İstanbul Bilgi University
Electrical and Electronics Engineering

EEEN 490-EEEN 491
Senior Design Project Midterm Report

RADAR CIRCUIT IMPLEMENTATION (SIGNAL PROCESSING AND HARDWARE)

Submitted by: Emir İslam Özgül

Project Advisor: Assoc. Prof. Okan Zafer Batur

14.12.2020

1. Introduction

Radar (RAdio Detection And Ranging) is a device that detects distant objects' speed, direction, and distance with the help of the reflection of radio waves. Radar Technologies have a wide range of application areas. There are quite a lot of applications in civil life like observing weather for estimations and predictions, ground and air traffic control to guide the aircraft and to determine the speed of the vehicles. On the other hand, the defense industry is very important for radar technologies and most of the projects are carried out in this area.

FMCW radar (Frequency-Modulated Continuous Wave radar) is a special type of radar sensor which radiates continuous transmission power. Chirp waves, signals in which the frequency increases continuously, are sent from the antenna of an FMCW Radar at certain intervals. The IF signal is obtained by multiplying the outgoing and returning chirp waves from an object. FMCW radar technique is that obtains range and speed information through frequency modulation of a continuous signal. The transmitted signal and echo signal are modulated by a periodic saw wave. The received signal is a copy containing the frequency offset (Doppler shift, fd) and time delay τ. As shown in Fig. 1. With the frequency difference between the transmitted and received signals, range and speed can be calculated. [1]

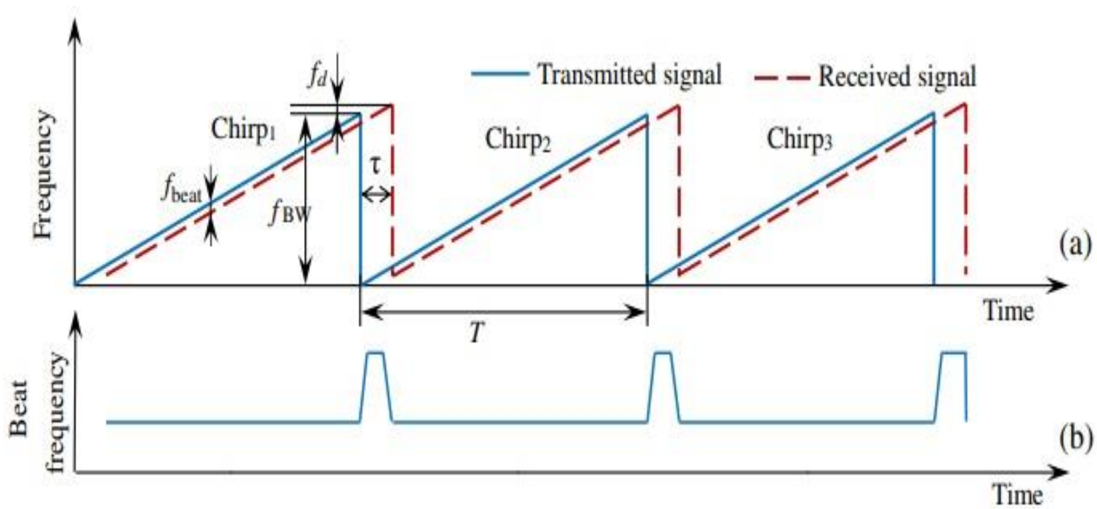

Fig. 1 FMCW radar with the sawtooth shape modulation.

τ: Delay time
fbeat: Measured frequency difference [Hz]
fbw: Bandwitdh
T: Period of one pulse

FMCW Radar is very important because they have measurement capability even at very short ranges (Smallest Measurement Range available in wavelength region). In addition, the range and radial velocity can be measured simultaneously, and the accuracy of its measurement is very high. Since high power pulses are not used, dangerous radiation does not occur, and radar is safer to use in this method. [2]

In this project, the modulated signal in the specified frequency ranges is sent from the first antenna (Tx) and the echo signal coming to the second antenna (Rx) is mixed in the mixer after passing through the LNA. In the next step, the signal is amplified in a video amplifier and sent to the output channel. The signal obtained with a cable connected to the audio output of the laptop is saved as a ".wav" file (audio file).

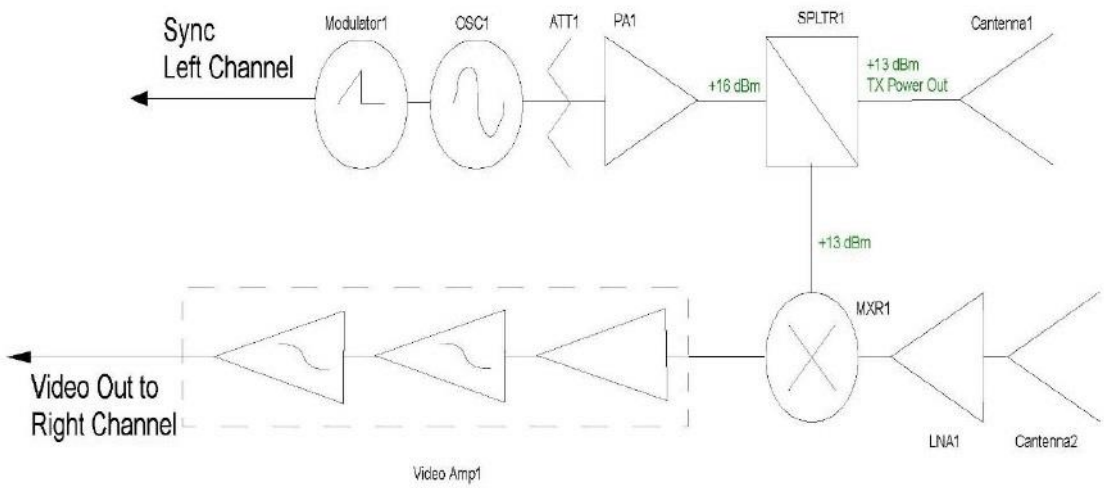

Fig. 1.1 Block diagram of FMCW radar.

The recorded audio file consists of two channels. The first is the SYNC signal and the second is the resulting echo signal. From the data obtained by processing the signals in the two channels separately, the distance or velocity of the objects can be measured. In this project, a two-dimensional radar picture will be obtained by digitally encoding the analog sound waves obtained from FMCW radar operating at 2.4 GHz and creating the necessary algorithms by using Python. The FMCW radar used in the radar project previously made in the MIT Lincoln laboratory is the same as the radar in this project, so an experiment has been made with the algorithm that measures the distance written using the recorded audio file. [3]

The maximum range of the radar is defined with the calculated range resolution and bandwidth. Next, the SYNC and echo data are separated. The measured data is parsed according to the rising edge of the SYNC pulse and a new matrix is created. This new matrix is then averaged to get rid of the average DC term. The data is converted into time domain by inverse fourier transformation, and then the final stage is completed by converting it to decibels. [4]

2. Objectives

The main objective of this project is to design an algorithm that can measure the time-dependent range changes and time-dependent doppler frequency changes of objects using the FMCW radar and present them with a two-dimensional image.

It is aimed to obtain a near-perfect image by processing sound waves that can work even in areas where there is no light and cannot be seen by the human eye.

3. Approach and Methodology

The information about the radar theory was collected after the necessary literature researches. However, there was not enough data on how to design signal processing or imaging or how to set up algorithms specifically for radar. Reading and understanding the books found and then setting up the algorithm did not seem to be a good method in this limited time. As a new method, the codes obtained after the analysis of the projects about the FMCW radar were reverse-engineered. It has been observed that learning Python simultaneously and doing detailed analysis and testing of the code is more efficient.

How the code should work and what changes were made for what purpose was learned by testing multiple times and, although it was difficult at first, it was observed that the ease of learning and understandability increased logarithmically.

4. Work Completed

Firstly, the audio file is taken from MIT. Secondly, the required radar parameters were determined. Pulse time and frequency ranges were entered in the same way without changing their values at MIT. This is because it is the sound wave recorded by a radar adjusted with those values. Then the maximum range was calculated. The data obtained contained two channels, and these signals were extracted and inverted. Each rise in the SYNC channel was combined with the other channel to create new data.

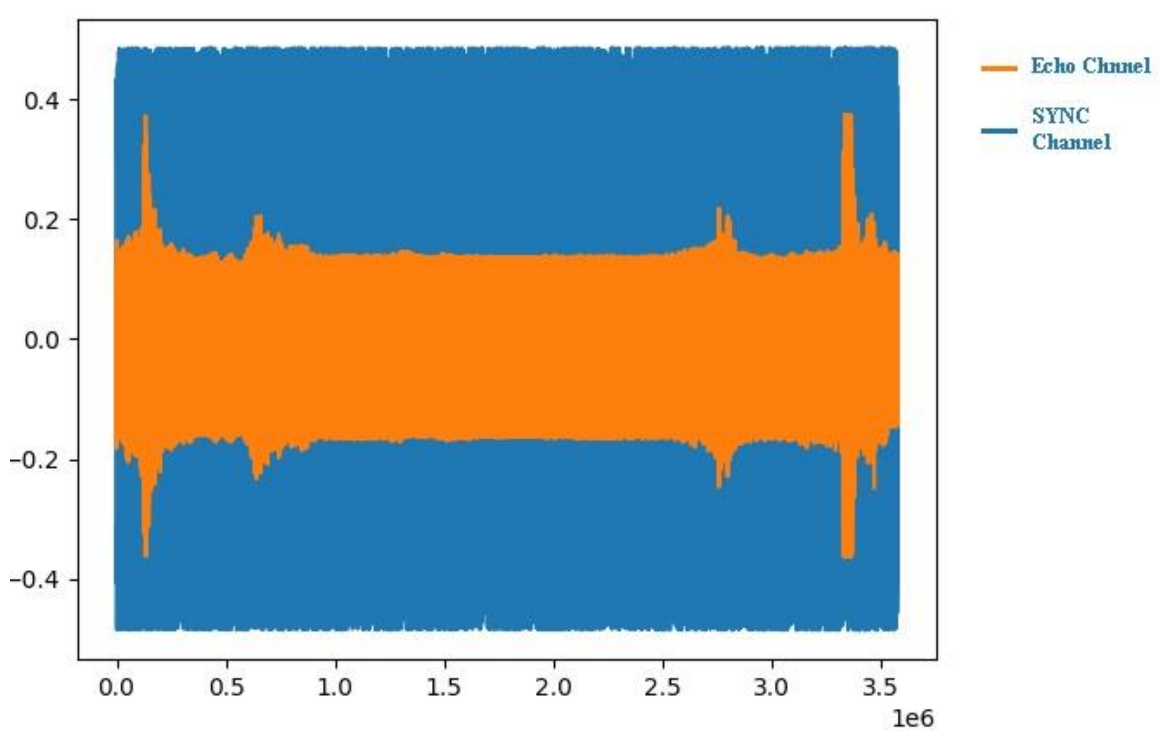

Fig. 4: Sampled time graph of the 'running_outside_20ms.wav'.

To get rid of the mean DC term, the mean of 'sif' was subtracted from itself. The final version of 'Sif' was converted to decibels by taking the inverse Fourier transform at the specified values. With the obtained 'time' and 'range_label' (which is a maximum range with matrixed with specified values) x and y axes, the RTI plot was obtained with 'ss_2-m_2' (scaler matrix).

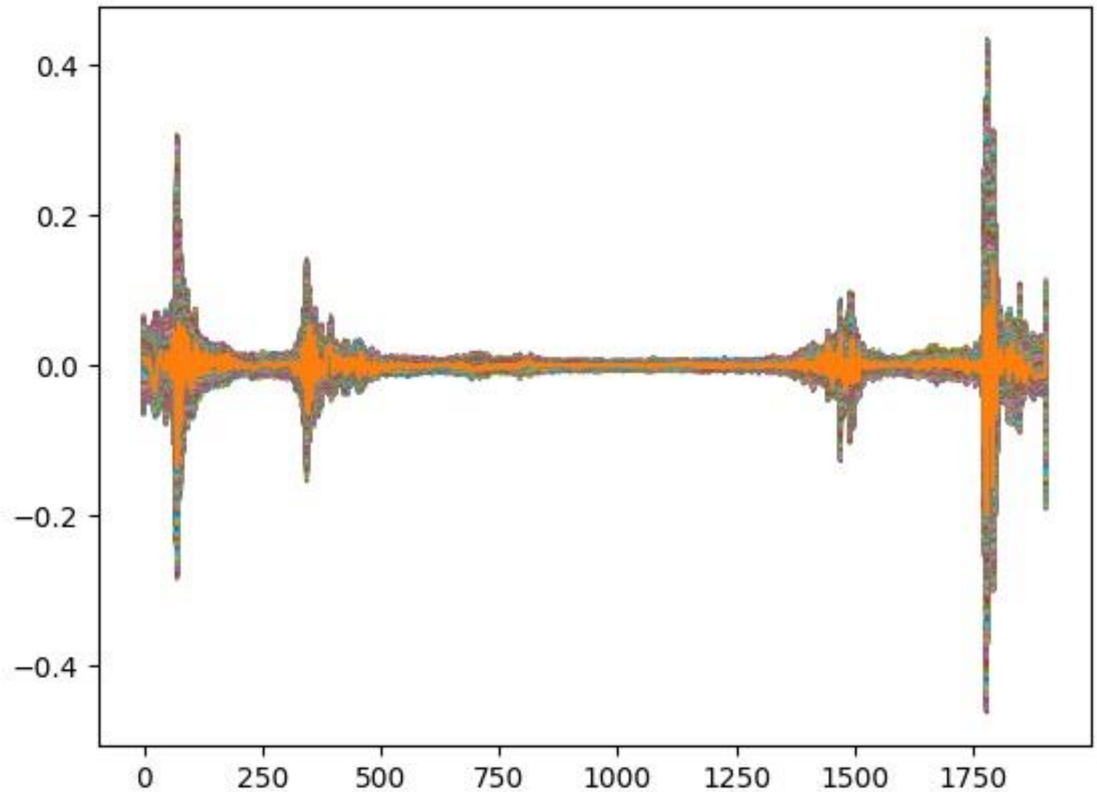

Fig. 4.1: Sif graph after average DC term subtraction.

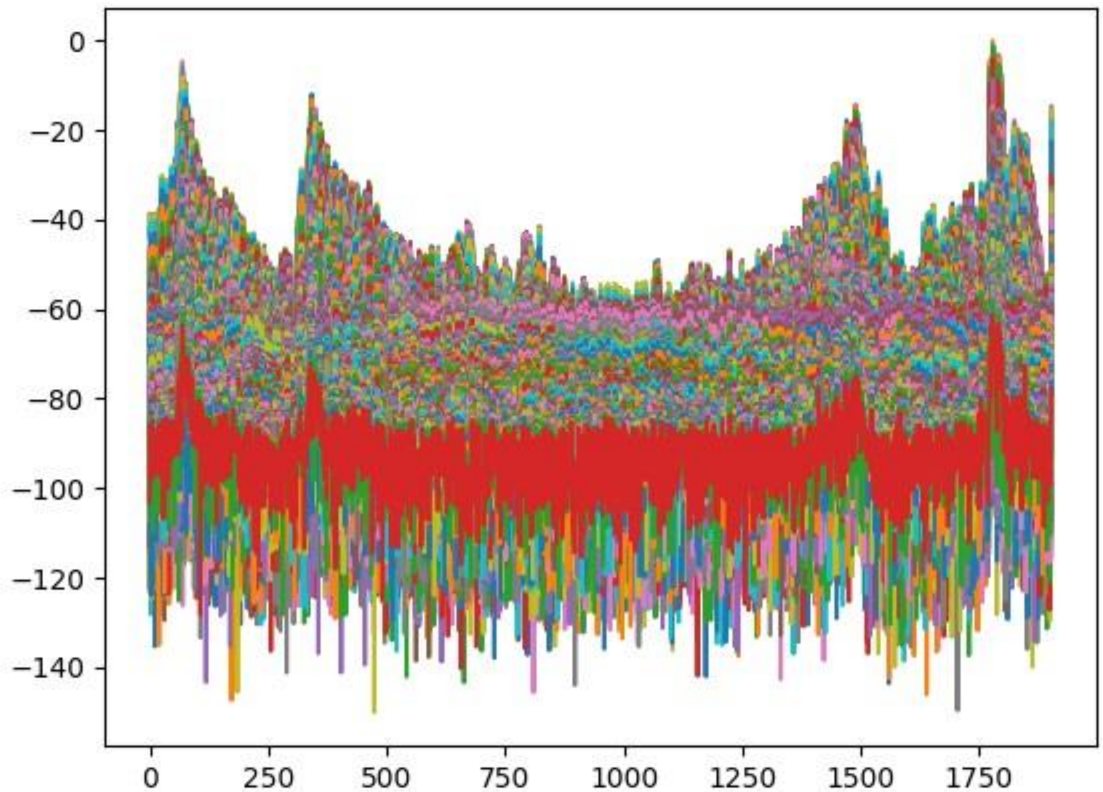

Fig. 4.2: Decibel versus time graph of inverse fourier transformed ‘sif’.

Python Code:

```
#-----------------------------------------------------------------------------------------------------------
import math
import statistics
import numpy as np
import matplotlib.pyplot as plt
#Reading File
import soundfile as sf
data, samplerate = sf.read('running_outside_20ms.wav')
#RADAR PARAMETERS
c=3e8              #Speed of light
Tp=0.02             #Pulse time
N=Tp*samplerate     #Sampled pulse time
fstart=2260e6       #Start freq.
fstop=2590e6        #Stop freq.
Bw=fstop-fstart     #Bandwitdh

#Range Resolution
range_res=(c)/(2*Bw)
range_max=(range_res*N)/2
```

```
#Be sign is (-), inverted plus sign
trig=-1*data[:,0]
s=-1*data[:,1]

#Decibel function
def dbc(ar):
    return 20*math.log10(abs(ar))
dbc_2=np.vectorize(dbc)

#Making (0-1) logic array
b=0
start_1=trig>b
start=start_1*1

a=np.size(trig,0)
count=0
for i in range(100, a-int(N)+1):
   if start[i]==1 and np.mean(start[i-11:i])==0:
       count=count+1
       sif=np.empty((count,int(N)))
       time=np.empty((count))

count_2=0
for i in range(100, a-int(N)+1):
   if start[i]==1 and np.mean(start[i-11:i])==0:
       count_2=count_2+1
       sif[count_2-1,:]=s[i:i+int(N)]
       time[count_2-1]=i*1/samplerate

ave=sif.mean(axis=0)
for i in range(np.size(sif,0)+1):
    sif[i-1,:]=sif[i-1,:]-ave

#RTI plot without cancelor
zpad=int(8*N/2)
v=dbc_2(np.fft.ifft(sif,zpad))
ss_1=int(np.size(v,1)/2)
ss=v[:,0:ss_1]
m=np.amax(v)
range_label=np.linspace(0,range_max,zpad)

#plt.imshow(ss-m,extent=(range_label[0],range_label[np.size(range_label)-
1],time[0],time[np.size(time)-1]))
#plt.show()
#-------------------------------
```

```
#2 pulse cancelor RTI plot (RTI with 2-pulse cancelor clutter rejection)
sif2=sif[2:np.size(sif,0),:]-sif[1:np.size(sif,0)-1,:]
v_2=np.fft.ifft(sif2,zpad)
ss_2=dbc_2(abs(v_2[:,0:int(np.size(v_2,1)/2)]))
m_2=np.amax(ss_2)

plt.imshow(ss_2-
m_2,cmap='jet',extent=(range_label[0],range_label[np.size(range_label)-
1],time[0],time[np.size(time)-1]),aspect='auto')
plt.xlabel('Range (m)')
plt.ylabel('Time (s)')
plt.title('RTI with 2-pulse cancelor clutter rejection')
plt.colorbar()
plt.clim(-80,0)
plt.show()
#---------------------------------------------------------------------------------------------------------
```

After many mistakes made, the algorithm that provides the image in Fig.4.3, which is obtained by correcting these errors, has been worked without fault. It is expected that radar images of sound files recorded in different specified bandwitdh will be obtained.

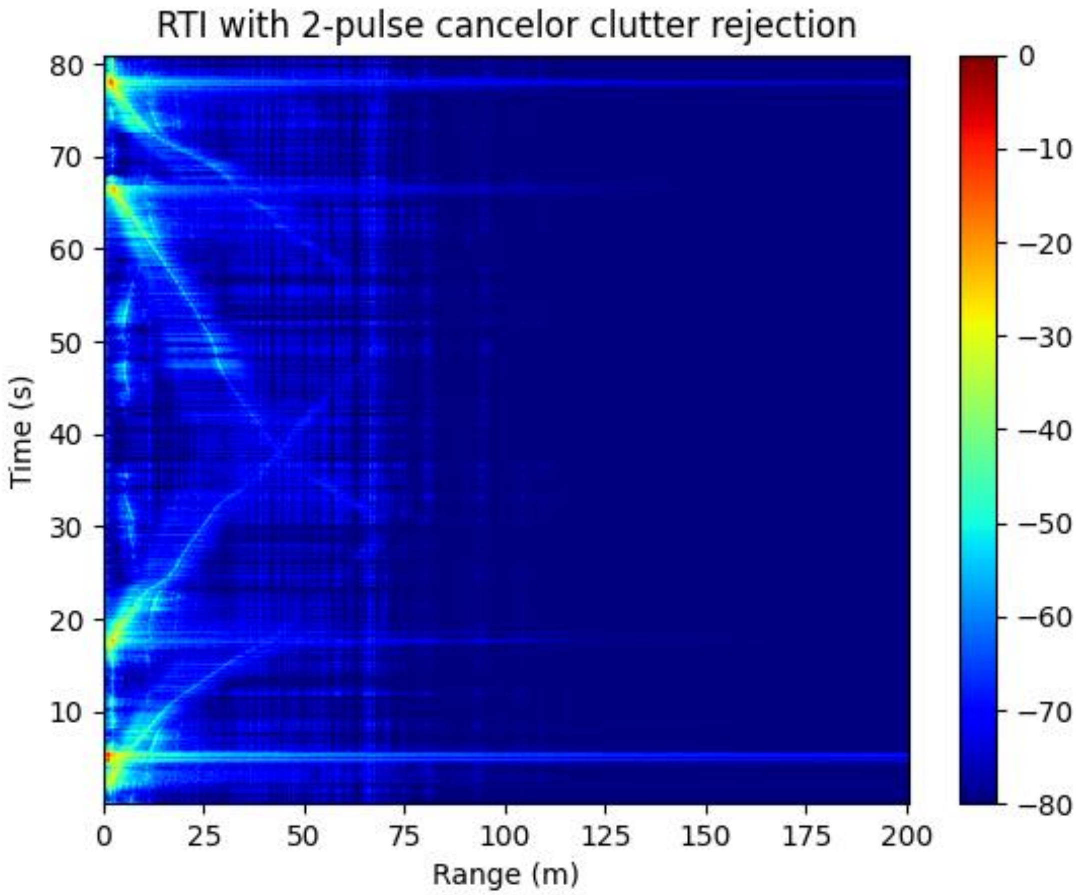

Fig. 4.3: The time-dependent range change image obtained when running the 'running_outside_20ms.wav'.

5. Work To Be Completed

During the remaining time, an algorithm will be designed that can calculate Doppler frequency change or velocity change of objects and transform them into visuals. Then, when the device is powered on, it will be observed how the audio file should be saved or whether it is working. Finally, when we turn on the device, it will be provided to give a two-dimensional field image in the maximum range. If the experiments and tests performed are positive, the project will be completed as desired.

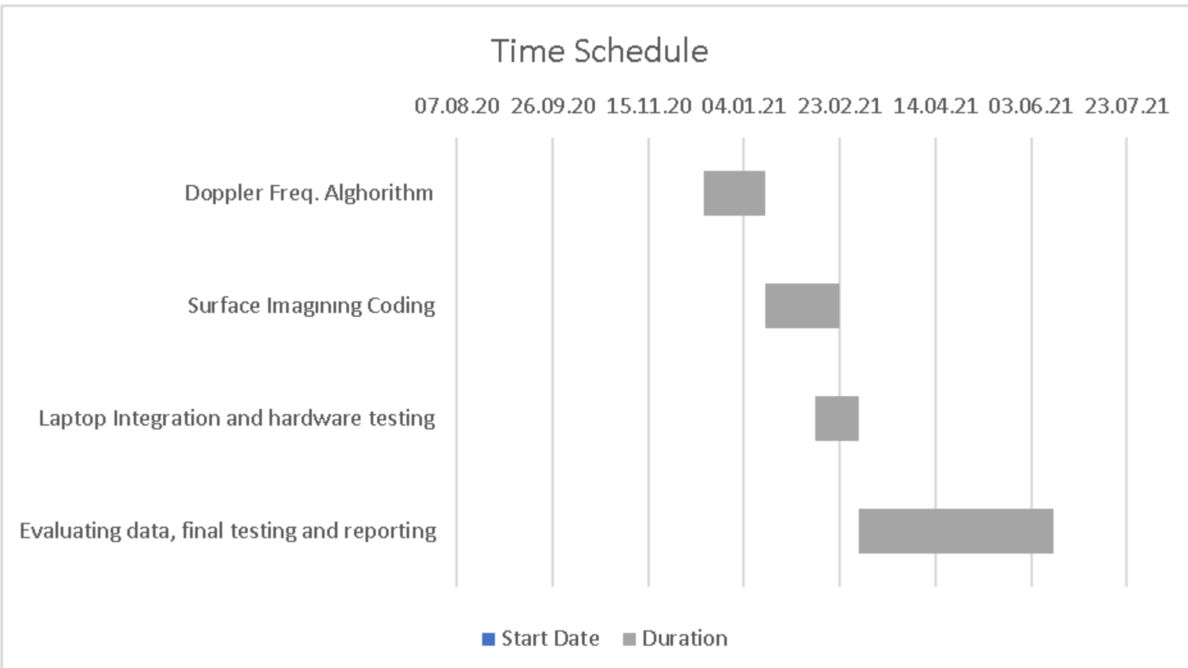

Fig. 5: Time Schedule

6. Realistic Constraints

a. Social, Environmental and Economic Impact

Since radio waves are used in this project, it can help people to easily detect moving or stationary objects around without the need for any light environment. In some cases, even objects inside walls can be detected and this can benefit people in many areas.

Radio waves are used in many areas around the world and since it does not have any destructive effect on the environment, this project does not cause any harm to the environment or people.

There are many types of radars and they generally have economically high costs. However, this project's cost is much lower than other radars.

b. Cost Analysis

Table. 6: Cost analysis.

Matlab Licience	275$
Books	100$
Salary 28 weeks x 20$	560$
Total	935$

c. Standards

This project will obey IEEE 521 - Standard Letter Designations for Radar-Frequency Bands and I2C standards.

EU/NATO/US ECM Bands	IEEE Band	Frequency
A	HF	3 - 30 MHz
B	VHF	30 – 330 MHz
C	UHF	300 MHz – 3 GHz
D	L	1 -2 GHz
E, F	S	2 -4 GHz
G	C	4-8 GHz
H,I	X	8 -12 GHz
J	Ku	12 – 18 GHz
K	K	18 -27 GHz
K	Ka	27 – 40 GHz
L,M	mm	40 – 100+ GHz

Fig. 6: Radar frequencies

7. References

[1] **Url-1,** https://www.researchgate.net/publication/330951560_Assisting_the_visually_impaired_Multitarget_warning_through_millimeter_wave_radar_and_RGB-depth_sensors

[2] **Url-2,** https://www.radartutorial.eu/02.basics/Frequency%20Modulated%20Continuous%20Wave%20Radar.en.html

[3] **Url-3,** https://ocw.mit.edu/resources/res-ll-003-build-a-small-radar-system-capable-of-sensing-range-doppler-and-synthetic-aperture-radar-imaging-january-iap-2011/

[4] **Url-4,** http://dart.ece.ucdavis.edu/education/files/eec134-2015-2016/Team_Hertz/AN_Amanda_Williams_+.pdf

[5] **Url-5,** https://ocw.mit.edu/resources/res-ll-003-build-a-small-radar-system-capable-of-sensing-range-doppler-and-synthetic-aperture-radar-imaging-january-iap-2011/lecture-notes/MITRES_LL_003IAP11_lec03.pdf

[6] **Url-6,** https://polen.itu.edu.tr/xmlui/bitstream/handle/11527/7685/14099.pdf?sequence=1&isAllowed=y

[7] **Url-7,** http://www.codar.com/images/about/1973Barrick_FMCW.pdf