measured was accurate, the ideal frequency setting was approximately 60Hz and was considered as the mid frequency range in this project.

One finding based on the current studies were the identical results, at lower frequency where more data points are captured and the signal penetrated better where signal passed through objects. Moreover, the change in frequency, distance and other settings could affect the results and the efficiency of the radar sensor where false detection were present and high frame rates.

Although similar results were obtained, the Sleep Breathing detector would be selected for this project as it is optimised for detecting breathing movements when the target is asleep. The Sleep Breathing detector functionality corresponds with the focus of this project; monitoring the breathing movements of elderlies when sleeping. Nevertheless, the breathing and revised detector both provided sufficient information of the target and are useful for monitoring breath movements. Hence, it is essential to consider the configurations of the Sleep Breathing detector to enhance the performance and efficiency of the XM112 radar sensor.

# Chapter 5

# Conclusion and Future Work

## 5.1 Conclusion

The project priority was to test and validate the performance and accuracy of mmWave radar sensors to expand into homes of the elderlies. With assisted living facilities being expensive and low in capacity [1], [2], [6]. mmWave radar sensors prove to be a promising solution with several advantages such as detecting and recognizing objects.

Acconeer XM112 radar sensor was selected as it is user friendly and offers relevant and applicable services and detectors that support this project. Moreover, it caters to different applications which gives flexibility in exploring other possibilities for this project.

With the emphasis of providing aid and support to elderlies, studying their sleep breathing experiments were conducted to identify if Acconner XM112 radar sensor was a viable solution. This was done by installing the required software and configuring the radar sensor to execute the GUI. Upon completion, settings could be adjusted based on preference and measurements can begin. The following service and detectors were evaluated: two services (IQ and Envelope) and three detectors (breathing, sleep breathing and revised detector).

Acconeer XM112 radar sensor displayed favourable results. Results gathered showed accuracy in detecting small movements, the target range, and doppler profile. Moreover, results were comprehensive which makes it easy to be analysed by signal processing in MATLAB.

While assisted living facilities cover a wide range of daily needs, incorporating radar sensors into daily living proves to negate part of the needs of relocating to a specialized facility. It could potentially be a cheaper alternative as the cost of a radar sensor is a one-time payment and provides a precise monitoring solution to elderlies. Whereas the cost of living in such facilities from $4,000 to $5,000 per month [2].

Although there were several challenges faced such as inconvenience to access data without software and decoding raw data into MATLAB. These were resolved through tests and discussions which provided insights to enhance knowledge.

After research and countless experiments, Acconeer XM112 radar sensor shows consistency in its results that certifies its reliability, functionality and capability. Thus, leveraging on the benefits, Acconeer XM112 radar sensors have a great potential in assisting elderlies to improve their standard of living and provide care to them.

## 5.2 Recommendation in Future Work

In this project, two services (IQ and Envelope) and three detectors (breathing, sleep breathing and newly developed detector) were used to research and study on. After experimentation, it was concluded that Acconeer XM112 is an effective solution with high efficiency. With this understanding and fact, the first aspect that can be worked on is developing this radar sensor into an application that monitors sleep movements and provides necessary assistance if abnormality is detected.

Next, one limitation was being unable to access the data without the required software downloaded as data could only be viewed in GUI. Files are saved under H5 format which makes it difficult for individuals to decode and understand the data. Hence, another aspect is to modify the code to immediately process raw data after being saved so information can be processed easily.

Finally, in this project, MATLAB was utilized to process raw data to acquire range measurement and signal power fluctuation. The current process of the plot could be improved by comprehending the data values used by the radar sensor to provide better information and details for analysis.

To conclude, these areas; developing an application, and signal processing on MATLAB, could be developed for future progress to provide opportunity to incorporate mmWave radar sensors into daily living.

# Reflection on Learning Outcome Attainment

This FYP journey has been an extremely fruitful and fulfilling experience. It allowed me to work and improve in several areas that helped me transition into the next phase: the working world. While mastering new skills, and enhancing my knowledge. I understood the importance of lifelong learning.

Taking on a different subject of interest as compared to my current specialization has allowed me to broaden my horizon, attain unfounded knowledge, and learn new concepts. Being a practical project, it is key to be able to grasp the fundamental concepts for both theory and practical. Even when facing difficulties, the ability to identify the root cause and navigate through possible solutions is insurmountable. On top of that, effective communication allowed me to clear the air and avoid confusion when seeking a third party opinion.

With different software such as MATLAB and Python being highly relevant and prevalent tools being used in the industry today, it has equipped me for future tasks related to this field. Learning how to navigate and troubleshoot with these software is beneficial as it is reshaping the world today and we are constantly relying on it. Being involved in it enabled me to work effectively with more reliable data and enhanced analysis.

These soft and hard skills gained are lifelong empowerment and builds towards my competency as I enter the working world. As learning is essential in my growth, boosting my confidence, unveiling new opportunities and igniting my creativity, it has encouraged me to nourish my mind and pursue new knowledge every day. I am emboldened to cover more in-depth concepts and new areas relevant to this FYP.

Stepping out of my comfort zone allowed me to constantly grow and build on my interpersonal and technical skills. To conclude, this has been a process of learning, growing and personal development.

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