Science and Technology Council

Indian Institute of Technology, Kanpur

WiTrack-3D Tracking via Body Radio Reflections

Final Report

July 8, 2019

Contents

1 Abstract

The main objective of our project is to track an occluded object through radio signals. We have implemented a frequency modulated chirp generator consisting of a sweep generator(Agilent 33250a) which is used for linearly varying the frequency of the carrier wave, a signal generator(WaveTek Signal Generator- 952) for generating sinusoidal waveforms, horn antenna for transmission, dipole antenna for reception, the mixer which gives us the required beats that correspond to distances and oscilloscope(Agilent DSO X1012A) for data visualization & acquisition. The chirp varies from 1.6 GHz to 2.4 GHz over a duration of 100ms. The data is thereafter logged to the PC through PyVISA, which is a module that is used for communication between devices. The given data is processed using MATLAB. The steps involved in post-processing are segmenting the received waveform into appropriate number of parts, applying Fast Fourier Transform to it, and finally doing background subtraction for eliminating static reflectors. The goal of tracking linear paths of any moving human occluded by a solid obstacle(a wooden board kept between the antenna pair and the walking human) has been achieved upto a ditance of 3 m from the antenna pair.

2 Acknowledgements

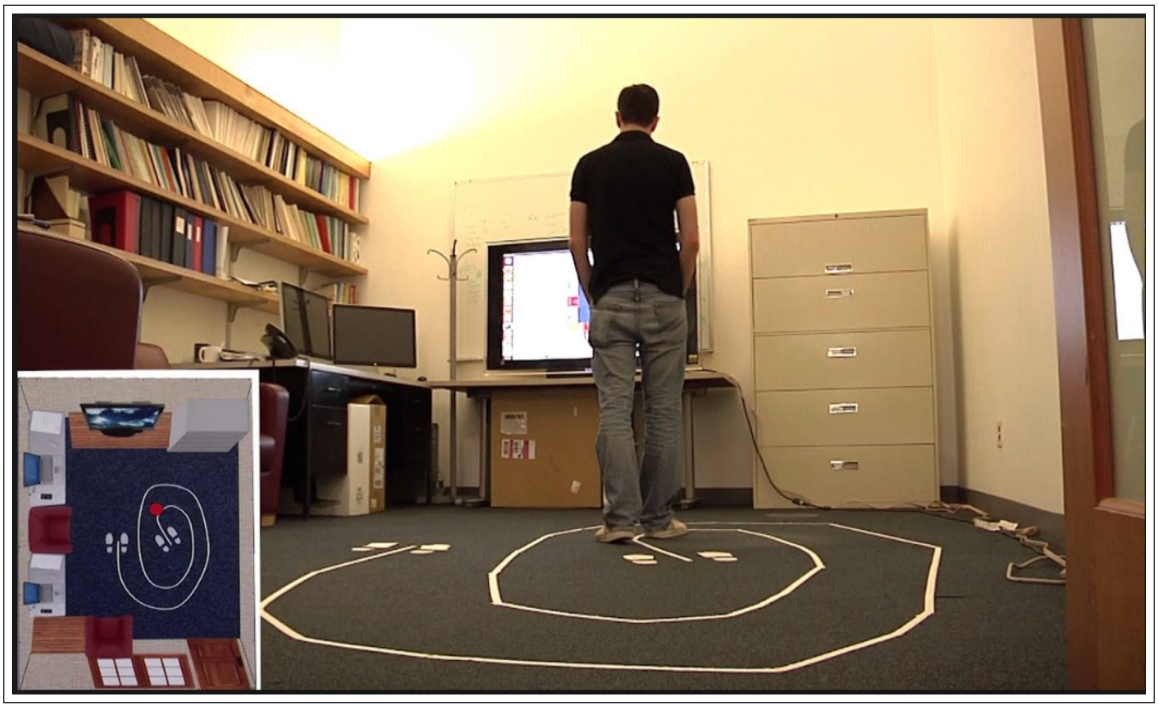
Our team would like to express their gratitude to Mr. Abhigyan Verma, General Secretary, Science and Technology Council, Student's Gymkhana, Project Mentor Mr. Nitish Vikas Deshpande and to the Electronics Club giving us invaluable guidance and support in doing this project. We also would like to thank Prof. A.R. Harish for providing us the necessary equipment for our final model, Ms. Anchal Agrawal for aiding us in operating the given components correctly, Prof. Ketan Rajawat for providing us with a NI USRP, Mr. Anant Chopra and Mr. Brijendra Kumar Gupta for guiding us with LabVIEW.

3 Introduction

WiTrack [1] is a device that tracks the 3D motion of a user from the radio signals reflected off their body. It works even if the person is occluded from the WiTrack device or in a different room. WiTrack does not require the user to carry any wireless device, yet its accuracy exceeds current RF localization systems, which require the user to hold a transceiver. It transmits wireless signals whose power is 100 times smaller than Wi-Fi and 1000 times smaller than cellphone transmissions.

WiTrack localizes the center of a human body to within 10 to 13 cm in the x and y dimensions (about the size of an adult hand), and 21 cm in the z dimension. It also provides coarse tracking of body parts, identifying the direction of a pointing hand with a median of 11.2 degrees. It can also detect falls with 96.9 percent accuracy. WiTrack can be incorporated into consumer electronics and has a wide set of applications.

WiTrack has one antenna for transmission and three antennas for receiving but here due to lack of hardware components we will be using one transmitting and one receiving antenna to loacalise a human in 2D. At a high level, WiTrack's motion tracking works as follows. The device transmits a radio signal and uses its reflections to estimate the time it takes the signal to travel from the transmitting antenna to the reflecting object and back to each of the receiving antennas. WiTrack then uses its knowledge of the position of the antennas to create a geometric reference model, which maps the round trip delays observed by the receive antennas to a 3D position of the reflecting body.



4 Primer

4.1 FMCW

Frequency Modulated Carrier Wave (FMCW) [2] is a technique that allows a radio device to measure the depth of an RF reflector. An FMCW device transmits a frequency chirp –i.e., a periodic RF signal whose frequency linearly increases in time, as shown in the illustration.

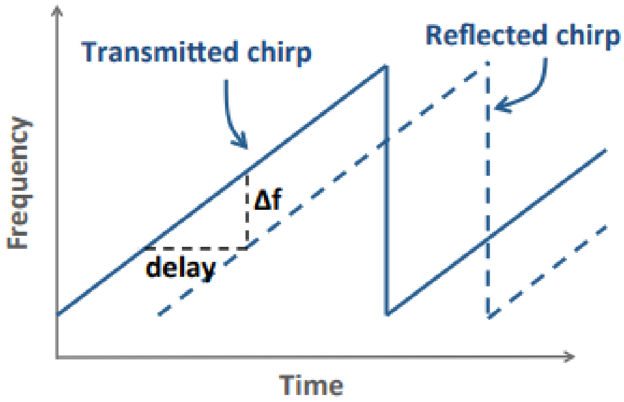


Figure 1: Frequency Chirp

The chirp reflects off objects in the environment and travels back to the device after the time-of-flight. The device can measure the time-of-flight and use it to infer the depth of the reflector. To do so, the device leverages the linear relationship between time and frequency in chirps. Specifically, it measures the time-of-flight (and its associated depth) by measuring the frequency shift between the transmitted and received signal. Mathematically, a frequency chirp of slope k can be used to compute the signal power P emanating from a particular depth r as

$$P(r) = \left| \sum_{t=1}^{T} s_t e^{j2\pi \frac{kr}{c} t} \right| \tag{1}$$

where st is the baseband time signal, c is the speed of light, and the summation is over the duration T of each chirp. Furthermore, by increasing the bandwidth of the chirp signal, one can achieve finer depth resolution. Specifically, a frequency chirp of bandwidth B has a depth resolution

$$\Delta r = \frac{c}{2B} \tag{2}$$

4.2 RF

An RF signal is a wave whose phase is a linear function of the traveled distance. By sampling the signal, we can record both its amplitude and its phase. The sampled signal can be represented as a complex discrete function of time t as follows :

$$s_t = A_t e^{-j2\pi \frac{r}{\lambda} t} \tag{3}$$

, where r is the distance traveled by the signal, λ is its wavelength, and A is its amplitude.

4.3 IQ

Quadrature signals, also called IQ signals, IQ data or IQ samples, are often used in RF applications. A pair of periodic signals are said to be in "quadrature" when they differ in phase by 90 degrees. The "in-phase" or reference signal is referred to as "I", and the signal that is shifted by 90 degrees (the signal in quadrature) is called "Q". An RF signal with any type of modulation can be created with the appropriate I(t) and Q(t) baseband signals (which in turn vary the amplitudes of the cosine and sine waves that are summed together).

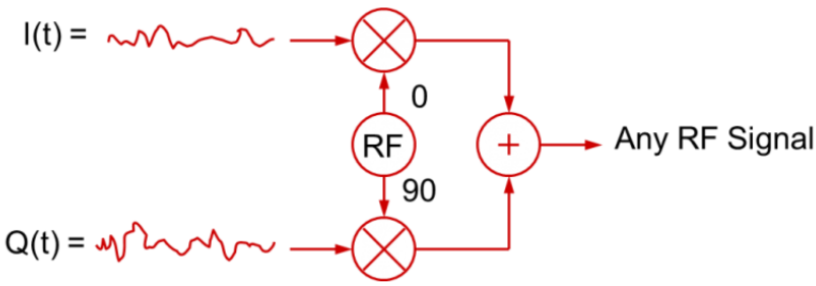


Figure 2: Quadrature Modulation

Software Defined Radio (SDR) systems use these concepts extensively because the baseband I Q signals are often represented as discrete time sampled data. Therefore, digital signal processing (DSP) can be used to literally define the transmitter and receiver characteristics including filtering, modulation and demodulation, AGC, etc.

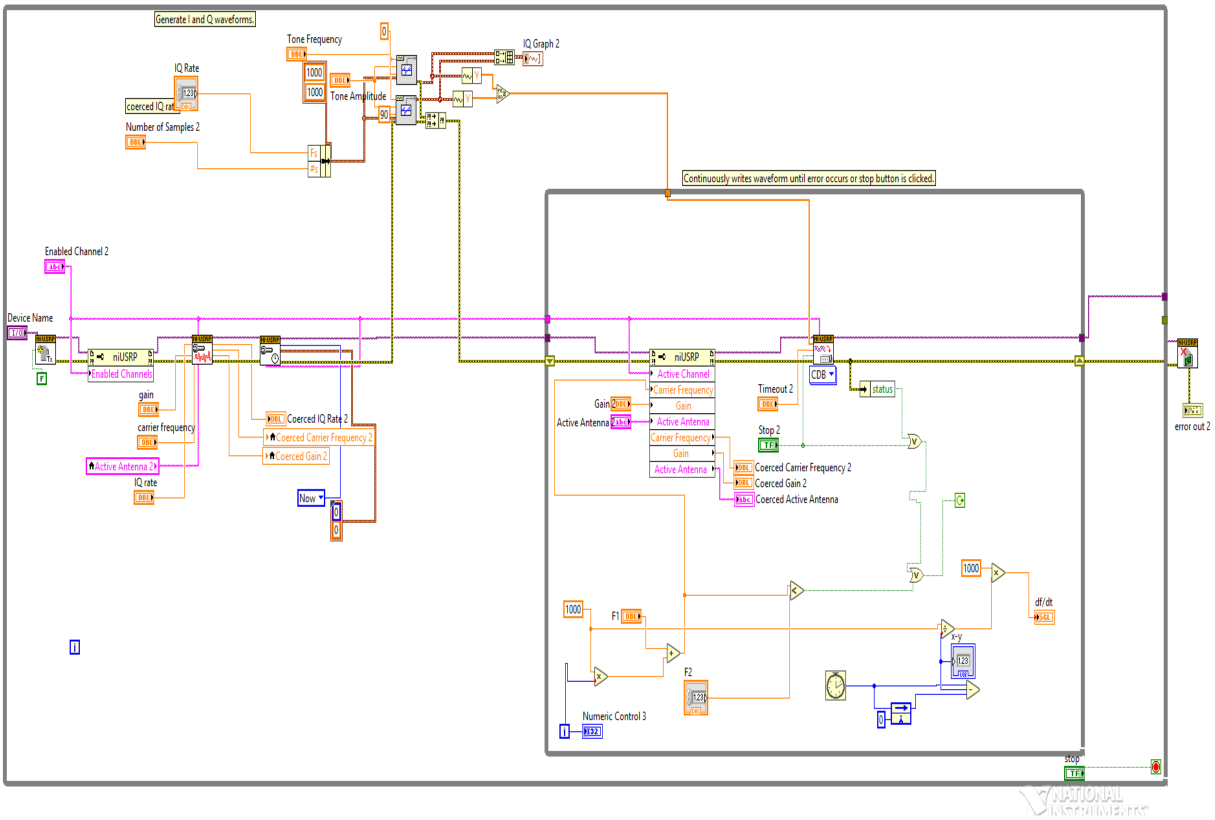
Figure 3: SDR

5 Initial Approach

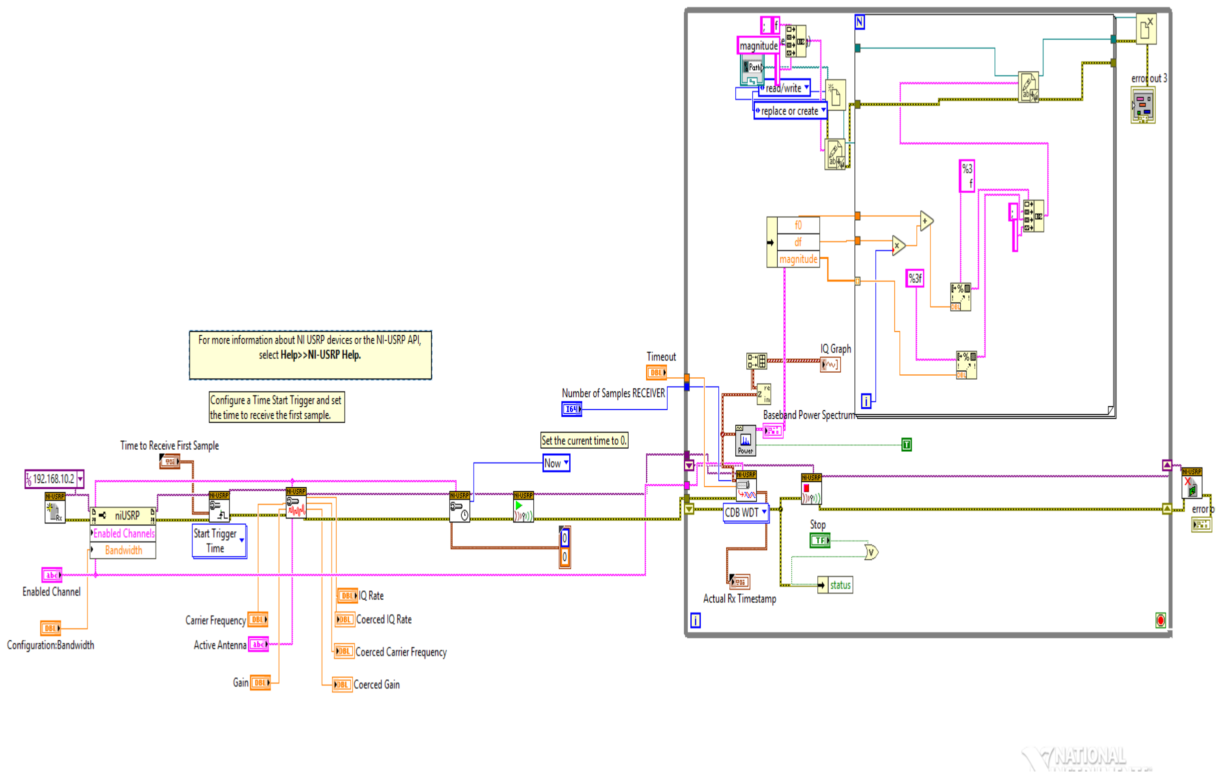
Initially we were using USRP N210(SDR-Software Defined Radio),2 VERT 900 ANTENNAS as hardware components to generate the required FMCW for mapping the person the room.We used LabVIEW 2019[1] as a software interface in our laptop(Windows 10) to simulate FMCW and transmitted the signal using the TX1/RX1 port of USRP through VERT 900 transmitting antenna and received it using VERT 900 attached to the RX2 port of the USRP.

5.1 Methodology Adopted

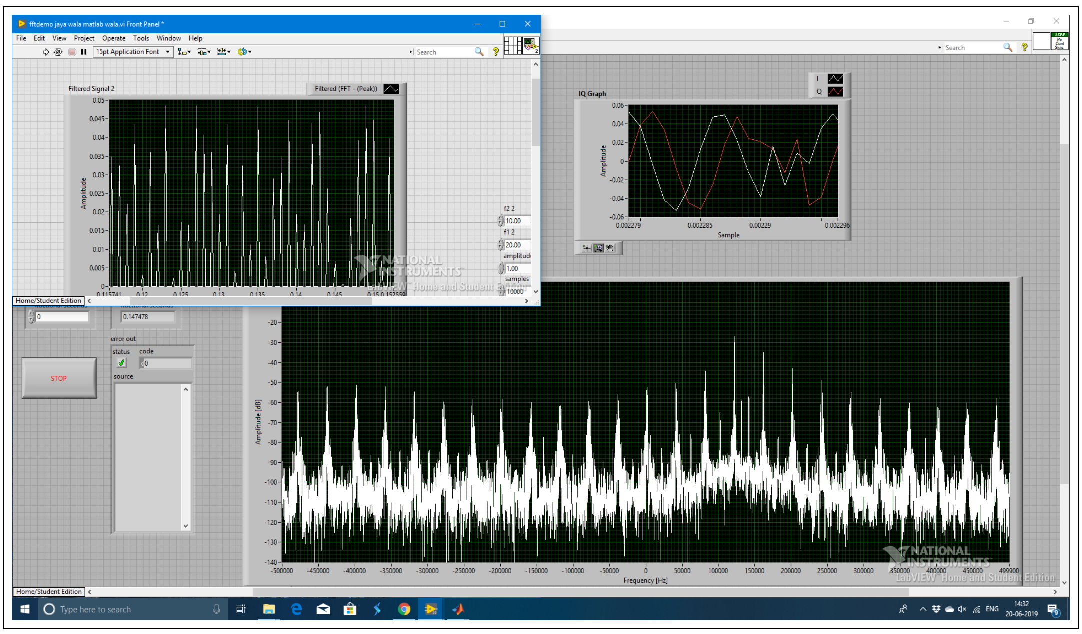
1. We transmitted the RF(Radio Frequency) by generating sawtooth I(In-phase) and Q(Quadrature) components for the same and transmitting them using a sine wave as a carrier wave of 2.0GHz and thereafter after receiving the RF signal we converted that into respective I and Q signals to extract the information.Below are the VIs for the transmitting and the receiving part.



[1]http://www.ni.com/academic/students/learn-labview

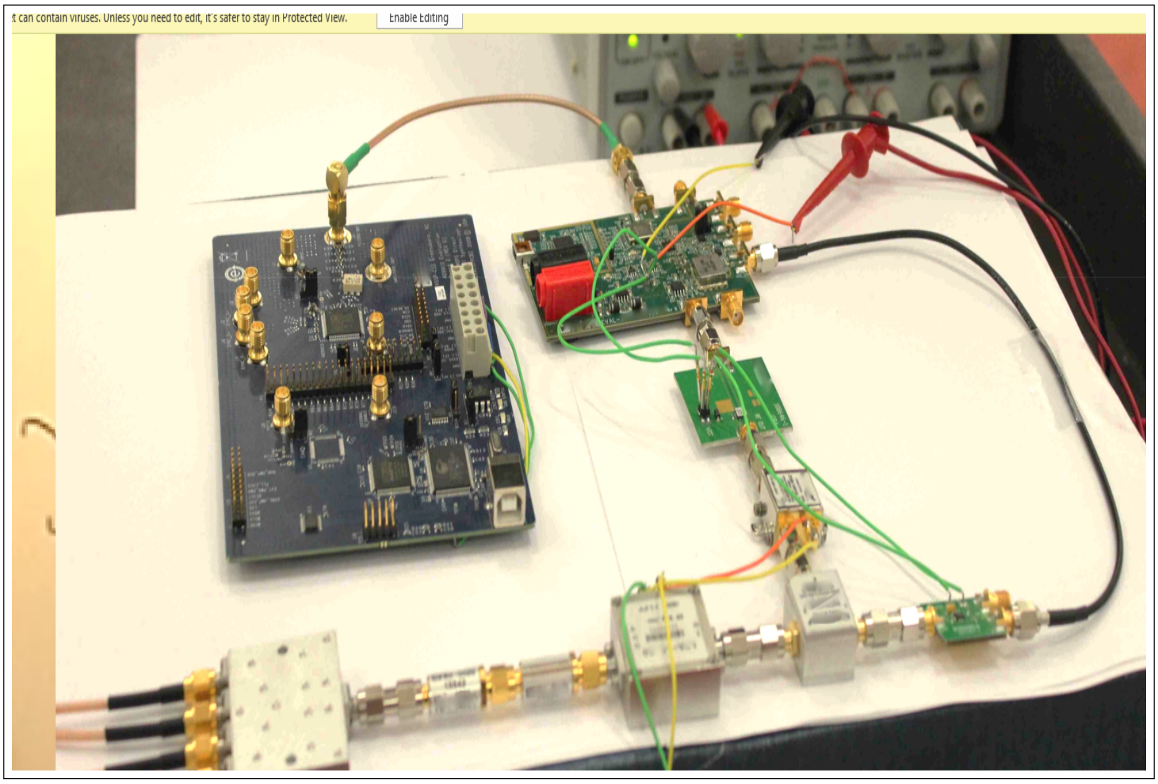


2. We thereafter took the received waveform and attempted to implement cross-correlation upon it to get the difference between the two waveforms in real time. However, due to the limited bandwidth, the given method could not work.



5.2 Problem in this Approach

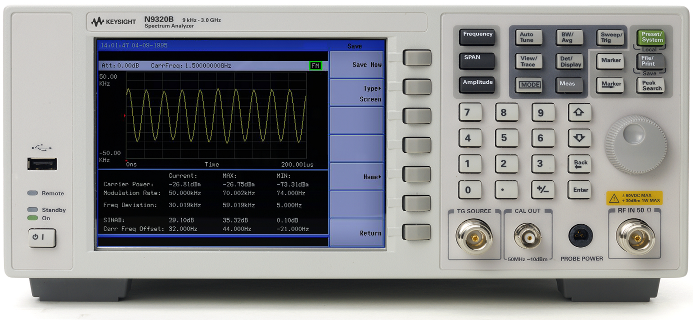
Through the above approach we were able to transmit and receive RF signals in GHz .But the approach failed when we realized the limitations associated with the USRP N210 and VERT 900.USRP can work within a dwelling time omilliseconds of received data but the resolution we needed to detect the required changes in our data was of nanoseconds.Originally,RF-Capture[3]'s algorithms were implemented in software on an Ubuntu 14.04 computer with an i7 processor, 32GB of RAM, and an Nvidia Quadro K4200 GPU.They implemented the hardware control and the initial I/O processing in the driver code of the USRP.The coarse-to-fine algorithm in §5 is implemented using CUDA GPU processing to generate reflection snapshots in real-time. In comparison to C processing, the GPU implementation provides a speedup of 36 .Also they had built an FMCW radio on a printed circuit board (PCB) using off-the-shelf circuit components which was not possible for us to build.The nanoseconds sampling wasn't possible through USRP which was required to detect the object,hence there rose a need to change the approach and we had to use other hardware components with better resolution to accomplish the same.Below is the USRP FPGA and other components used by MIT to accomplish nanoseconds sampling.



6 Setup

6.1 Hardware Components

- **SWEEP GENERATOR**
A sweep generator is a piece of electronic test equipment similar to, a function generator which creates an electrical waveform with a linearly varying frequency and a constant amplitude. Sweep generators are commonly used to test the frequency response of electronic filter circuits. Our model used was WaveTek 952.



- **SIGNAL GENERATOR**
A signal generator is an electronic device that generates repeating or non-repeating electronic signals in either the analog or the digital domain. It is generally used in designing, testing, troubleshooting, and repairing electronic or electroacoustic devices. The model we used was Agilent 33250a.

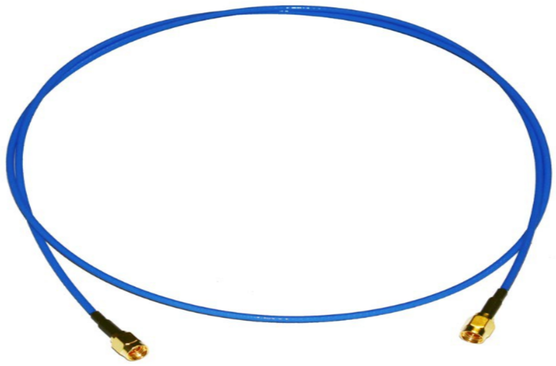
- **POWER DIVIDER**
A power divider is a component that equally divides the power of an input signal among multiple output signals. The application note illustrates a three-resistor power divider

that consists of three 16 $2/3 - \omega$ resistors. Such power dividers are often utilized in test-and-measurement systems.

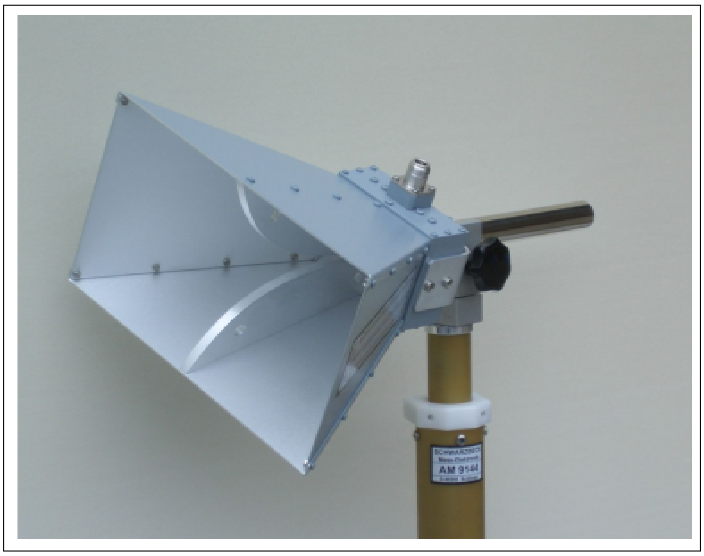
- **MIXER**
  An electronic mixer is a device that combines two or more electrical or electronic signals into one or two composite output signals. There are two basic circuits that both use the term mixer, but they are very different types of circuits: additive mixers and multiplicative mixers. Additive mixers are also known as "analog adders" to distinguish from the related digital adder circuits.

- **OSCILLOSCOPE**
  An oscilloscope is a laboratory instrument commonly used to display and analyze the waveform of electronic signals. In effect, the device draws a graph of the instantaneous signal voltage as a function of time. The model we used was Agilent DSO-x 1012A.

- **SMA CABLES**



- **HORN ANTENNA**
  A horn antenna or microwave horn is an antenna that consists of a flaring metal waveguide shaped like a horn to direct radio waves in a beam. Horns are widely used as antennas at UHF and microwave frequencies, above 300 MHz.

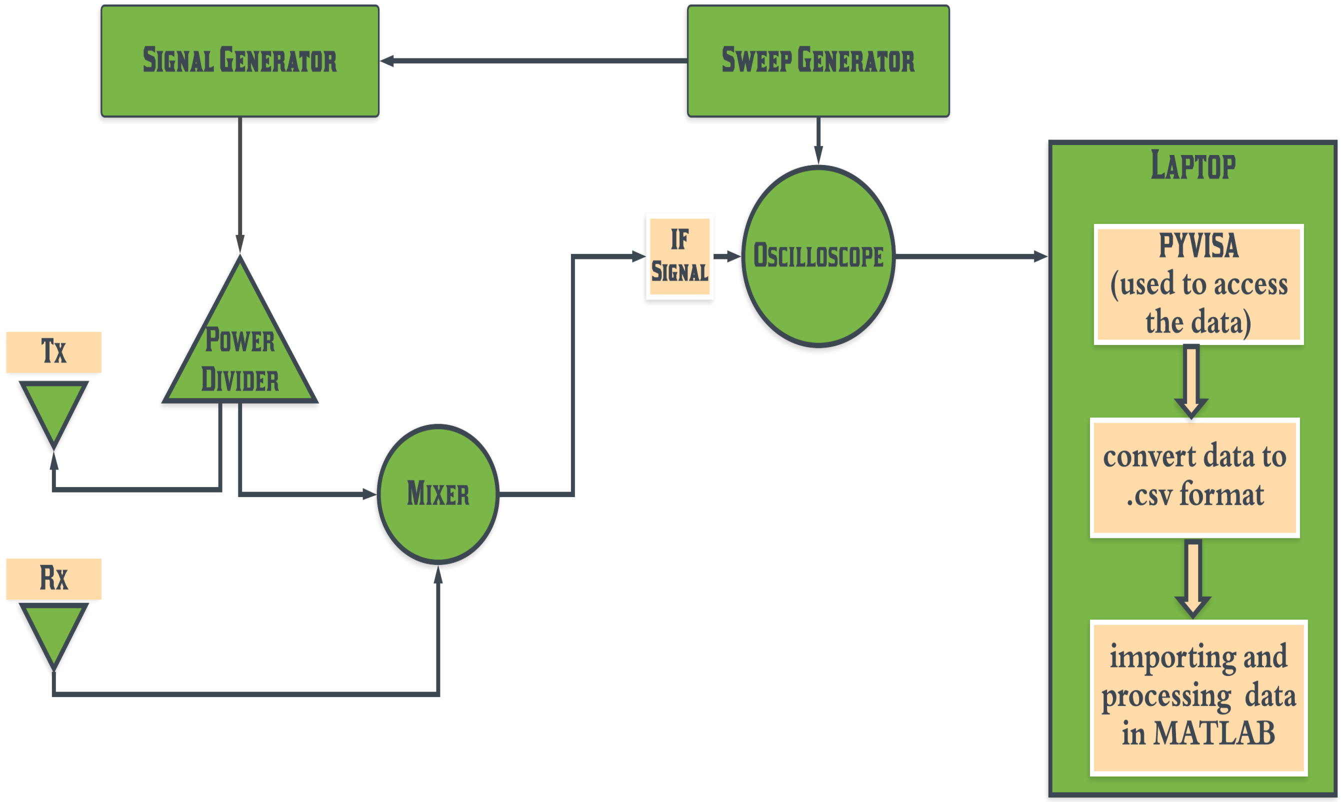


6.2 Software Used

We have mainly imported data of oscilloscope through PYVISA, a module in PYTHON and converted it into .CSV file.After that,the subsequent file was acessed by MATLAB and signal processing was done on the data to generate required spectrogram.

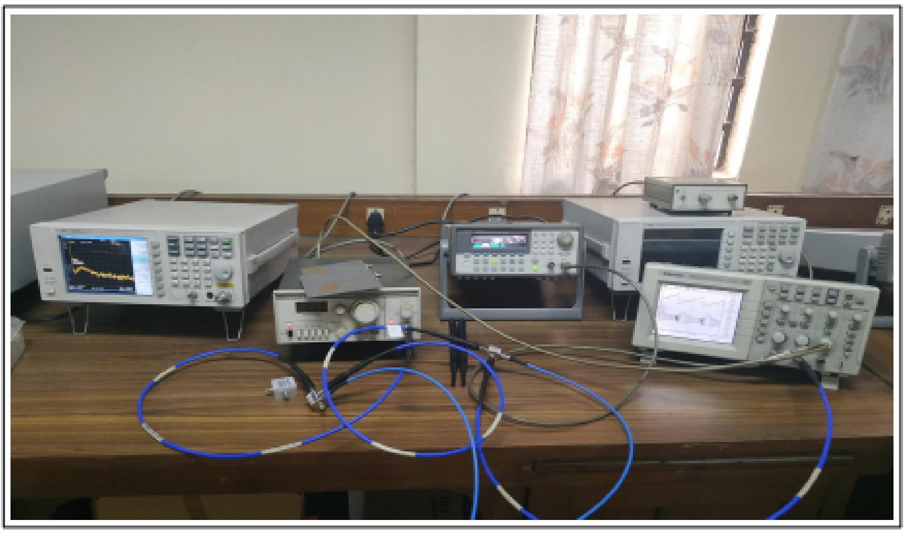
7 Our Current Approach

7.1 Block Diagram



7.2 Our Setup

We implemented the following set up whose flow chart is shown above.This cumbersome setup brings limitations to our project as the setup is not portable.So it makes difficult to track humans outside our working lab.Our setup includes all the hardware components mentioned like sweep generator along with mixers and horn antennas.



7.3 Working of the setup

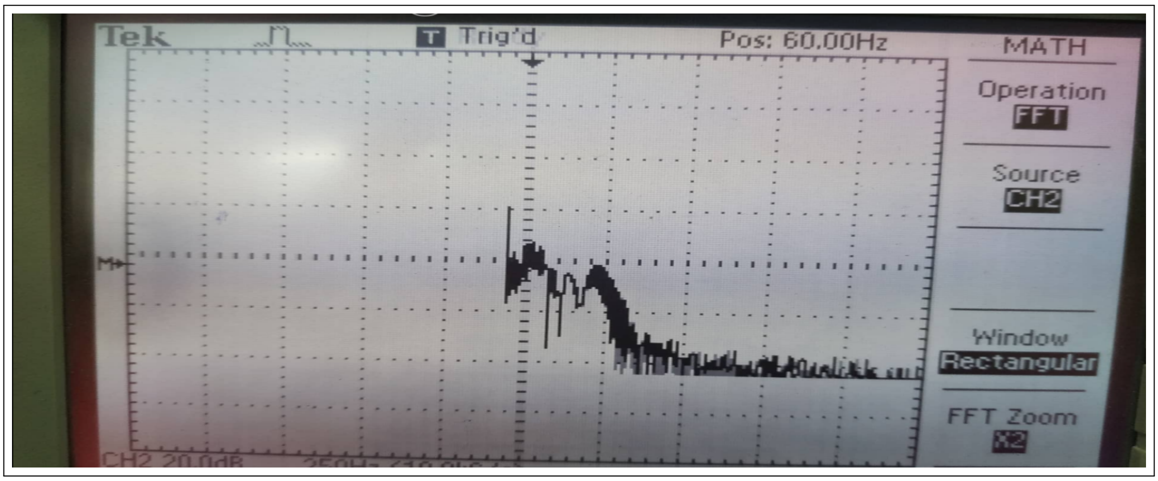
- The sweep generator was fed with an external stable source with sweep time around 100ms. This helped us send narrow sawtooth chirp signals henceforth giving us better range and better resolution.Actually the generator generates a sawtooth signal which is fed to the signal generator to add a sine carrier wave of desired higher frequency to it.

- Thereby the Signal Generator receives sawtooth wave and modulates the sine carrier wave accordingly producing a FMCW i.e Frequency Modulated Carrier Wave which is sent to power divider.

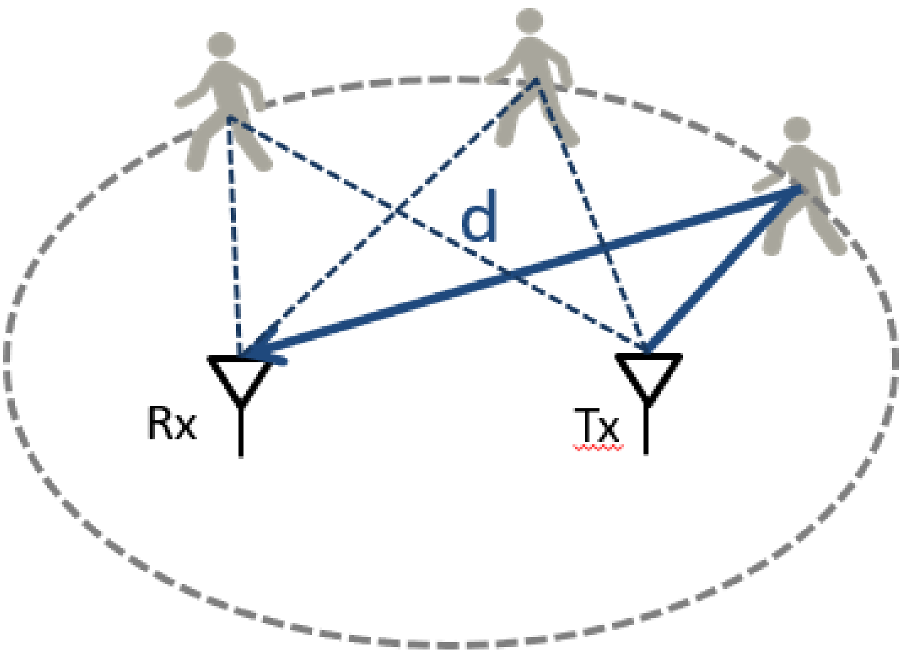
- The signal output was divided into two parts through a power divider, one was fed to the down converting mixer, and the other was fed to the transmitting horn antenna which sends the RF in real-time environment.

- The received signal was received through another antenna, and fed to the mixer.From the mixer we extract Intermediate Frequency[2]. The corresponding beat signal data which we get was fed into the channel 2 of Oscilloscope. The data from the Oscilloscope was thereafter transferred to a Computer through Serial Communication.We could observe FFT of the signal through mixer in oscilloscope as well as shown below.

[2] Drive Folder containing real time plotting of the intermediate frequency `https://drive.google.com/drive/folders/1q2-YoxG5_RFphrIogZUe1D4xuueiPuxx?fbclid=IwAR1-qYAZ72z8vzuQJRvLHDNgiSia6aCZzj4XzKWCPE7vjqBCRuWCiPcBcsY`



- The given data was logged by using PYTHON and sending commands to oscilloscope through the code.The data was collected and sent to MATLAB.Next the FFT [3] was implemented upon it through MATLAB.
- The FFT arrays were then background subtracted with the previous frame of FFT arrays, and the resultant matrix was made into a surface plot. The corresponding peaks in the surface plot are associated to the object that is moving in real time.
- This approach helps us get access to a single coordinate of the objects location. If we add more antennae to our model, we would be able to get a better idea about our object's location in 3-D Space.Location of an object can be traced just by using a simple concept of ellipses.

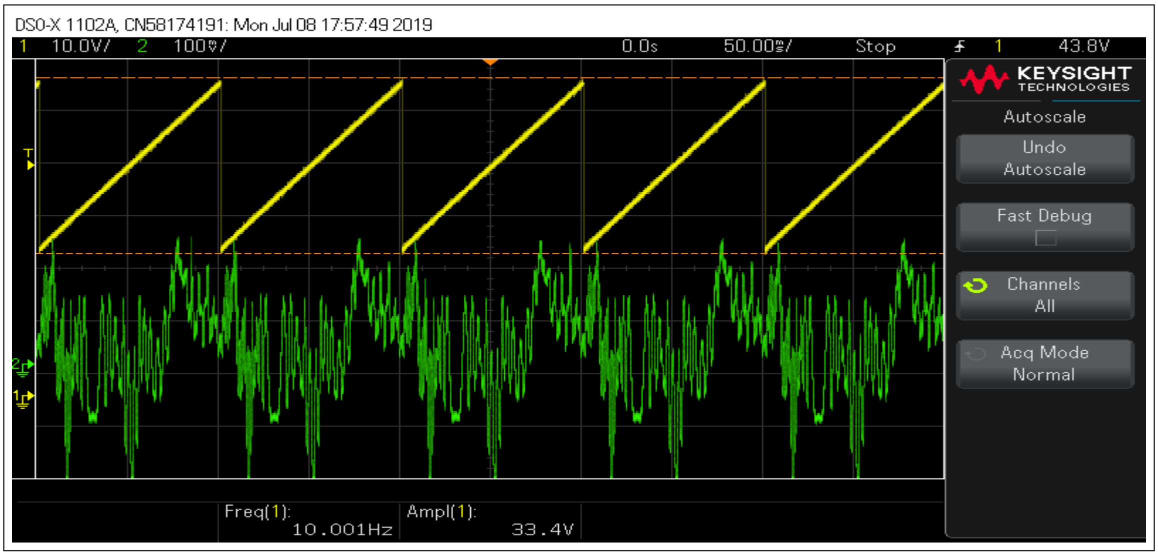


[3] `https://in.mathworks.com/help/matlab/ref/fft.html`

8 Experiments and Results

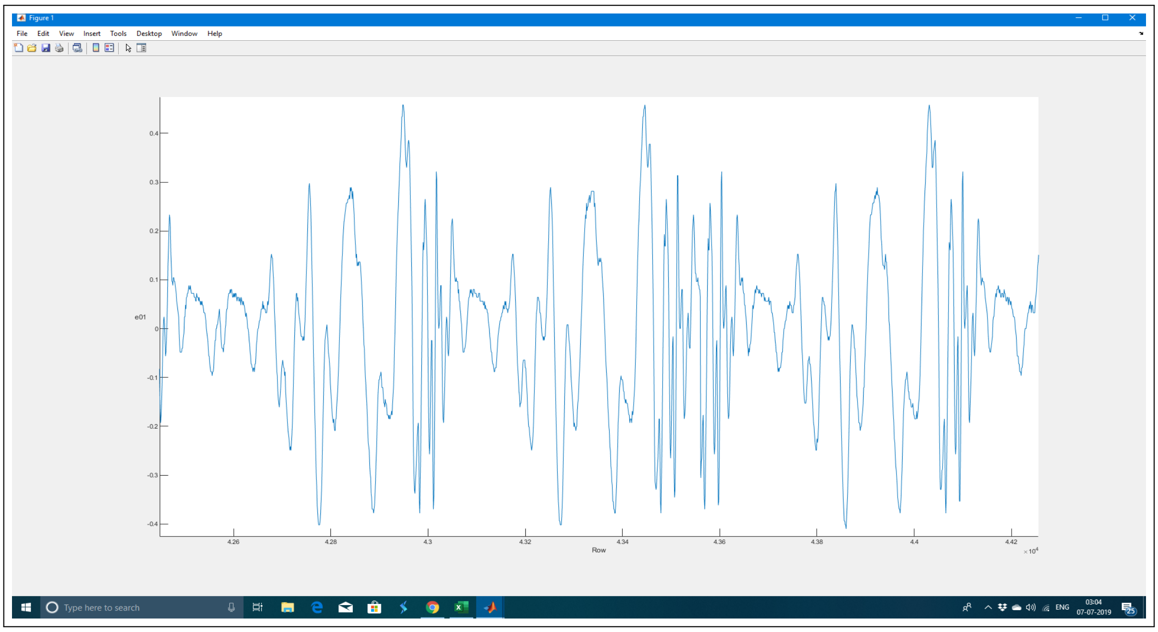
8.1 In Oscilloscope

- In our current approach we conducted a lot of experiments to track a single human body using RF signals.The body was made to hold a metal plate for better reflecting received.We observed that as the human approches the antennas we could clearly observe fluctuations in the waveform received through the mixer and in it's FFT as well.This clearly depicted the difference in frequencies.

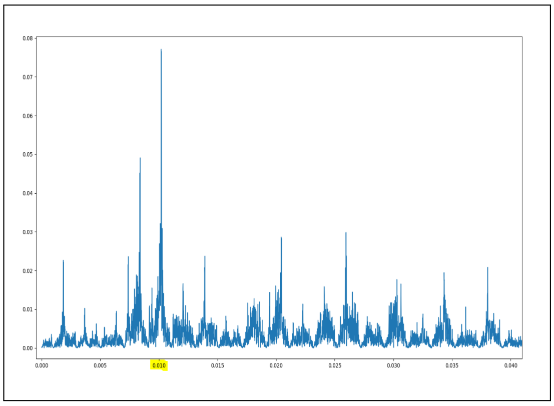


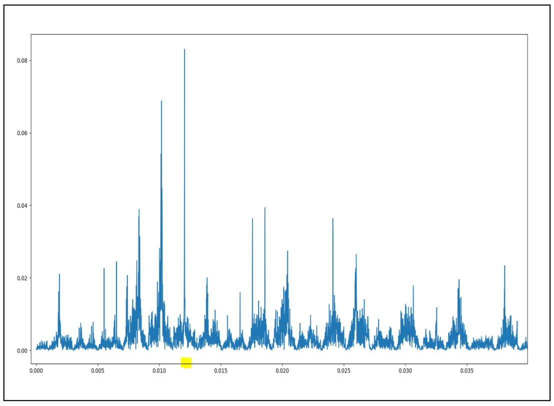
8.2 In MATLAB

- Next from the data received from the oscilloscope we plotted the received waveform in MATLAB after importing the data from the .CSV file.Below the observe the beats which is basically difference in frequencies of the transmitted and the received signals.

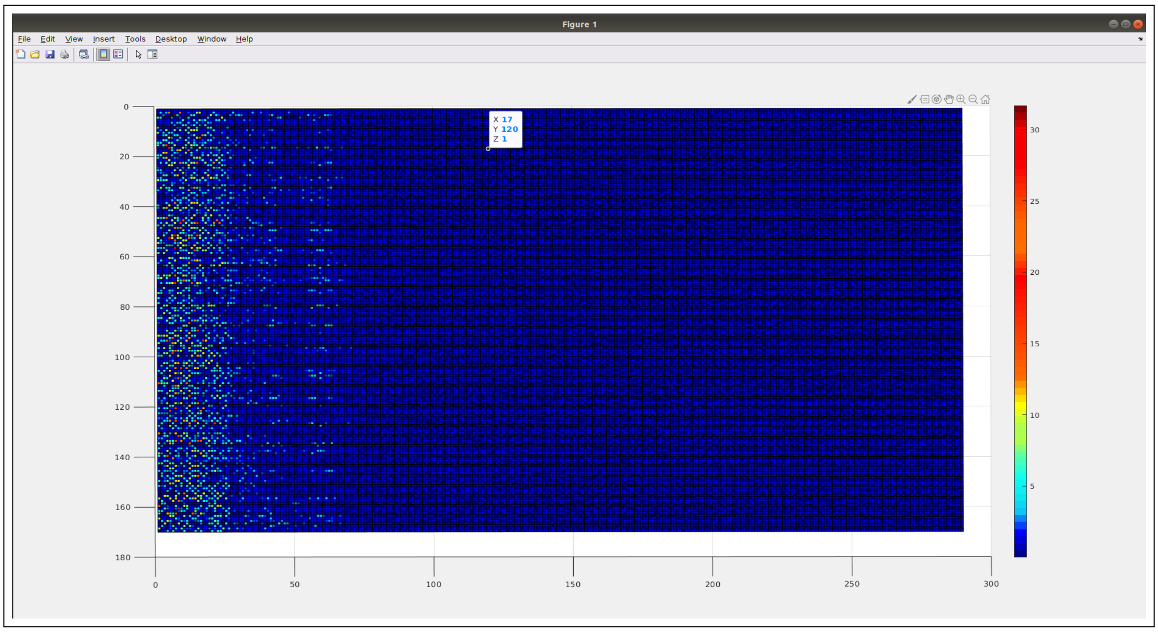


- We on an average received 99,000 samples for 100seconds.Below data reflects the average of all the snapshots we achieved at 1m and 2m .We can notice a moving peak in the figures below.

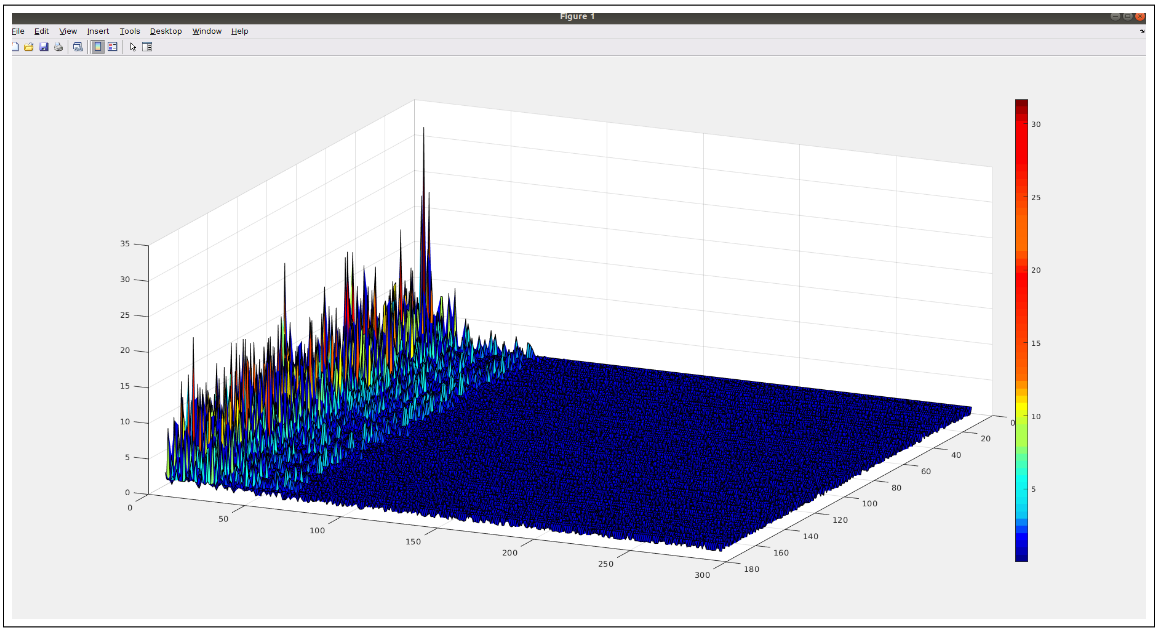




- Next we took the FFT of the above beats and plotted the same.We also did background subtraction.The reason behind this being that our system will detect the various peaks in FFT.But not all the peaks will give us the required distance.So we use an algorithm which runs the beats in loop and consequently subtracts one beat from the other.Thus at last what we expect to get as a result is a single dominant moving peak and few other reflected peaks of low intensity.Now the concept we apply to differentiate between our desired peak and others is by plotting a spectrogram of the same.



Top View of FFT Surface

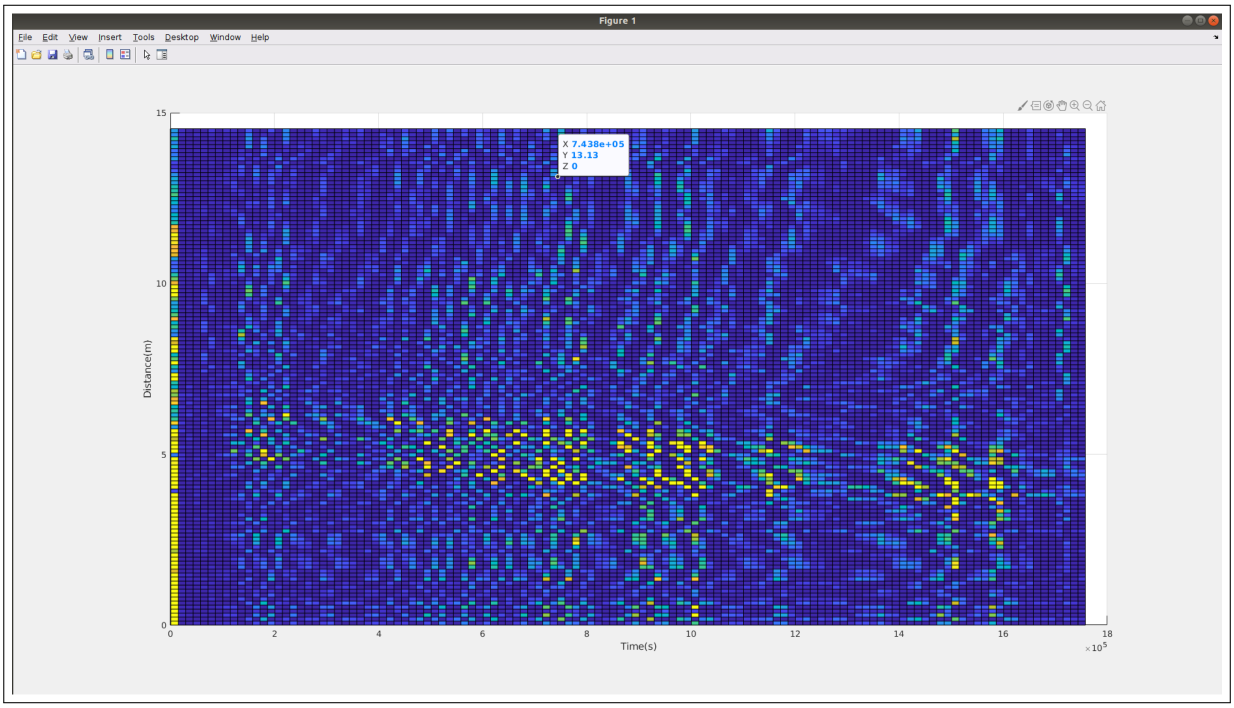


Side View of FFT Surface

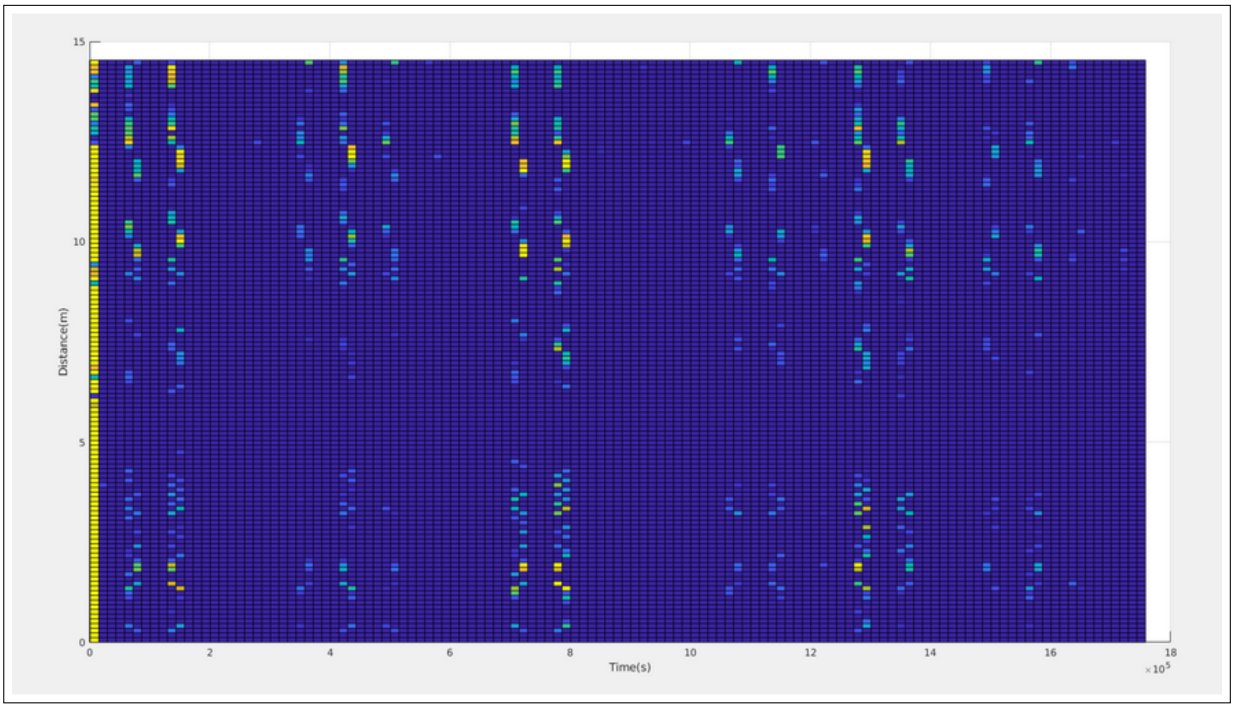
- Below is the result of spectrogram which clearly depicts that a human body is moving.(This is made after plotting on an average of 18 lakhs datapoints).The yellow points are the ones which reflect the signal most efficiently and the blue ones denote less efficient reflection.The human we mapped was made to hold a metal plate for strong reflection hence it was expected that the yellow points will be that of the human.

- To explain a bit more in detail,our human was made to move very slowly from 3m to 1m continuously at a uniform speed.We could clearly observe change in waveform shape of the beats in our oscilloscope.The reflections which we could possibility get were from human,objects around and reflection of reflected rays.Therefore the human was made to hold a metal plate for high power reflection.The RF which was transmitted was from

1.80GHz to 2.5GHz.This range was chosen keeping in mind the limitations of our different hardware components used.

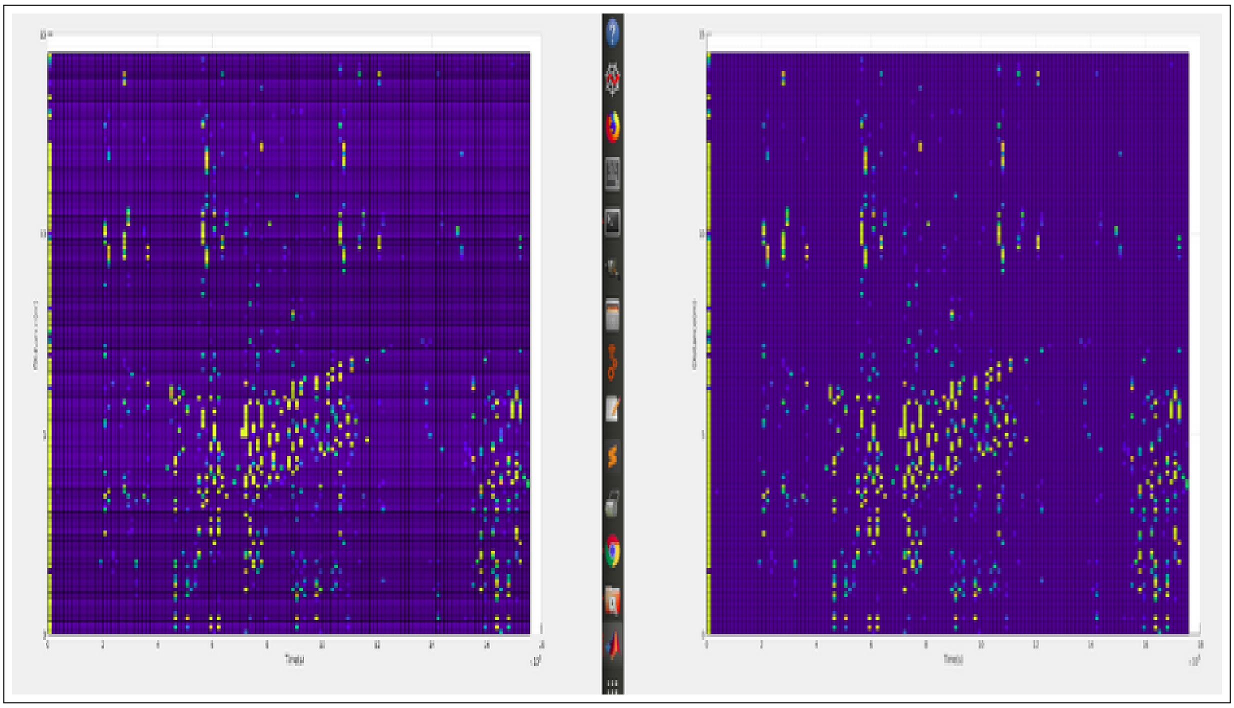


Spectrum depicting a walking Human



Spectogram with no moving object after background subtraction

Setup with wooden board as obstacle between the human and antenna pair



Comparison of spectograms with and without the obstacle

9 Scope of Future Work

– One may refer to the following link that contains all the links that were referred to in the project.

- 3-D Position estimation of body can be achieved by using a Linear Antennae Array. The more the number of antennas in the antenna array, the better the resolution of the heatmap of the object.
- Gesture recognition can be implemented upon those heatmaps generated, which can be later on used for fall detection, device control etc.

10 Team

10.1 Project Mentors

- Prof A.R Harish
- Ms. Anchal Agrawal
- Nitish Deshpande
- Jay Mundra
- Soumya Ranjan Dash
- Mudit Agrawal

10.2 Team Members

- Afzal Rao
- Anshul Rai
- Apoorv Bansal
- Apoorv Goyal
- Chittoor Murari
- Jaya Srivastava
- Jeet Prajapati
- Kushangi Mittal
- Preeti Menghwani

References

[1] Fadel Adib et al. "3D tracking via body radio reflections". In: *11th {USENIX} Symposium on Networked Systems Design and Implementation ({NSDI} 14)*. 2014, pp. 317–329.

[2] Sven-Erik Sandström and Imad K Akeab. "A study of some FMCW radar algorithms for target location at low frequencies". In: *Radio Science* 51.10 (2016), pp. 1676–1685.

[3] Fadel Adib et al. "Capturing the human figure through a wall". In: *ACM Transactions on Graphics (TOG)* 34.6 (2015), p. 219.