2020/2021 FYP FINAL Report

A RADAR SYSTEM FOR SENSING AND TRACKING (LH01)

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Abstract

This project presents a radar system to detect and track moving human targets. In contrast to mature radar sensor hardware, few works have been done on the software side, especially for surveillance applications.

We first developed a simple version of the moving object detection algorithm by applying FFT. Second, FFT results of different types of objects were measured and compared with the human target, and a human detection algorithm was developed. Lastly, a human tracking algorithm was developed for a special case that moving objects are at an equal distance from the radar sensor. We developed a graphical user interface (GUI) to graphically present the number of human targets detected in real-time.

In this work, we achieved 87% of successful detection, which is much higher than 40% of accuracy without a human tracking algorithm at equidistance. This is higher than the measurement result of embedded Infineon Software which showed 80% of accuracy.

1) Introduction

1.1 Background and Problem Statement

Doppler radar has been used in a variety of applications such as aircraft navigation, weather forecasting, and satellite detection. The main principle behind Doppler radar is the Doppler effect – the change in frequency of a wave with respect to an observer. This enables us to acquire information such as speed about an object that we want to analyze.

Frequency modulated continuous wave (FMCW) radar is a type of Doppler radar that is widely used today for its advantage in detecting distance. It sends out frequency modulated signals, and when the signal reflects off an object, the radar receives the signal. By examining the phase delay between transmitted and received signals, distance from an object can be determined. Therefore, lots of applications can be done using FMCW radar. One example is a vital sign sensor; FMCW can detect human breathing and heart rate, and thus an alarm can be sent if a person is in an emergency.

FMCW radar is a useful tool for surveillance purposes. In essence, it detects the motion, distance, and angle of a target inside a designated area. Compared to existing security cameras, it can automatically report any motion detected directly, preventing dangerous situations very quickly. Moreover, compared to other technologies that reveal more information about an object such as computer vision and machine learning, radar system requires a reasonable amount of cost, which make them commercially powerful.

Thanks to the development and improvement of the Monolithic Microwave Integrated Circuit (MMIC), the use of signals at milli- meter wave range can be made possible. 24 GHz radar has recently been used in various applications such as vital sign detection and automotive.

Although great effort has been put into the hardware side of the system (24 GHz products are well-established and now 77 GHz products began to appear on market), signal processing techniques and required algorithms are still in need for each application. Especially for surveillance systems detecting human actions, a major interest of this project, additional effort is required to differentiate human actions against objects such as walls or trees. In this project, the FMCW radar system will be used for human target detection and tracking, for surveillance purposes.

1.2 Motivation

As stated earlier, establishing a real-time surveillance system in which immediate action can be achieved is crucial. Conventional CCTV systems are only for recording purposes; this is to gather information after an incident has occurred. However, if unwanted motion can be detected and reported earlier, there is a greater chance to prevent crimes.

Besides existing fancy technologies for surveillance, a radar system is cost-effective. It can be widely used in many areas. Thus, if one can develop a reliable system (with high accuracy), a strong surveillance system can be easily achieved. As radar gathers information regarding motion, there would be no issue regarding privacy, unlike many other technologies. As many radar systems could be interconnected at real-time basis, this not only enhances the security of one building/sector but also the country as a whole.

As radar system does not reveal much information about moving objects, accuracy is the most crucial factor. Without high accuracy, this system would be useless. Therefore, establishing human target detection and tracking algorithm is the most important issue here, calling for greater attention.

1.3 Literature Review of Existing Solutions

1.3.1 Real-time Intruder Surveillance using Low-cost Remote Wireless Sensors [1]

Camera based systems are not hidden and due to this fact, the sensors or the part of system can be damaged at any time. This system uses two Received Signal Strength Indicator sensor nodes hidden behind the wall to detect the motion of people moving to and from and sends signal if there is any movement detected. This is done by noting the signal during the time when there is no movement. The power of signal will be steady during that time. However, if there are any obstacles within the range, the signal will change and motion will be detected.

The results of the provided system were a fall of received signals with kind of variation. The amount of reduction in signal was greater if there were more walkers. However, the fixed threshold for distinguishing exact number of people could not be calculated. Apart from counting exact number of people, the system is limited to fixed passage, which means a very small area to only check entry and exit of people.

1.3.2 Camera surveillance system [2]

The camera surveillance system requires both camera and PIR sensors. PIR sensors along with camera switches on the camera when there is movement detected in the area. Later the sensor will check the motion and moment of people. This sensor with program can distinguish between ordinary movement of people. The camera can count the number of people in area by facial recognition and the data will be transferred to PC. If there are no movements detected by the PIR sensor, the camera will automatically switch off.

Given system could be utilizing less energy, since the camera is only on during the movement. However, due to the limited range of sensor's detection and angle of camera setup, the area of detection will be relatively small. This system also might be less accurate, as the camera is entailed for counting number of people. If there is less light present in the area, the system may not have good detection rate.

1.3.3 Human target detection, tracking, and classification using 24-GHZ FMCW radar [3]

This journal paper is about signal processing algorithms that are required for human target detection, tracking, and classification. This journal uses the same MMIC as our project, which is BGT24MTR12. This journal consists of both hardware and software part of the system. Since our project is interested in its algorithm part, moving target detection part will be our scope (chapter IV of the paper). Whole system is very similar to our project as all radar system follow the similar concept (transceiver → FFT → tracking algorithm).

Human detection part of the paper starts with moving target indication filtering. It is a linear filtering that allows the system to distinguish moving target from static targets such as wall and tree. It uses other techniques such as chirp data combination and Doppler compensated angle of arrival for higher accuracy of human detection. There are several mathematical models for human tracking. This part is to estimate target's location. It suggests 1) target management and 2) track filtering. For track filtering, alpha-beta filter is used. In human classification part, which might or might not be included in our project, gives statistical model for distinguishing human from quasi-static targets such as trees.

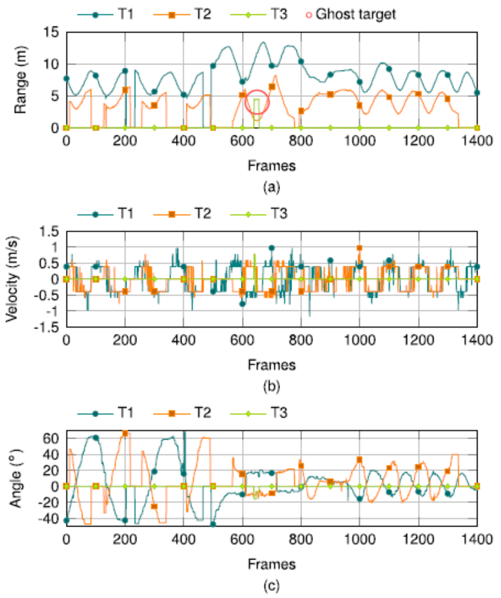


Fig. 17. (a) Range, (b) velocity, and (c) angle as tracking results for two moving persons.

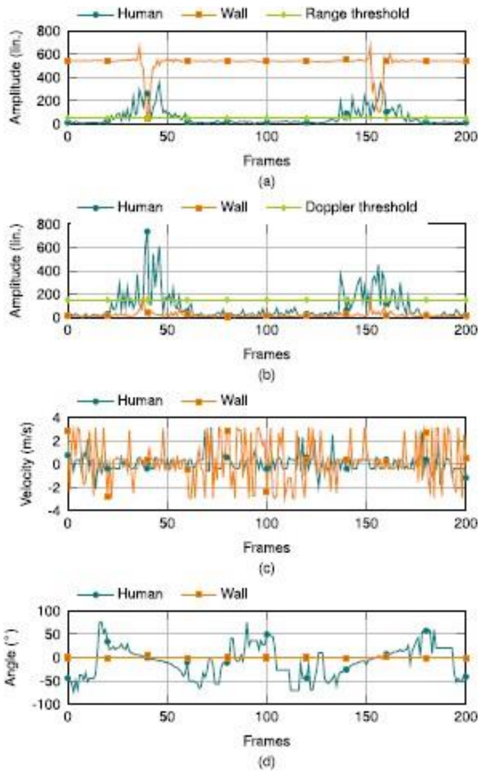


Figure 1: example of Figures in the paper

In each part of this paper, it gives good results. Figure 1 from this paper gives a good insight how the values should be like to see if there is any error. In addition, it gives good idea of how experiment should be done. Seeing how human targets are identified using various data such as amplitude, velocity, and angle is interesting.

1.4 Objectives

1.4.1 Main Objective

This project is to design FMCW radar system that can successfully detect and track moving human targets using signal processing techniques and algorithms

1.4.2 Objective Statement

- To process received signals using FFT and identify necessary information regarding a moving object.

  Received signals can be acquired from transceiver output that is integrated within position2go demo board. Digitized frame-domain output should be converted to frequency-domain by applying FFT, and an object can be detected by finding peak frequency according to radar theory. This also helps to calculated distance, angle, and velocity of the moving object as well.

- Establishing basic object detecting algorithm for single and multiple persons.

  Object detecting algorithm can be established by comparing human data with other types of obstacles in frequency domain. Detecting multiple targets uses similar approach. Specific threshold value should be established for both human detecting algorithm and multiple human detecting algorithm.

- Apply human tracking algorithm

1.5 ECE Knowledge

ELEC5280 (high frequency integrated circuit): this course is mainly about RF-front end. This is very helpful understanding structure of radar sensor used since itself is a transceiver (transmit and receive signal). This course also has a communication system part where it elaborates on modulated signal. Frequency modulation used in FMCW radar is widely used technique in communications.

ELEC3600 (radio frequency engineering/electromagnetics): this course is about wave equations. It is helpful understanding waves used in radar.

ELEC3300 (Introduction to Embedded Systems): this course helps to understand about functionality of embedded system. In this course, one can learn how to build and design modules in embedded system and also build algorithm to link the modules and make the whole system functional.

ELEC3100 (digital communication): signal processing techniques including Fast Fourier Transform (FFT)

2) Methodology

2.1 Overview of the Main Objectives

2.1.1 Main Objective Diagram

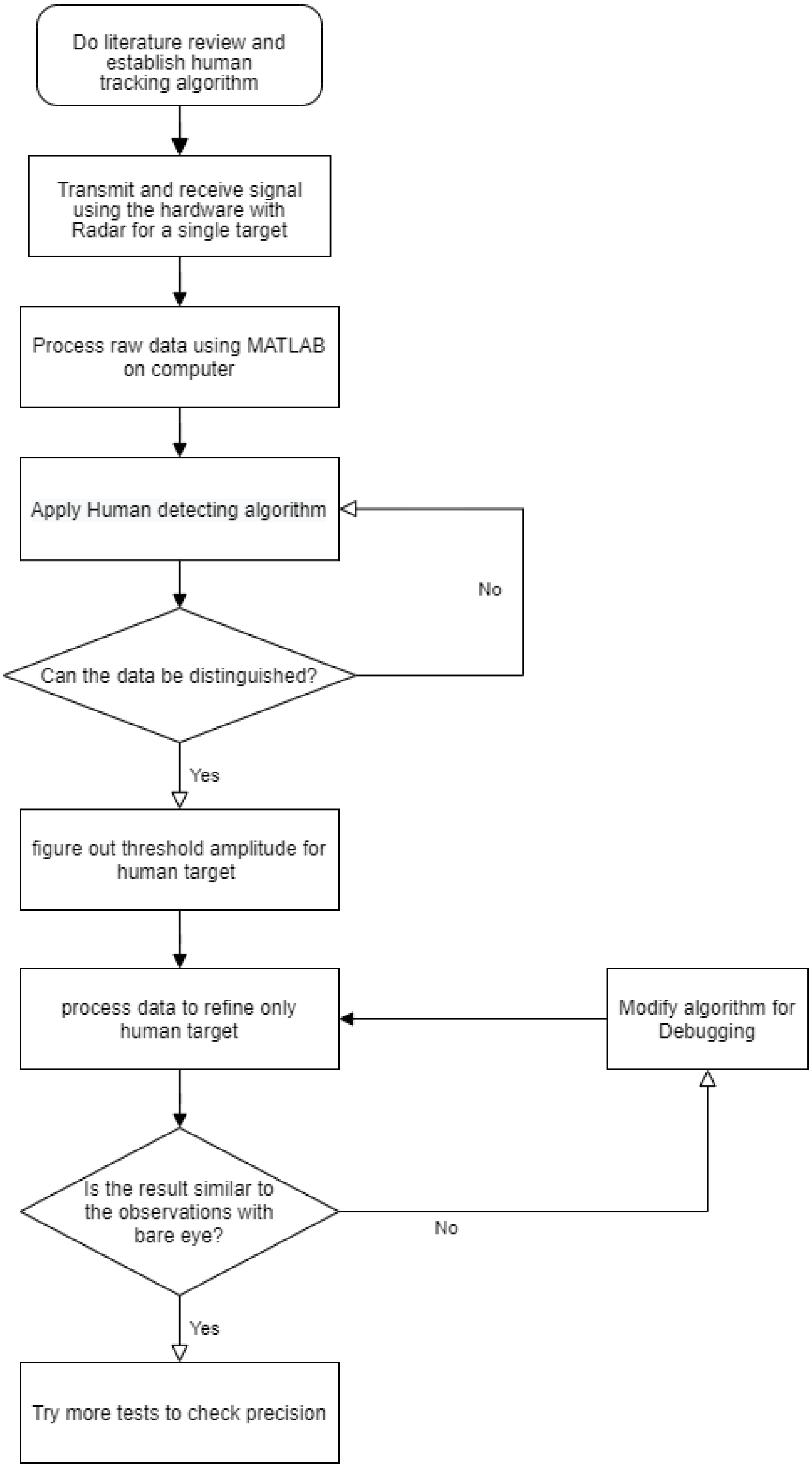


Figure 2: flowchart for progress

In this project, we make use of Position2Go board which is a radar demo board produced by Infineon as a radar sensor to detect moving object. It is based on operation of BGT24MTR11, a silicon germanium (SiGe) MMIC. It is a comprehensive tool that includes both transceiver and MCU. Thus, data can be easily processed by user. Figure 3 is a system level block diagram that well describes how this radar board works.

As described in Figure 2, human detection and tracking process starts from hardware setting to transmit and receive radar signal after doing literature review on tracking algorithms. Once received signal is available at the transceiver integrated on board, raw data output is accessible to users, so that we can interpret this signal and process. At this point, we should understand hardware operation of hardware board to understand raw data output and have a sense on what those data represent.

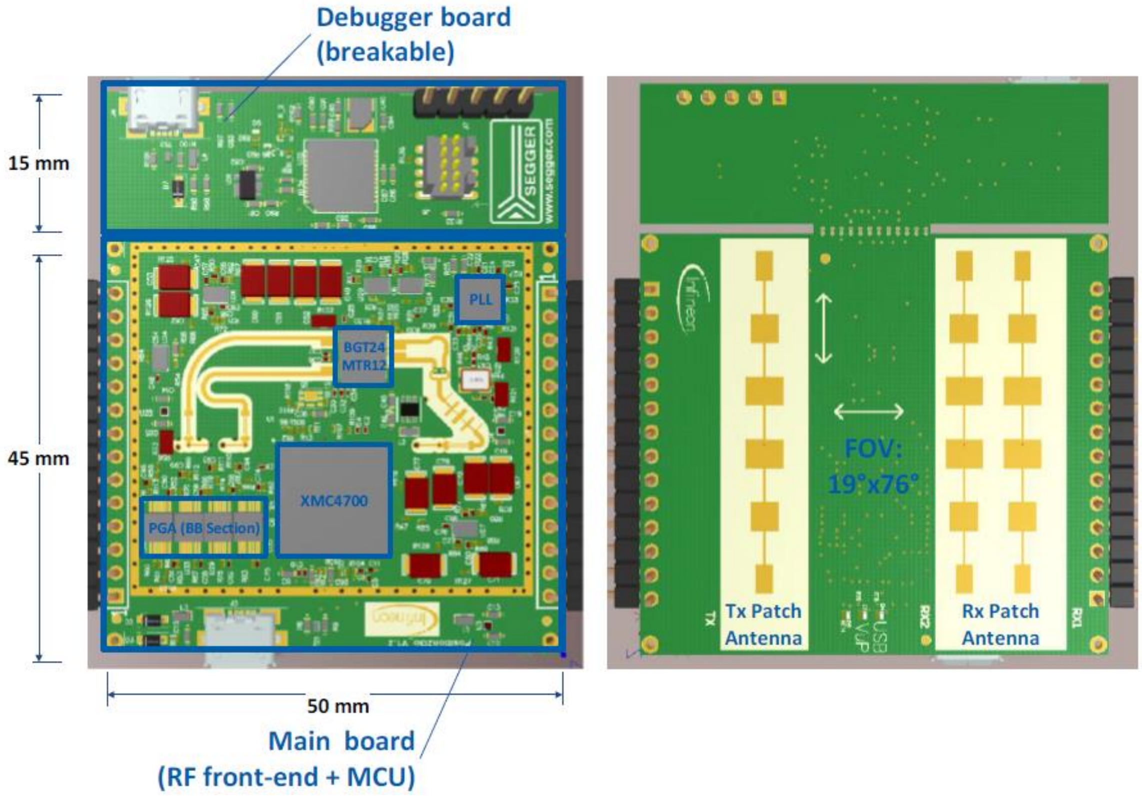


Figure 3: Appearance of Position2Go board (Left: Printed Circuit Board (PCB); Right: Antenna)

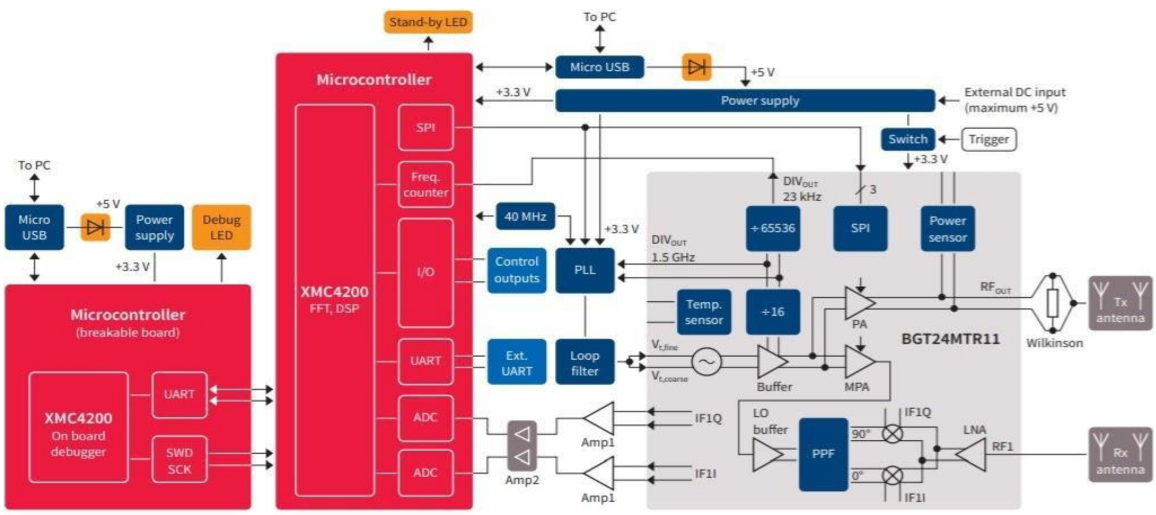


Figure 4: Block diagram of Position2Go board

Shown in Figure 3&4, BGT24MTR11 is type of a RF transceiver which transmits and receive signals. 24G Hz signal, center frequency at which this system works, is generated by Phase Locked Loop (PLL) and loop filter as a sinusoidal wave. This wave is amplified by Power Amplifier (PA) since signal goes through attenuation that it loses its magnitude (power) propagating in non-free space medium. When a signal is reflected from an object, it is sensed by the Rx antenna. In receiver architecture, bottom part of the block diagram, Low Noise Amplifier (LNA) is the first element. This is because first element in the cascaded system has a largest influence on noise Figure (NF). Then this signal is modified to intermediate frequency (IF). This is because it is difficult to directly convert the frequency to baseband. Mixing at phase difference at 90 degree is for image rejection. These I/Q signals are converted to digital using ADC since signal processing in digital domain is much easier than it in analog domain. After receiving signals in digital domain, microcontroller is used.

Therefore, received signal is in digital form where dependent variable is magnitude and independent variable is frame time. To fully understand theory behind FMCW operation of position2go, more elaboration is needed. Detailed operation FMCW radar is addressed in section 2.2. In signal processing and data manipulation phase (i), this received signal should analyzed in frequency domain as it is much easier to analyze signals in frequency domain. This process is done by applying FFT. What should be noted is that when radar signal is reflected off an object, stronger signal should be arrived at the antenna. This means that when there is an obstacle, magnitude of received signal would be comparably higher at certain frequency component, and this frequency component is called beat frequency. Once we establish method to detect an object, our next step is to measure different types of object including human target and compare empirical data of those to establish human detecting algorithm in human detection phase (ii). At last, in human tracking phase (iii), human targets are not properly tracked (specifically at equidistance in this project), requiring more advanced tracking algorithms. During the process, if the algorithm does not work as expected, debugging codes are required before proceeding to the next step.

Once human detection and tracking algorithm is fully developed, the system will apply those algorithms to the raw data and check if number of human targets inside the surveillance area.

MATLAB will be used for processing raw data as it is a convenient tool that is widely used. Basically, human detecting and tracking algorithms can be written as codes. To do this, deep understanding of radar signals is required as raw data are in form of EM signal. Moreover, several step-by-step procedures are required, as it is depicted in Figure 4. When addressing real-time data, c++ based GUI software is developed. This automatically presents number of targets detected, distance of the moving object, time-domain raw data, and other useful information. Summary of our process is described in Figure 6. After radar sensor detects a moving object, its raw data will be extracted. This data will be automatically processed by pre-established human detection and tracking algorithms accordingly. We make use of indoor environment for initial model development, and outdoor environment (HKUST Lawn Area) for the actual measurement to see the performance of our algorithms.

2.1.2 Components List

Items*	Specifications/Model
Position2Go	Including BGT24MTR11 (MMIC), MCU, micro USB port, and antenna

2.2 Objective Statement

2.2.1 To process received signals using FFT and identify necessary information regarding a moving object.

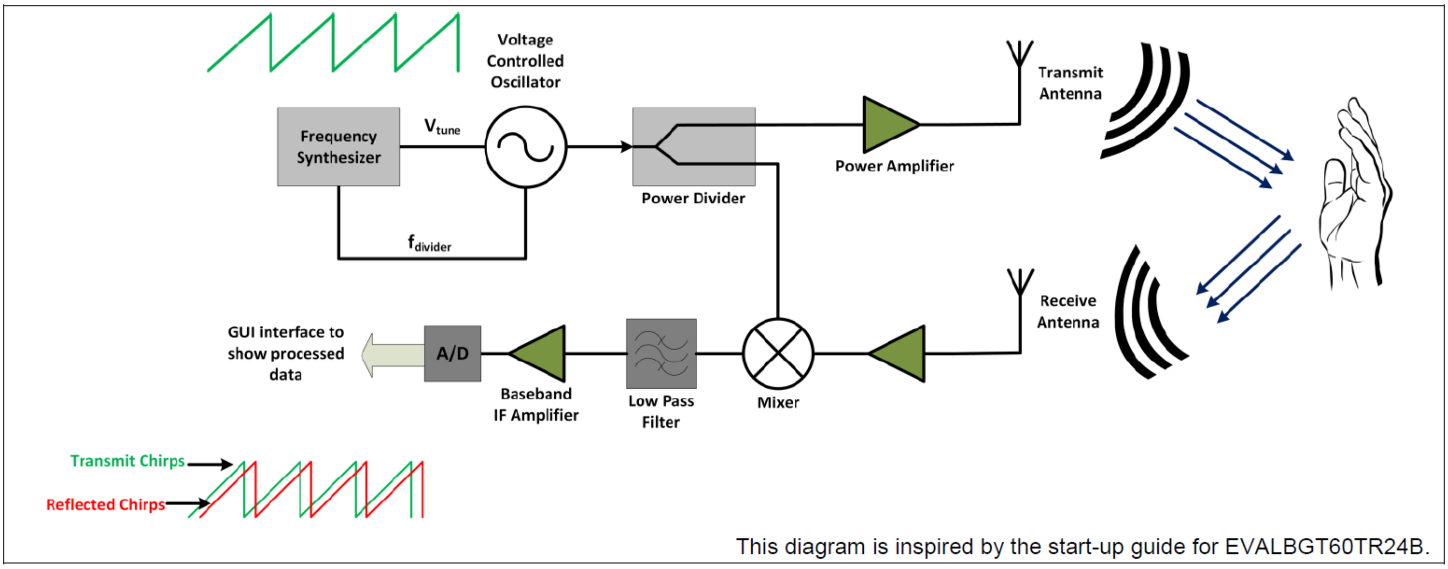


Figure 5: General FMCW radar system

Although a more detailed diagram of the entire radar system is described in Figure 4, the above diagram shows a simplified view of a FMCW radar system. It is crucial to understand how FMCW system works in order to process raw data extracted from the radar and lead to meaningful results.

Transmission of data is modulated by controlling VCO frequency through feedback loop, thus increasing and decreasing transmitting frequency in the time-domain. This periodical movement of signal is referred as chirps in the time-domain. As described in Figure 5, output of radar would be digital form of continuous wave. Therefore, we can expect that raw data extracted would be a digital complex number where its y-axis would be magnitude of signal and x-axis would sample.

Parameter	**Description**	**Default**	**Valid range**
	General configurations		
FW_MODULATION_TYPE	Firmware modulation type, Doppler [0] or FMCW [1]	1	[0 to 1]
NUM_OF_CHIRPS	Valid range of chirps in relation to the DATA_SIZE	16	[1 to 64]
SAMPLES_PER_CHIRP	Size of IQ raw ADC buffer	64	[32 to 256]
FRAME_PERIOD_MSEC	Time period of one frame to capture data (units in ms)	150	[50 to ...]

Figure 6: Default values of radar in FMCW mode

Figure 6 shows that there are 64 samples in one chirp and total of 16 chirps in one frame (transmission).

```
val(:,:,1) =

   0.5101 + 0.4911i   0.4720 + 0.5932i
   0.5092 + 0.4791i   0.4381 + 0.6838i
   0.5035 + 0.4779i   0.4227 + 0.7167i
   0.4969 + 0.4801i   0.4230 + 0.7184i
   0.4913 + 0.4840i   0.4252 + 0.7079i
   0.4830 + 0.4911i   0.4315 + 0.6911i
   0.4757 + 0.4979i   0.4364 + 0.6723i
   0.4647 + 0.4950i   0.4422 + 0.6503i
   0.4571 + 0.4877i   0.4501 + 0.6269i
   0.4574 + 0.4777i   0.4557 + 0.6122i
   0.4615 + 0.4674i   0.4628 + 0.5985i
```

Figure 7: example of raw data extracted

It is remarked that there are two sets of data from left to right. As it is visible on Figure 7, two data sets are extracted as there are two antennas embedded in RF transceiver. Use of this point would be crucial in later part of this project.

In this section, raw data will be processed in both the time and frequency domain and see subtleties within the data and how we can build detection algorithms based on given data. Also, fundamental theories will be addressed to emphasize the importance of each analysis and parameters that we discuss. Matlab software was used for programming purposes.

2.2.1.1 Specific Task 1 (Jaemoo Ahn): acquire and process raw data from radar demo board using FFT and radar theory to establish draft version of moving object detection model

To establish a basic algorithm, a single moving person was measured from certain distance away from the radar. Its simulation data would be evaluated in comparison with the actual data in 2.2.1.3. Measured data is shown in Figure 8.

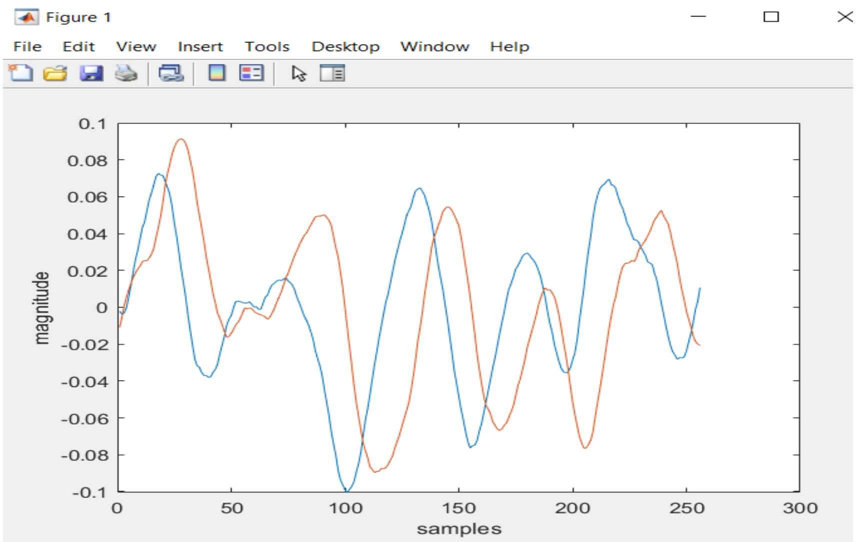


Figure 8: raw data in sample(time)-domain

Red and blue lines represent I and Q channel respectively. In orthogonal multiplexing system, more information can be derived from the usage of complex numbers. I is the real part and Q is the complex part of the raw data. It is obvious that there are 256 samples in one chirp, and this only shows a single chirp result of the system. Practical radar systems work in real-time; however, it is enough to analyze a single chirp data in this case.

For an ideal case, both signals should be in sinusoidal shape if we remind ourselves of wave equations from electromagnetics theory. However, if there are noises in the channel, possible reflections could occur from other objects, and many other potential limitations. Another point is that both I and Q signals are merely phase shifted signals. We can notice that if I signal lags Q signal, then the moving object is departing from the radar, vice versa. It can be easily understood if we think of complex numbers in frequency domain. In Figure 8, Q lags I and the object is moving toward the radar sensor.

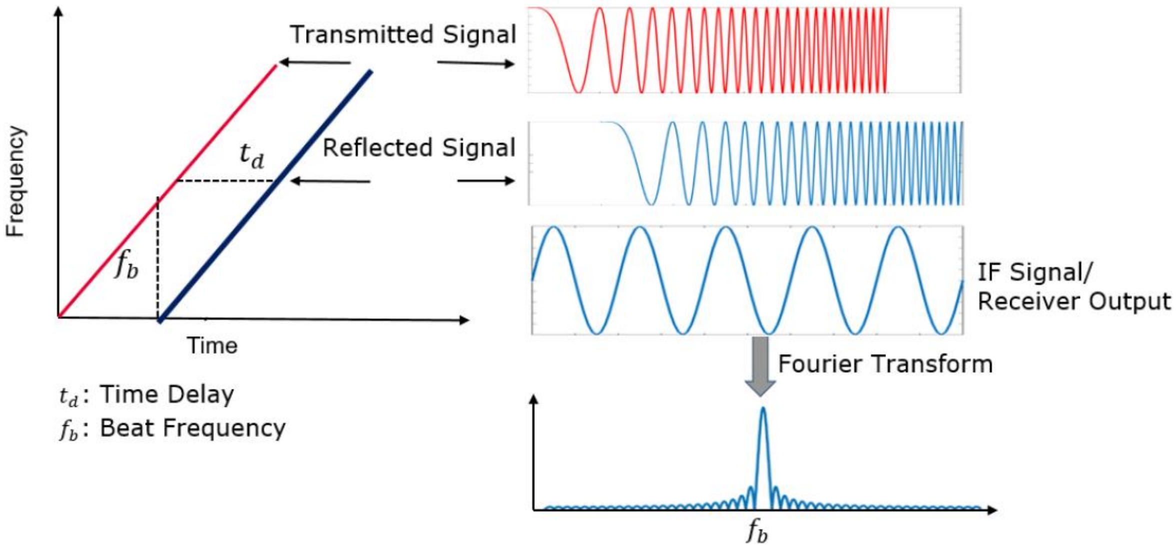


Figure 9: FMCW system in frequency domain

In order to detect an object from the radar, it is necessary to express received data in frequency domain. This is because if a signal is reflected by an object, its magnitude would be high compared to other frequency components. This frequency is called beat frequency in which highest peak is detected. Fast Fourier Transform (FFT) can be applied to change time domain data in frequency domain. The basic idea of how FFT is performed is depicted on Figure 9 Before applying FFT, DC value should be removed by applying filter that rejects mean value of the data.

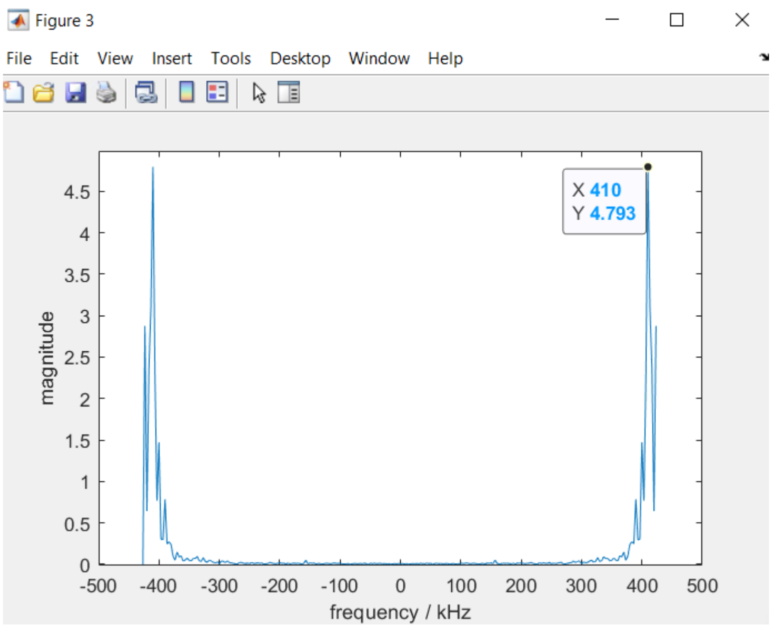


Figure 10: FFT result of single moving person

From this frequency response Figure, clearly there is a peak at 410kHz for a single moving object. Using this peak frequency, distance between an object can be calculated using following expression:

$$R = \frac{C \times Tc \times fb}{2B}$$

where R= target distance, C = speed of light, Tc = up-chirp time, fb = beat frequency, B = Bandwidth.

FMCW configurations			
FMCW_SUPPORTED	Comment/uncomment this macro, to enable/disable FMCW support	-	N.A.
BANDWIDTH_MHZ	The bandwidth range is defined as the difference between the minimum and maximum RF frequencies of a device (units in MHz)	200	[1 to 200]
CHIRP_TIME_USEC	Up-chirp time (units in µs) Note: Down-chirp time (100 µs) and chirp time delay (100 µs) are fixed	300	[50 to 3000]

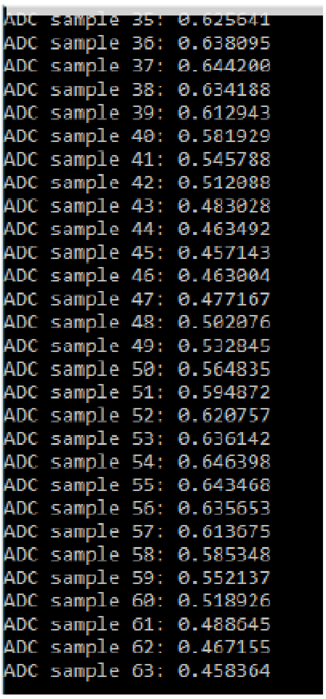
Figure 11: FMCW Configuration

Using default value, target distance can be calculated as shown in Figure 10 and Figure 11 In 2.2.1.5, accuracy of this approach regarding distance will be analyzed. Cases that multiple moving objects share same frequency response as a single version will be discussed in 2.2.2 and 2.2.3.

2.2.1.2 Specific Task 2 (Kijun Yu): Write codes in C language

The analogue data collected by the antenna were sent to ADC (analogue to digital converter) which is present in the Position2Go device (radar) used for our project. To analyze the data in detail, it first had to be collected and visualized as numbers on the computer screen. The data from radar was collected and displayed on the screen with help of the C programming language. Also, by modifying the provided libraries from the manufacturer and C itself, it was possible to collect the data for saving purposes which can be analyzed later and even display on the screen to monitor the situation in real-time.

First, the code was written to detect the radar connection to one of the laptop computers (our own) for testing the device and display data on the monitor of the computer to which the radar was connected. To do this, an algorithm was built to initially scan all possible USB connections present in the computer and list out the active connection. Then the program specified the incoming data from each of those connections to locate which one is giving the data inflow of radar from part 2.2.1. The real-time display of collected data is visible in figure 12.



```
ADC sample 35: 0.625641
ADC sample 36: 0.638095
ADC sample 37: 0.644200
ADC sample 38: 0.634188
ADC sample 39: 0.612943
ADC sample 40: 0.581929
ADC sample 41: 0.545788
ADC sample 42: 0.512088
ADC sample 43: 0.483028
ADC sample 44: 0.463492
ADC sample 45: 0.457143
ADC sample 46: 0.463004
ADC sample 47: 0.477167
ADC sample 48: 0.502076
ADC sample 49: 0.532845
ADC sample 50: 0.564835
ADC sample 51: 0.594872
ADC sample 52: 0.620757
ADC sample 53: 0.636142
ADC sample 54: 0.646398
ADC sample 55: 0.643468
ADC sample 56: 0.635653
ADC sample 57: 0.613675
ADC sample 58: 0.585348
ADC sample 59: 0.552137
ADC sample 60: 0.518926
ADC sample 61: 0.488645
ADC sample 62: 0.467155
ADC sample 63: 0.458364
```

Figure 12: Real-time display of data collection

After the proper connection was detected by the program, the incoming data was translated to human-readable numbers. Which was then displayed on the command screen (Terminal) and saved into the text file at the same time. The saved text file could be further studied by the algorithm to enhance the job of distinguishing between normal objects and human movements.

2.2.1.3 Objective Statement Evaluation

In order to test validity of our initial method, we calculated distance from our processed data and compared this with the actual value. This result is to check if our system detected right object, so we expected accuracy of 95% and above.


Figure 13: Measurement was done in HKUST Lawn Area

Actual Distance (m)	5	10	15	20	25
Calculated Distance (m)	5.04	9.87	15.33	19.21	24.17
Accuracy (%)	99.2	98.7	97.8	96.05	96.68

Figure 14: target distance measurement result

Calculated target distance is close to the actual value. (Shown in figure 14) From beat frequency, velocity and angle of moving object can also be calculated. In surveillance application, target distance is the major parameter. Use of angle will be addressed in later part of this report. These tests were taken at HKUST Lawn Area (Figure 13)

It was not an easy process to work together for the project. Due to the pandemic, our group could not meet up physically to work together on the project. The one working with radar to collect data had to look for a person to provide help as it was a project based on human detection. Even planning and writing code was not an easy process as live debugging could not be carried out.

However, the experiments and research for several algorithms were carried out separately and through online media, the idea and results were shared. Doing so, it was possible to overcome the difficulties somehow and continue to work as a group.

The calculations and detection have the possibility of not being perfectly ideal. It would be best to experiment with an anechoic chamber and only a human was present to detect. Yet, the experiment was carried out in a computer barn and there were many different objects other than the specific target for monitoring. To overcome this issue. The collected data were filtered according to frequency and amplitude to only refine the data based on human detection. The details of how it is detected and filtered are discussed in later parts of the report.

2.2.2 Establishing basic object detecting algorithm for single and multiple persons

In outdoor environment, there can be different types of obstacles that can possibly reflect radar signals and be interpreted as an object. However, our scope is to identify moving human targets only. Therefore, we should compare human data with other quasi-static objects and figure out method to detect human target.

First, signal processing should be done for non-human objects.

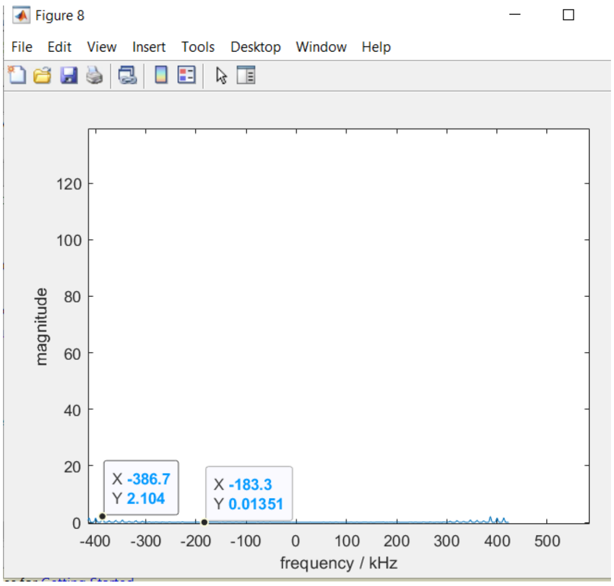


Figure 15: Frequency response of plants

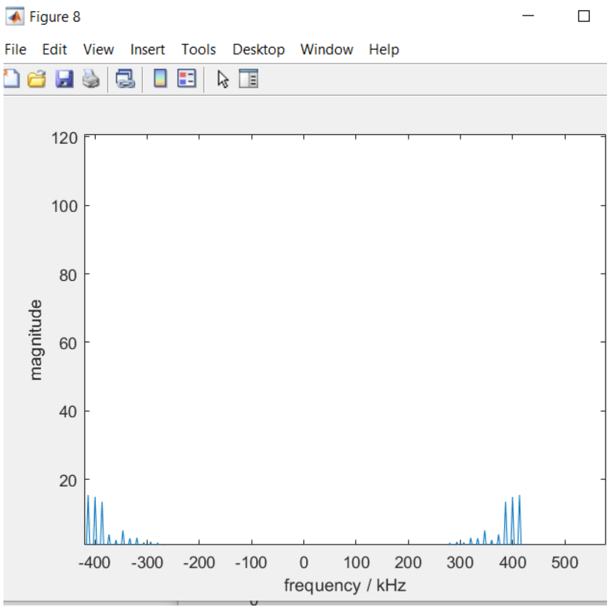


Figure 16: Frequency response of walls

These are the examples of when non-human targets are reflected by FMCW radar signal. On the Figure 15 and 16 it is visible that static or quasi-static objects shows evenly distributed magnitudes at different frequencies. This gives insights regarding how human detecting algorithms should be done. Assuming multiple types of objects are within detecting range, there should be an algorithm to filter out non-human targets with smaller magnitude without any outstanding peaks. Analysis of this effect and specific algorithms established would be addressed in following sections. For wall, magnitudes are much higher compared to the plants. This would not be an issue for open area that we make experiments on. Also, this data was derived for walls that are very close to the sensor. Its magnitude can be further suppressed by described in following section.

Compared to moving human, static or quasi-static shows evenly distributed magnitudes at different frequencies.

2.2.2.1 Specific Task 1 (Jaemoo Ahn): measure different types of objects and compare FFT results of those objects to establish method to differentiate human targets from other objects

I/Q data represents magnitudes of real and imaginary part of extracted raw data.

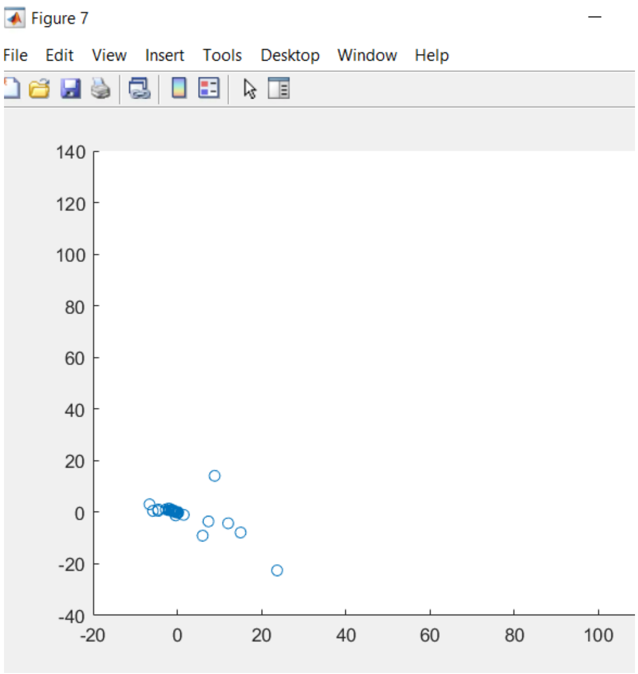


Figure 17: I/Q data of static/quasi-static object

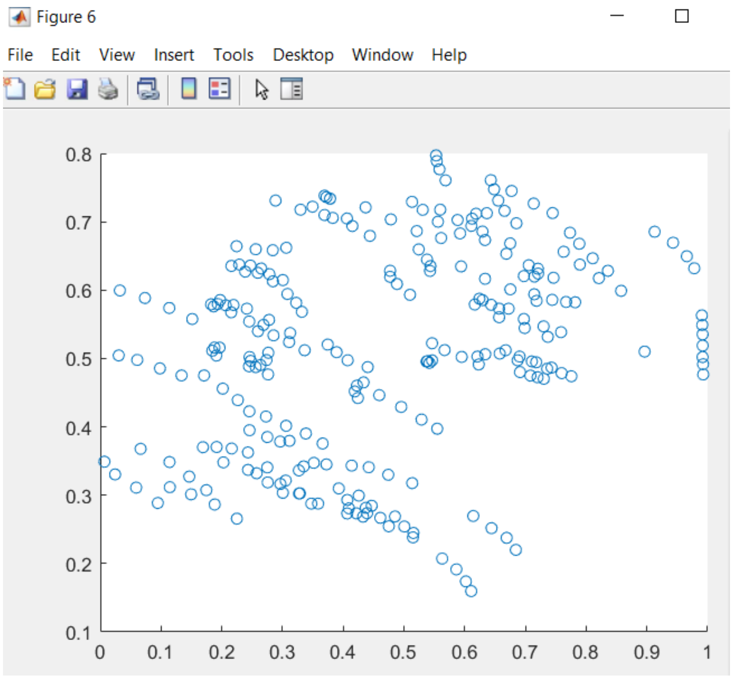


Figure 18: I/Q data of moving object

As plotted in Figure 17 & 18, moving objects show less tendency to be concentrated in a single point. This is obvious since moving objects will show varying magnitudes and phases of reflected signals to the radar. And this information will be transferred into a single outstanding frequency component in the frequency-domain. Therefore, beat frequency component of human target will be much higher compared to any obstacles. Regarding non-human targets as noise in signal processing perspective, DC removing filter will further suppress its magnitudes.

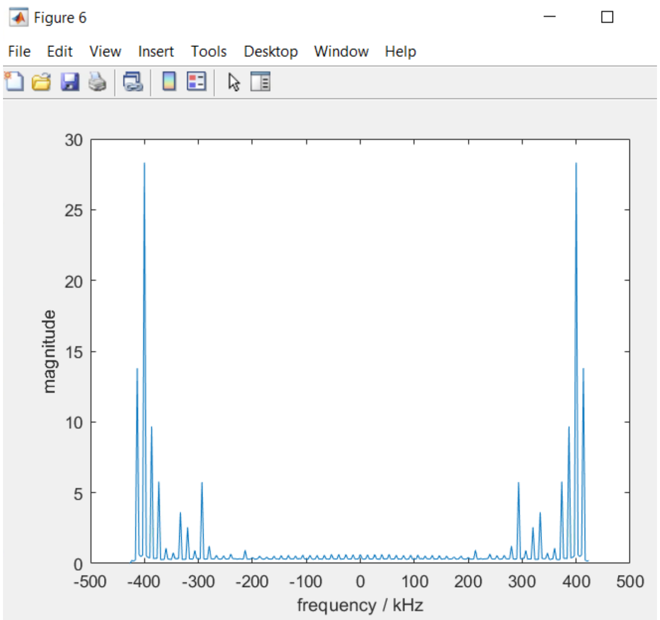


Figure 19 two moving targets trail 1

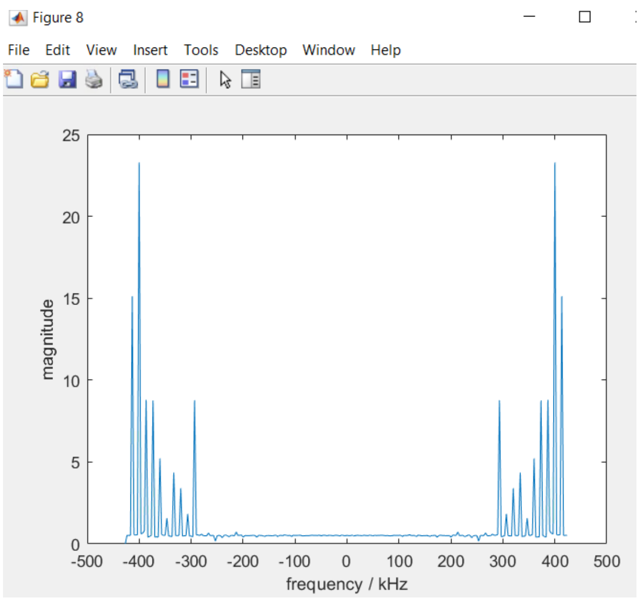


Figure 20: *two moving targets trail 2*

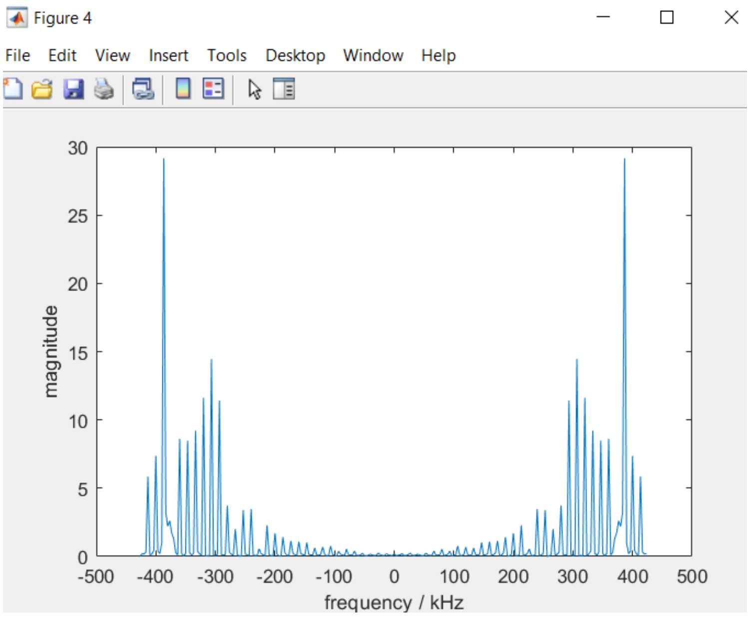


Figure 21: measurement result for two moving targets trails 3

These are the measurement results for two moving targets. For Figure 19 & 20, two peaks are appeared at beat frequency that is close to each other. For Figure 21, second target detected was further away from the first target. Although we didn't note down the exact distance for this sample data, the second target was located further and further for each trial, so the results are coherent. At peaks, both magnitudes are all above 14. The threshold magnitude is set to be 13 to give some margin. One problem is that near beat frequencies, there are large frequency components. Special algorithms are needed to suppress interference near beat frequencies because if these components are above threshold magnitudes, they will be counted as human targets.

These results are sample data that are not measured in the lawn area. Thus, there could be multiple reflections from unexpected objects. Thus, a complete experiment will be done after 2.2.3 human tracking algorithms as section 2.2.3 is comprehensive one that adds on what is addressed in this section.

2.2.2.2 Specific Task 2 (Kijun YU): Building human counting algorithm

Based on the works done above the algorithm had to be built only to count humans as objects. To do this, the algorithm should be designed in a way, that the processed data will not include any signals from other objects and environmental noise. The main flowchart of the developing algorithm is shown in Figure 22

The initial environment should be checked beforehand to evaluate the initial state of the target area. This data needs to be studied to design a DC filter for removing the possible noise present in the space. Given that the initial state had no movements and there are some obstacles present, the initial data will contain all the information of such a case. Once we filter out these data from testing the actual human targets, the visualized data will be clear compared to the tests done above.

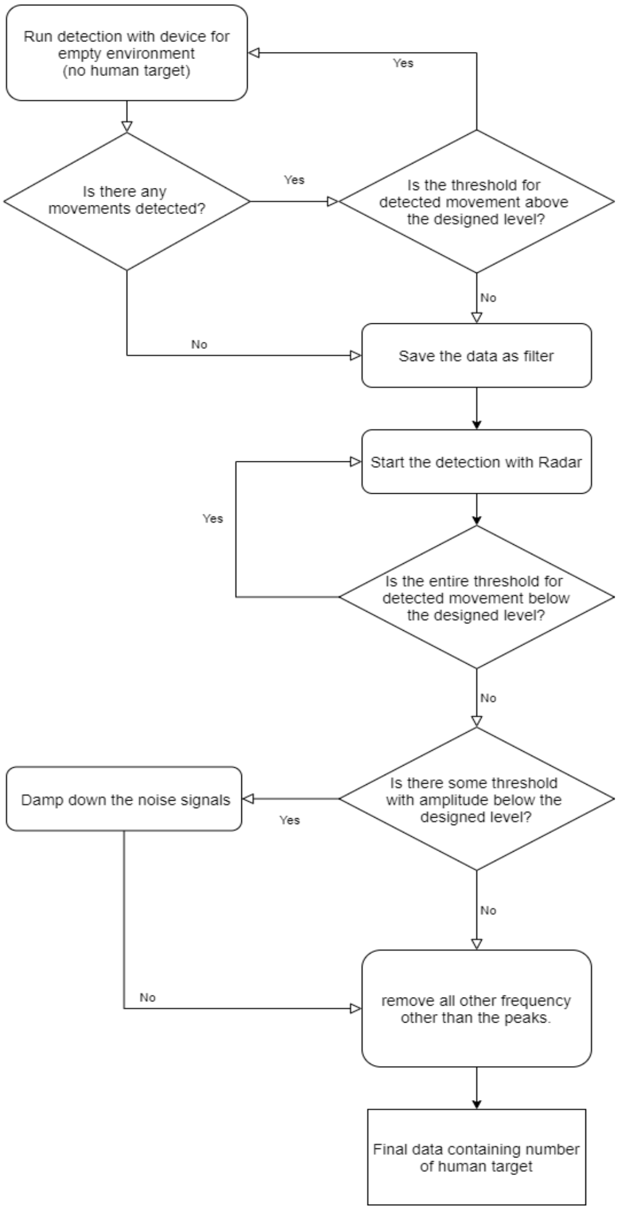


Figure 22: Flowchart for the human detecting algorithm

Also, as it is mentioned in part 2.2.2.1 the threshold for human target can be predefined to amplify the signals above that level and damp other signals with less amplitude. By doing so, it will be made easier to distinguish the signal reflected from human target and other signals from various objects present in the target area. Above is the algorithm outline flowchart for getting better result for human detection with the setup device.

2.2.2.3 Objective Statement 2 Evaluation

For the given set of sample data that are collected, the data depicts an accurately detected number of humans present inside the designated area. However, if we increase the number of trials, there would be high inaccuracy for the reasons described in the technical challenges part of this section. We decided that meaningful experiment should be done after combining these detecting algorithms and the tracking algorithms.

Nevertheless, this section shows the worst case and compare how moving human target shows different data apart from other objects. It well differentiates human targets from other objects such as plants and walls that are not very close to the radar sensor. Moreover, those signals reflected from non-human targets can be further suppressed so that human targets are solely detected. Complete Evaluation will be done in section 2.2.3.3.

Finding the appropriate threshold magnitude and identifying the correct beat frequency was a challenging part of this section. There were many limitations such as moving targets at a similar distance, the obstacle that is very close to the radar sensor, and unwanted reflections. We made this experiment in an environment that is far from an ideal case on purpose. We wanted to consider the worst case in which many unwanted signals are received to the sensor so that we could develop algorithms to filter out those signals. Still, this result cannot be accurate as we need special human tracking algorithms that will be developed in section 2.2.3. When the human detecting algorithm is combined with the tracking algorithm that will be developed in the following weeks, we expect to present meaningful outcomes. As for now, radar sensors cannot differentiate targets at a similar distance. It is unclear for us to determine if the peak frequency represents a single target or not. Moreover, frequency components near the beat frequency might represent another human target although we intentionally filter them out. This unclarity is resolved in the next section.

2.2.3 Apply human tracking algorithm

As addressed in section 2.2.2, differentiating human targets from static objects is not a major issue. More challenging part is accurately calculating the number of people that are close to each other. To be more specific, moving objects with equal distance from the radar is the challenge. This is because beat frequency reveals information about objects, especially their distance. Equal distance away from radar sensor means equal beat frequency will be found. This means it is difficult to identify accurate number of persons. Fortunately, inside the RF transceiver, there are two antennas Rx1 and Rx2. Two sets of raw data will lead to two sets of similar frequency response and distance. Difference is their angle in respect to the sensor. If the detected objects is a single person, the angle should be the same, or highly correlated. If multiple objects are detected, angle should be different. Solving this concern is the interest of our human tracking algorithm.

Figure 23: example of inaccurate detection of targets at equal distance using Infineon radar software

2.2.3.1 Specific Task 1 (Jaemoo Ahn): calculate target angle using two sets of raw data from Tx1 and Tx2

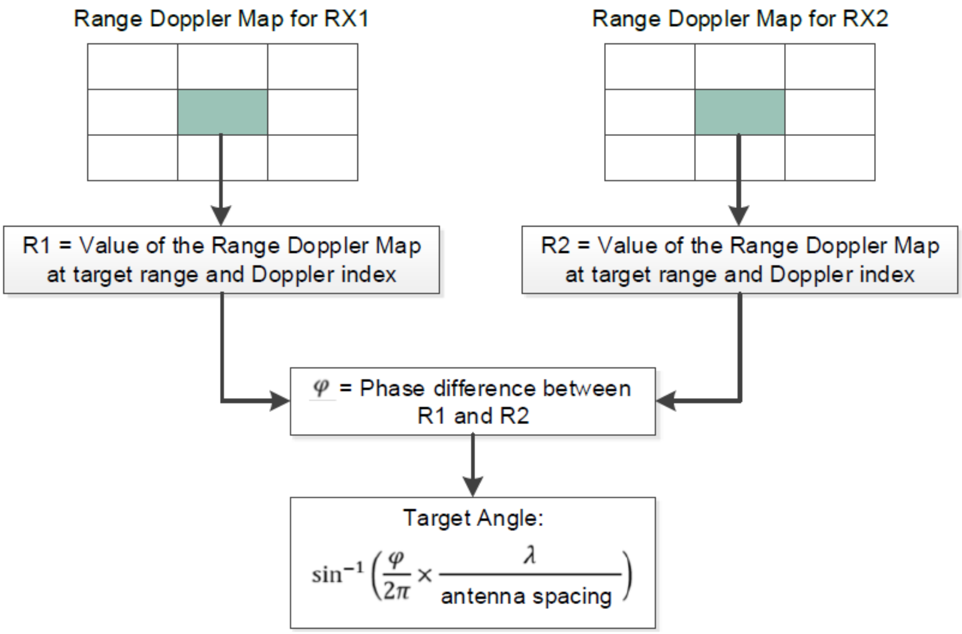


Figure 24: calculation of target angle from received raw data

$$\lambda = wavelength = \frac{c}{f}, where\ c = \ speed\ of\ light = 3\ \times 10^8\ and\ f = beat\ frequency$$

$$Antenna\ spacing\ \approx\ 5mm$$

Phase difference can be calculated by phase difference of two time-domain data received by each of the antenna as shown in Figure 24 (Rx1 and Rx2). The phase difference can be further utilized to calculate radial velocity of moving target. Radial velocity could be useful for further application; however, this is outside the scope of this project.

$$\boxed{\Delta\omega = \frac{4\,\pi v_r\, T_c}{\lambda}}$$

$\Delta\omega$: Change in phase [rad]

v_r : Radial velocity of moving target [m/s]

T_c : Chirp duration [s]

λ : Wavelength [m]

Figure 25: equation for change in phase using Doppler estimation

Finally, if target angle is larger than threshold angle, it means there are more than one object at same distance from the radar board. This prevents potential misdetection of number of targets at equidistance and correct number of targets can be tracked. For example, if two moving human targets are detected and suddenly one of the targets disappear from the detection without going out of the detection range, system automatically calculate target angle and decide if two targets are at equidistance, and keep the number of human targets as two.

For experiment, two moving human targets at equal distance from the radar board was measured. Algorithm with and without tracking algorithm were used, and this result was compared with Infineon Software that contains human tracking algorithms. We measured number of targets tracked at different distance from 5m to 25m, and did three trials for each. Summary table of tracking result is presented in evaluation part.

2.2.3.2 Specific Task 2 (Kijun YU): Visualize data into graph

In Section 2.2.2 the single antenna could only detect the presence of a human target in designated area. However, if 2 antennae are used the collected data from each antenna can be processed with equation in figure 25 to get distance and angle of the detected human target. The in-built basic libraries for any programing language are not very precise in carrying out such equations for certain decimal units. Therefore, it will be important to use some enhanced libraries to make more precise calculation for the above equations. Libraries such as “math.h” contains some functions to ease the trigonometric calculations and GSL has computational functions for applied math and sciences.

The equations were studied in detail to visualize the collected data on screen. Since, the data could not be collected at real-time the saved dataset from tests done by Jaemoo was used to visualize it on screen (further discussed on section 2.2.3.4). The collected data from several tests were not in good format. Hence, the first codes were written to arrange the data in good shape so that the data can be easily depicted on screen. To do this the Pandas library from python language was used to first read the data into table format, and compare the data shapes to match frequency values along with magnitude values from each antenna. The output of this data process resulted in clearly arranged format where the magnitudes could be compared for each frequency value. The idea of how data looks is shown in figure 26.

Frequency/kHz	**Antenna1**	**Antenna2**
0	6.5	6.6
10	7.7	7.9

Figure 26: Sample data set example

After the data is arranged. The GUI system for visualizing graphs and explanation of each data graph had to be placed on the program. The outlook of our own GUI program for data is shown in figure 27. The user of GUI program first inserts the number of data set by typing in the number and clicks on Read Data button. The comparison of data from two antenna is put on top parts with variable phase shifts (time-based graph). The below parts of GUI show the threshold of human target detected with frequency-based data of two antenna.

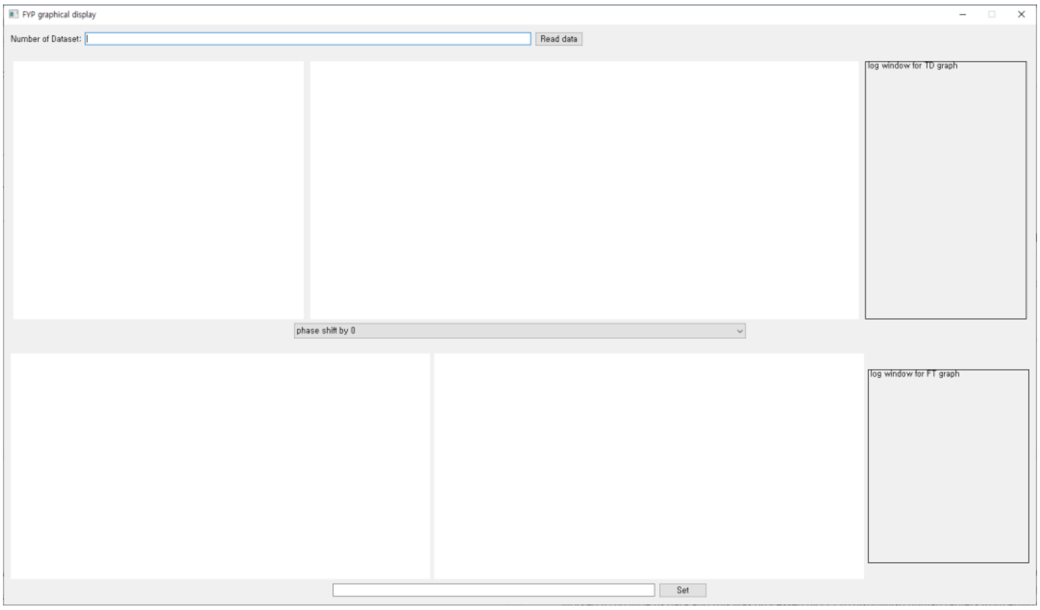


Figure 27: GUI display screen

2.2.3.3 Objective statement 3 Evaluation:

As soon as the number is inserted the program will compare the values from 2 antennae and figure out how much frameshift will give the most equalized data. The data from antenna 1 is put on the x-axis of the graph and data from antenna 2 on the y-axis. These 2 data are plotted as a scattered graph. The shift in frame number for data of antenna 2 will change the look of the graph at each time. The best fit of frameshift is decided when the average distance of each plotted point is closest to the x=y line (red line on the graph). Since the angle deviation depends on the frameshift, each test will have the best fit of different frame numbers. The difference of the graph at certain frameshift is shown in figure 28 and Figure 29. As it is visible in figure 29, the best fit data show a clear relation between scatter plot of data and sinusoidal graph of data from two antennae.

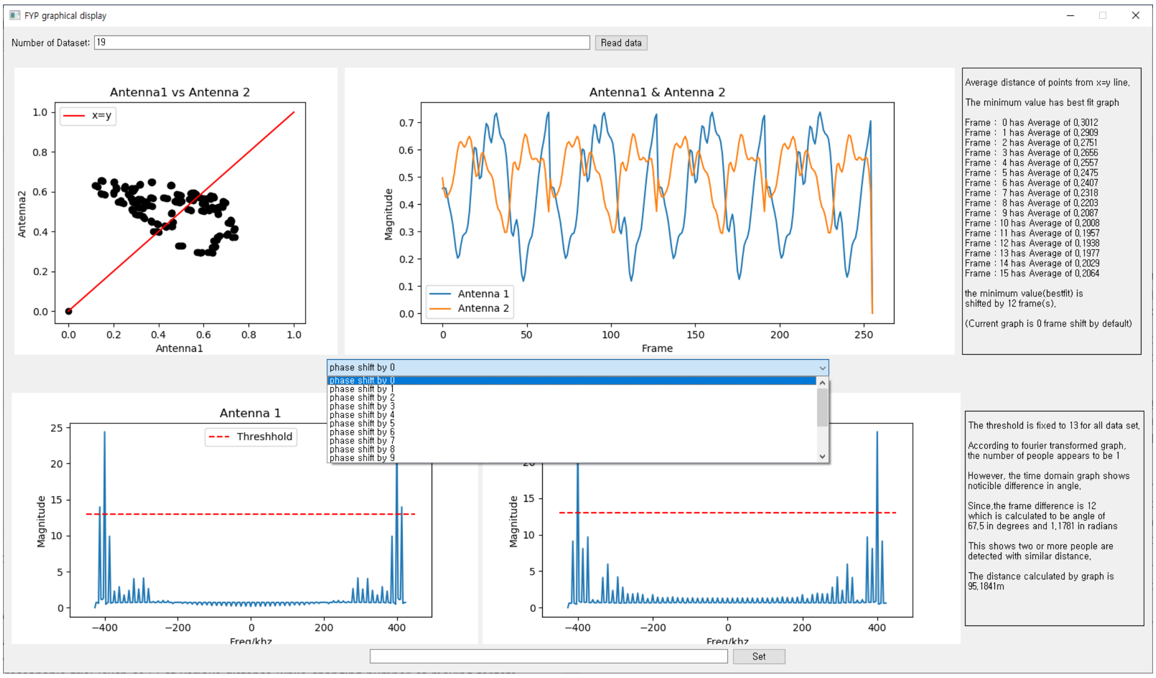


Figure 28: data number 19 at phase shift 0

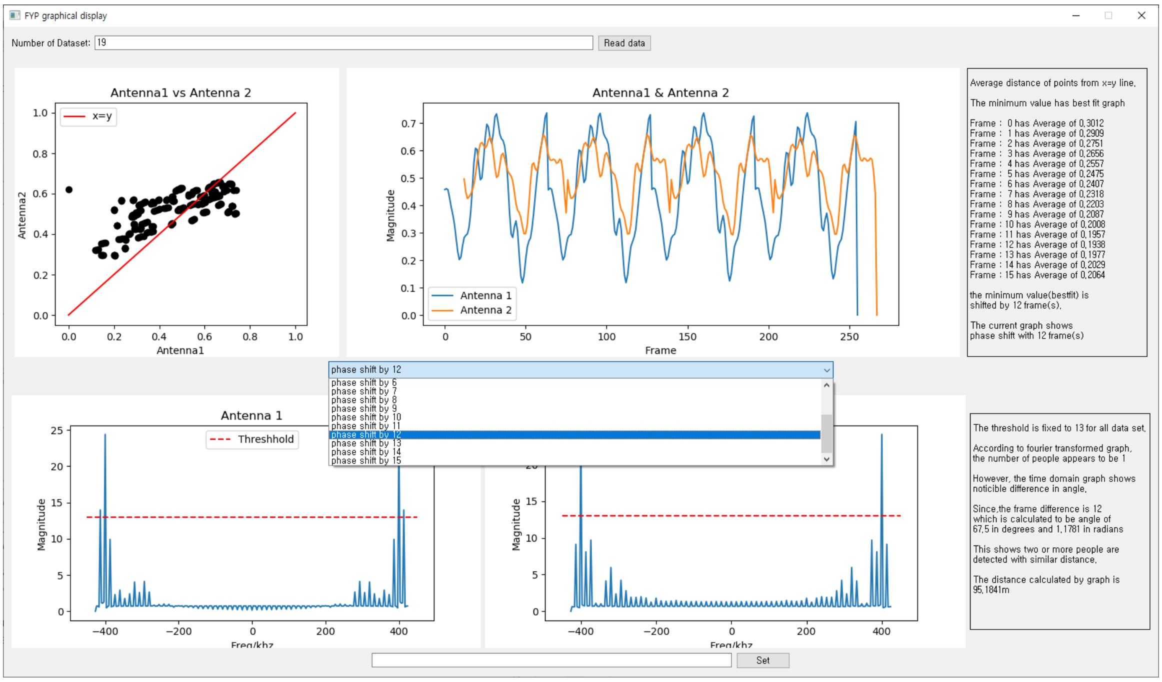


Figure 29: data number 19 at phase shift 12 (best fit)

The results of the data are first shown as the graph on the screen and the detailed information is shown on the right side of the program. The below graph from Figures 28 and 29 at Section 2.2.3.2 shows the preset threshold for the human target's magnitude. The number of human detections is decided by the number of frequencies above the preset magnitude threshold.

In the case of Figure X4, antenna 1 shows 2 frequencies are above the threshold (4 in actual but negative and positive frequency is combined to single data) and antenna 2 shows 1 frequency is above the threshold. The detailed explanation is also programmed to be displayed along with graphs. A clear picture of the explanation for graphs is shown in Figure 30.

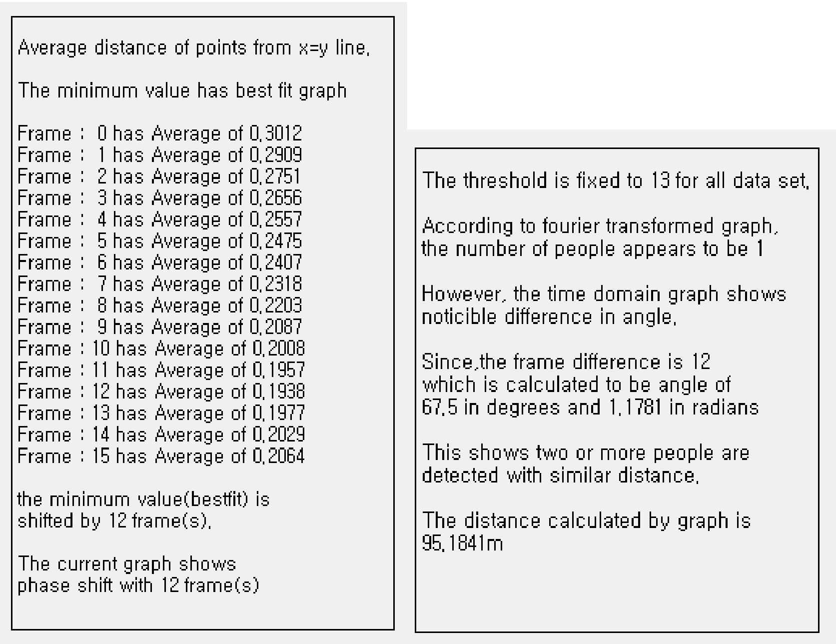


Figure 30: explanation of graphs (comparison of frame difference: right, threshold explanation: left

Experiment setup was the main challenge for this task. Since Jaemoo is in Hongkong, He collected the data by conducting several tests and provided it to Kijun in excel format. The data was then processed by kijun for visualization. The initial aim was to build a real-time system that can both collect and show data at the same time. However, since the group members are not physically together, the data was saved and shared to mock the real-time data visualization.

Finding out the correct threshold for each test data was also difficult as the magnitudes were slightly different for each test tryout. Hence to match the maximum and minimum magnitude of each data set, a constant was set to be multiplied to all data in the dataset. This way the level of various data set is set even at the distribution level. There might have been a minor deviation in the result of data which can be counted as the error rate of the final result.

2.3 Main Objective Evaluation and discussion

The main objective of this project was to design and build a system for human detection with help of FMCW Radar. During the initial stage of this project, a single antenna was used for testing and detecting the human target. This idea somehow functioned well to detect the human target but it lacked data to process the angular distance from the device (radar used for detection). Since the main aim was to precisely detect the number of humans in the target area. An accurate angular distance calculation was needed in the case of two human targets standing nearby. This is because a single antenna may detect the target as a single target whereas in reality there would be two or more targets.

In Section 2.2.3 we developed our device to function with two antennae. The amount of data collected from the radar was doubled as the number of antennae was increased. Even though the data was collected at the same time. It was processed separately by the ADC and a further process of joining these two data was required to compare and visualize the data.

To visualize the data, the equations were studied in detail, and algorithms were built to process the data as it is designed. For example. Equation from figure 11 at section 2.2.1.1. was used with a beat frequency of data above the threshold was used from below graph of GUI (frequency-based graph). And the calculated value is printed on the right screen of the graphical display of the processed data (GUI program). Also, to find the existence of angular deviation the frame difference is calculated by plotting a scatter graph of data from both antennae. And the best matching frame where two graphs meet at the same frame is found.

		Number of targets tracked		
	Distance (m)	Without human tracking algorithm	Infineon Software	*With human tracking algorithm*
Trial 1	5	2	2	2
	10	2	2	2
	15	1	2	2
	20	1	1	2
	25	1	2	1
Trial 2	5	2	2	2
	10	1	2	2
	15	2	2	2
	20	1	2	2
	25	1	1	1
Trial 3	5	2	2	2
	10	2	2	2
	15	1	2	2
	20	1	2	2
	25	1	1	2
Accuracy		40%	80%	87%

Figure 31: accuracy table of test results

Figure 31 shows the comparison between the actual condition and the results drawn with Infineon Software and our testing algorithm respectively.

Given there is a big difference of frame but shows only one data above the threshold, two or more targets might be standing at the same distance from the radar but at a different angle. Each frame was responsible for a specific angle difference. For example, in the case of the depicted diagram in figure 29, the frame difference is 12 and the entire data was 256 frames. The visible data shows around 8 π (in radians) and 1440 degrees (in degrees) this shows each frame is responsible for 5.625 degrees (1/64π).

The target position detection can be applied for various purposes. Utilizing this setup in a closed area to find out the crowd of humans, the users will be able to find out how close the people are. The provided information would contain the distance between several human targets and warn them if they are too close to each other. This might help to reduce the chance of droplet infected diseases such as COVID-19 which has been a critical issue for recent years. A similar idea can be used for auto-driving mobiles to detect the human objects on their way and an additional idea of calculation of the velocity of a certain object can be applied to avoid dangerous situations and stop the vehicle to prevent accidents.

3) Conclusion

In this project, we developed radar system for human target detection and tracking. We first did raw data manipulation and signal processing from transceiver output. Raw data was extracted and converted to frequency domain using FFT. This data was then analyzed to develop simple work to identify moving object. Second, basic objects detecting algorithm was established for single and multiple persons. To identify human target accurately, we measured other types of static objects, and their FFT results were compared with FFT result of human target. Appropriate algorithm was developed to automatically set threshold magnitude and compare magnitudes of different frequency component to present number of human targets only. Finally, we applied human tracking algorithm. Major problem with human tracking is that when they are at same distance from the radar sensor, radar system shows inaccurate tracking because at same distance beat frequency should be identical and the system interpret this as a single target. We used data sets of both antenna and calculated target angle because when objects are apart of each other but at the same distance from the sensor, there will be disparity in target angle. We presented GUI to show number of human targets tracked with other useful information regarding the target such as time domain signal graph and distance in real time.

Our algorithm showed much improved performance in terms of human detection and tracking. At moving human targets at equidistance from the sensor, as this is the weakest part of the tracking, our algorithm showed 87% of accuracy, which was much higher than 40% of our detection algorithm without human tracking, and 80% of Infineon radar software.

Major limitation of the result is that there is no standard figure-of-merit (FOM) to compare different algorithms. For example, for RF transceiver, specification such as SNR, phase noise, IIP3 are powerful merit to compare different hardware architectures. However, human detection and tracking algorithms, we should measure empirical data of human targets at different distances with many trials. However, outdoor environments vary and much more data points should be gained to see much more accurate result. Therefore, it is very difficult to accurately compare performance of different algorithms. However, still, it is clear that our system can accurately identify human targets and track those targets with much improved accuracy. Our result is comparable, and even higher in our experiment than tracking algorithm of commercialized product.

In the future, we can measure more data points to see more accurate result. We can also develop tracking algorithm to differentiate human target from dynamically moving non-human objects such as cars.

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Appendices

Appendix A – Final project plan

A.1 Project Schedule—Gantt Charts

A.1.1 Overall Gantt chart

Objective Statements + pre-demonstration of project	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
To process received signals using FFT and identify necessary information regarding a moving object.								
Establishing basic object detecting algorithm and study human tracking algorithm								
Apply human tracking algorithm and debug any error								
Pre-demo for testing results								

A.1.1.1 Gantt chart for "To be familiar with working principles of RF transceivers and radar system"

To be familiar with working principles of RF transceivers and radar system	WK1	WK2	WK3	WK4
Gain deeper understanding of FMCW radar				
Deep-dive into each component				

A.1.1.2 Gantt chart for "Establishing basic object detecting algorithm and study human tracking algorithm"

Establishing basic object detecting algorithm and study human tracking algorithm	WK5	WK6	WK7	WK8	WK9	WK10	WK11	WK12	WK13	WK14	WK15	WK16
Basic object detecting algorithm												
Study human target detecting and tracking algorithm												

A.1.1.3 Gantt chart for "Apply human tracking algorithm and debug any error"

Apply human tracking algorithm and debug any error	WK17	WK18	WK19	WK20	WK21	WK22	WK23	WK24	WK25	WK26
Write codes in MATLAB and C										
Do FFT on the collected data										
Visualize the data into graph										
Check for possible errors and noise										
Try test for various applications and environment										

A.2 Table of Responsibilities

Group Member	RF and Radar	Algorithm	Coding and Debugging
Ahn, Jaemoo	Specific Tasks 1 and 2	Specific Task 1 and 2	Specific Task 1,2,3,5
Yu, Kijun	No involvement	Specific Task 1 and 2	Specific Task 1,3,4

A.3 Budget

We don't require budget as we are utilizing the devices which is already present.

Appendix B – Meeting Minutes

Weeks	Meeting Hours	Contents Discussed
Week 1	21st August 2020	How to plan the project. Which area of our knowledge can be used for project? In what field our outcome can be utilized.
Week 2	4th September 2020	The tools to be used for our project. Basic idea about how to start with project Planning to timeline of project
Week 3	15th October 2020	Literature study for algorithm. How to setup the device for testing Sharing knowledge about FFT
Week 4	**20th November 2020**	**Checked the functionality of device.** **Software to use for processing data (Matlab and VS)**
Week 5	24th November 2020	Arrangement of device and sample demo Midway checking of progress done and future works (along with Poster for LANG course)
Week 6	2nd December 2020	Discussion for Proposal report plan Consultation with communication Tutor
Week 7	24th December 2020	Plan for spring term (could not fly to Hong Kong due to COVID) Divided role for the demo. (testing and coding)
Week 8	**6th January 2021**	**Shared the test results and discussed for the way of processing collected data in detail.** **Future plan to write codes for real time display and saving it as test file**
Week 9	15th January 2021	Discussed about what to be shared with the instructor for midway meeting. How to visualize the collected data from time-based to frequency-based mode (FFT)
Week 10	**22th January 2021**	**Mainly focused on the contents for the monthly report.** **Shared idea about how accurate the test results were.** **Planned to use two antennae for precise detection**
Week 11	11th February 2021	Tests carried out with two antennae and data were collected for further use.
Week 12	**25th February 2021**	**Final test results were processed and visualized on the GUI display. Details for GUI was discussed**
Week 13	11th March 2021	Discussed about how to wrap up final report.

Week 4 Meeting

Date: 20/11/2020

Time: 7pm (HKT)

Location: via Zoom meeting

Attendees: Jaemoo and Kijun

Minutes taken by: Kijun

- Jaemoo has acquired the device and checked the functionality of it. It had no problem running the test. He needs to check if we can get the data well by using Visual studio and matlab to use those data for human detecting algorithm.
- Kijun will be writing codes for checking connection with the device and get the raw data from device by using visual studio. The collected data is to be displayed on monitor in real-time and at the same time the data would be saved to text file.

Table 1. Action Items from Previous Meeting

Action Item to be completed	By when	By whom	Status
Gain deeper understanding of FMCW radar	Sep 24st	Jaemoo	Completed
Deep-dive into each component	Oct 1st	Jaemoo	Completed
Basic object detecting algorithm	Oct 22st	Jaemoo and Kijun	Completed
Study human target detecting and tracking algorithm	Nov 12th	Jaemoo and Kijun	Completed

Table 2. Action Items for Next Meeting

Action Item to be completed	By when	By whom
Try to run some demo test with device	Jan 7th	Jaemoo

Week 8 meeting

Date: 6/1/2021

Time: 7pm (HKT)

Location: via Zoom meeting

Attendees: Jaemoo and Kijun

Minutes taken by: Jaemoo

- Jaemoo worked on some demo test run for the device to check its proper functionality. The device seemed to have no problem when the provided software was used. However, when he was trying to collect data in other means, the program written by the group, it was not able to catch the data well.
- Kijun is to debug for the error in the codes and get the codes working until next meeting. He will be using visual studio to check the used libraries and codes written in C language to find out about the error present in the code. (kijun was not able to fly back to Hong Kong due to pandemic issue hence he would be working remotely via means of online along with help of Jaemoo)
- After the debugging is done and data can be processed by jaemoo to visualize it as FFT graphs.

Table 3. Action Items from Previous Meeting

Action Item to be completed	By when	By whom	Status
Try to run some demo test with device	Jan 7th	Jaemoo	Completed

Table 4. Action Items for Next Meeting

Action Item to be completed	By when	By whom
Write codes for Matlab for FFT	Jan 21st	Jaemoo
Write codes for collecting data in C and show on screen	Jan 21st	Kijun

Week 10 meeting

Date: 22/1/2021

Time: 7pm (HKT)

Location: via Zoom meeting

Attendees: Jaemoo and Kijun

Minutes taken by: Kijun

- Kijun worked on the codes for display and it was working fine. The changes in data were visible on screen as the objects position was changed. Also, at the same time the shown data was getting saved to text file in designated destination.
- Jaemoo will be working on matlab codes with the collected data to distinguish between human and environmental objects such as desk, wall, chairs etc. the noise can be filtered during transformation of time-based mode to frequency-based mode.
- After the test with single device, we encountered problem with objects in-line with antenna. The future plan is to use two antennae in different position to check the difference in reflected waves and detect multiple objects.

Table 5. Action Items from Previous Meeting

Action Item to be completed	By when	By whom	Status
Write codes for Matlab for FFT	Jan 21st	Jaemoo	Completed
Write codes for collecting data in C and show on screen	Jan 21st	Kijun	Completed

Table 6. Action Items for Next Meeting

Action Item to be completed	By when	By whom
Set up the testing with two antennae	Feb 25th	Jaemoo
Learn about the calculation mechanism with two antennae at setup position	Feb 25th	Kijun and Jaemoo
Write algorithm for detection and filtering the noise for finalized demo.	Mar 11th	Kijun and Jaemoo

Week 12 Meeting

Date: 25/02/2021

Time: 7pm (HKT)

Location: via Zoom meeting

Attendees: Jaemoo and Kijun

Minutes taken by: Kijun

- Jaemoo setup the testing environment with 2 antennae and tried out several tests. The results were collected and saved as file and shared to kijun for further progress of visualization
- Kijun worked on how to use algorithm to draw result by using programming language. The Graphical display of collected data were built with program where the user can choose the data set and compare the data according to the frame difference. The GUI also included short explanation of the collected data.

Table 7. Action Items from Previous Meeting

Action Item to be completed	By when	By whom	Status
Set up the testing with two antennae	Feb 25th	Jaemoo	Completed
Learn about the calculation mechanism with two antennae at setup position	Feb 25th	Kijun and Jaemoo	Completed
Write algorithm for detection and filtering the noise for finalized demo.	Mar 11th	Kijun and Jaemoo	Completed

Table 8. Action Items for Next Meeting

Action Item to be completed	By when	By whom
Complete final report	Jan 7th	Kijun and Jaemoo

Appendix C – Group Members contribution

Author: Yu, Kijun

Since the works for the hardware was focused on Jaemoo and the algorithm building and writing codes were focused on myself, I have worked remotely to plan and write programming codes for data process.
We held regular weekly meetings via zoom as Jaemoo is in Hong Kong working with the device to collect data and I am in Korea to get the collected data from Jaemoo and process those data based on the algorithms planned for the project.

Under are the list of works that either I did by myself or worked together as group.

1. Writing C codes for collection of data from Hardware.

   Our project is based on Hardware (RADAR) and it is important to visualize the data collected by the hardware by using program. So, I wrote a program to detect the connection of hardware with computer and collect the data incoming from the device. The incoming data is translated for visualizing the data.

   For the details of written program. The main program called for two function. The first one to automatically connect to the device with is collecting data and second function was to display those incoming data on screen.
   The connection to the device was started with C provided function to get USB port lists and the program would stop if there is no active port detected. If there is more than one active port, the program will check each active port and locate the actual port giving the data (the data coming from Analogue to digital converter of given hardware)
   Once the device is located, the information of connected device is checked to finalize connection. As the device is finalized the program looks for the endpoint id of the radar connected device. The register than calls back for the collection of data frame from ADC to collect raw data from the hardware. After the data is collected framewise. The program then prints the details of collected data in predefined format and at the same time the program saves those data for further use as text file.

2. Building algorithm for human detection.

   The literature reviews were studied in detail to detect human with provided hardware. Initially the data was collected in time domain to provide us with data samples according to the magnitude. The collected data was then transformed by FFT to visualize the data in frequency-based graph. The time domain graph might have looked quite random as the movements of human and the distance between the radar and object was changing in random manner. However, after the FFT the data would show peaks in one or several frequency depending on the situations of time when the data was collected. In ideal case the time domain data has to be sinusoidal given that there is no noise, but it is impossible to carryout experiment in such environment. First the data was collected with no human movement. This data still showed some deviations in time-domain, and also some magnitude difference was visible after FFT. Since this data was collected with no human movement, it could be used to as filter for the noise during the actual detection.
   The actual movements of human were than detected by our device. It showed some high peaks with specific frequency which would mean that the object was present. Of course, there were some noise data present after FFT. The data could be filtered with the previously mentioned filter for noise.
   We are yet to move on to the detection with two radar for lessening the error and get more precise data. The idea of using filters can be applied at our final stage to specifically locate only humans rather than environmental objects for better detection and results.

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I was responsible for hardware set up, experiment, and signal processing part of raw data manipulation. Working flow of our project was as following:

Hardware set up and measurement → Raw data extraction and signal processing through experiment → Algorithms to count number of human targets → Results

Major contribution made by my self was on signal processing part. Hardware set up and experiments had to be done by myself as I was the only one physically in Hong Kong.

1. Hardware set up:

Position2Go board from Infineon Technology was used in this project. This radar board was connected to my laptop and do measurement. Experiment data could be processed in Matlab software. Infineon Toolbox software was used as well for the reference.

2. Raw data extraction and signal processing:

For the raw data extracted from the board, this information had to be processed to give meaningful outcome. To do this, I was responsible for understanding radar theory and FMCW radar system. Once data sets are obtained in a form of complex numbers, both time domain and frequency domain analysis were done. Data samples were converted to time domain using chirp time, and frequency domain was achieved using FFT. Once analyzing frequency domain results, beat frequency was found. And using this information, range between target object and radar sensor was found. Velocity of the moving objects and angle was also found in later part of the project. Once data are processed, I gave Kijun results I had and what parameters that we should be aware of while establishing algorithms. Since I was responsible for theoretical part of FMCW radar system, I could understand how human detecting and tracking algorithms should be done. I also benchmarked existing research papers to see various methods. Literature review was done on signal processing on FMCW radar using FFT, frequency domain analysis, human detecting and tracking algorithms.

3. Experiment:

Experiment place and time choice was up to myself. Experiment was and will be done in Lawn Area for outdoor application. Sample experiments were done indoor to consider possible interference from unwanted reflections from environments. Multiple student helpers acted as human targets during the experiment.