Range Estimation

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Description:

The purpose of this report is to understand and implement a range estimation method with matlab. I will be deriving the range estimation method by performing step-frequency Frequency Modulated Continuous Waveform (FMCW) radar imaging using FFT. I will use data taken by a ground-penetrating radar (GPR) unit of a walkway in front of Broida Hall. The GPR gathered data at 200 positions 2.13 cm apart and at each position it sends 128 equally spaced microwaves frequencies starting at 0.976 GHz and ending at 2.00 GHz.

Method:

The main idea of this method is to find the time delay of the received signal of each frequency sent by the GPR, this time delay can be translated into distance as such:

$$R = \tau * v/2 \qquad where\ \tau\ is\ the\ delay\ and\ v\ is\ the\ velocity\ of\ the\ wave.$$

It is important to remember that since the signal travels twice the depth of the object before returning to the receiver, we must divide the time delay by two to get an accurate distance reading. We must also keep in mind the permittivity of the ground when calculating our signal propagation velocity. Since $\varepsilon_r\ is\ 6$, we can assume that the velocity at which the wave propagates is $v = c/\sqrt{6} = 122474487.1\ m/s$.

Both the transmitted and received signal can be modeled in phasor form for simplicity, where the received signal is attenuated and time-delayed in reference to the transmitted signal.

$$Transmitted\ Signal:\ Ae^{-jw_nt}$$
$$Received\ Signal:\ \alpha Ae^{-jw_nt}e^{-jw_n\Delta t}$$

In order to find the time delay of the signal, we multiply the transmitted signal with the conjugate of the received signal. This cancels the common phase term and leaves the phase term containing the time delay information.

$$Resulting\ signal:\ Ae^{-jw_nt} \ * \ \alpha Ae^{jw_nt}e^{jw_n\Delta t} \ = \ \alpha A^2e^{+jw_n\Delta t}$$
$$Substituting\ for\ \Delta t\ and\ w_n:\ \alpha A^2e^{+j2\pi f(2R/v)} \ = \alpha A^2e^{+j2\pi k\Delta f(2R/v)}$$

We can now start to see how we will derive distance information from the data given. After taking the FFT of at each position to get the range profile, we can match the complex exponential of the FFT operator to the time delay exponential in our resulting signal to derive a relationship between the FFT points and the distance at which an object is present.

$$Matching\ exponentials:\ e^{j2\pi k\Delta f\,(2R/v)} = e^{j2\pi nk/N}$$

$$j2\pi k\Delta f\,(2R/v) = j2\pi nk/N$$

$$k = N\Delta f\Delta t = N\Delta f\frac{2R}{v} = \frac{N\Delta f}{v}2R \quad where\ N\Delta f\ is\ the\ bandwidth\ and\ v\ the\ velocity\ of\ the\ signal$$

In our dataset the bandwidth is $2.00\ GHz - 0.976\ GHz = 1.024\ GHz$. With the above equation, we are able to map all FFT points to the object's distance to ground. Since we are not given the transmitted signal's amplitude, we are not able to normalize the range profile but instead we will use color mapping to show the highest values relative to each other.

Outcome:

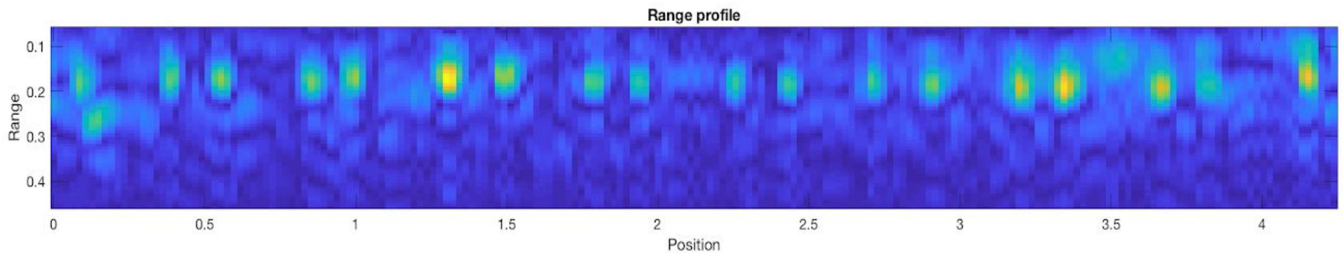
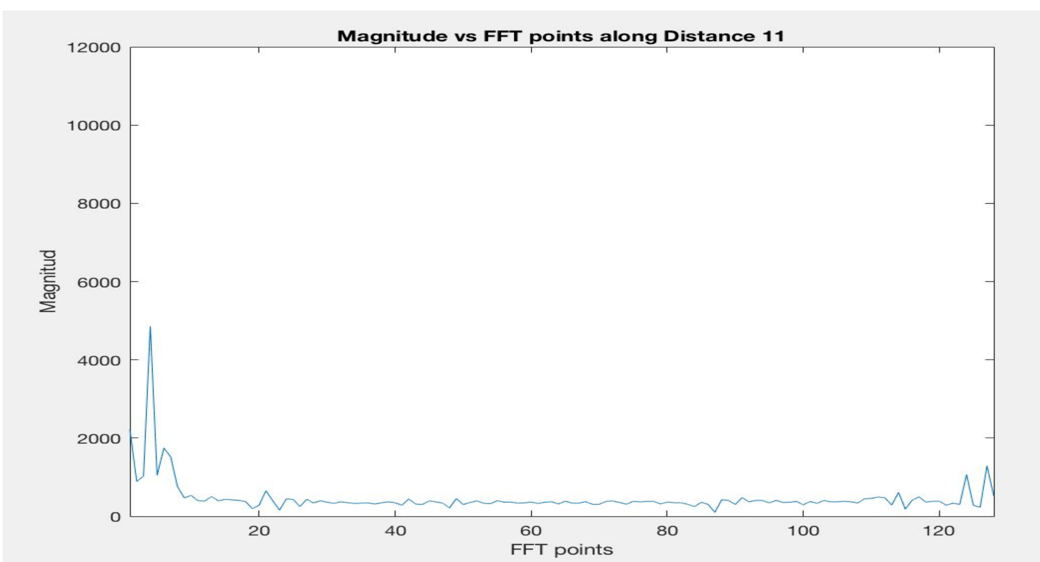
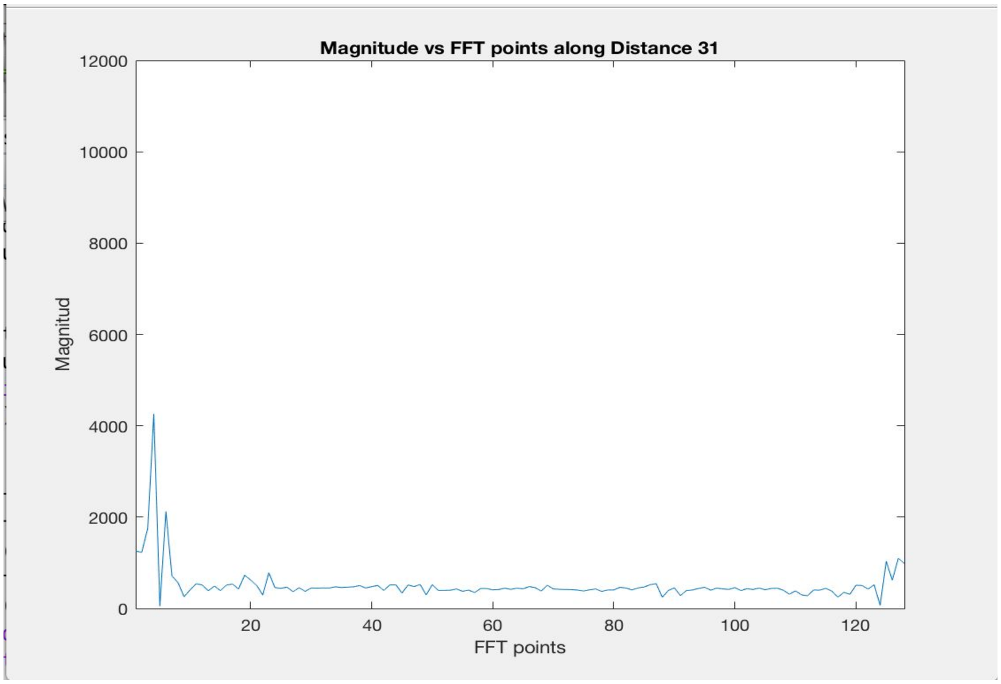
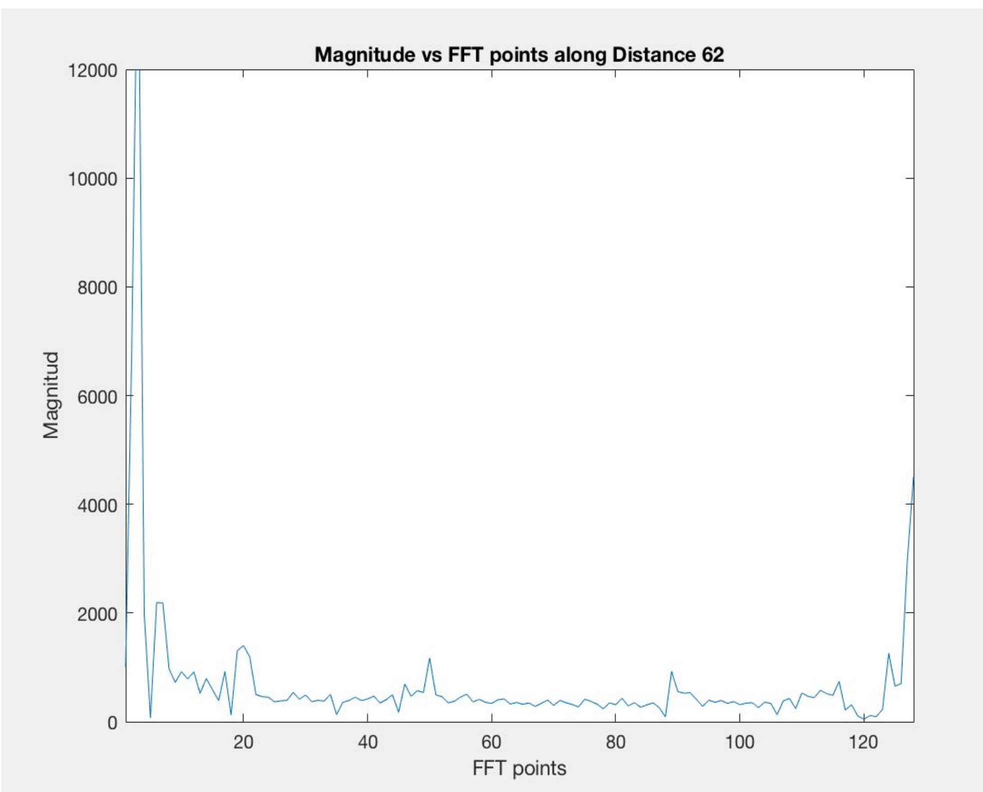


Figure 1

Figure 1 shows the range profile along 4 meters of a sidewalk in front of broida hall. It is clear that most objects are found at approximately 0.2 meters from the surface. Next I will show a few snapshots of a short video which iterates through each of the 200 positions and shows the magnitude of each FFT point which linearly maps to the range.




Magnitude vs FFT points along Distance 31
Magnitud
FFT points
12000
10000
8000
6000
4000
2000
0
20
40
60
80
100
120


Magnitude vs FFT points along Distance 62
Magnitud
FFT points
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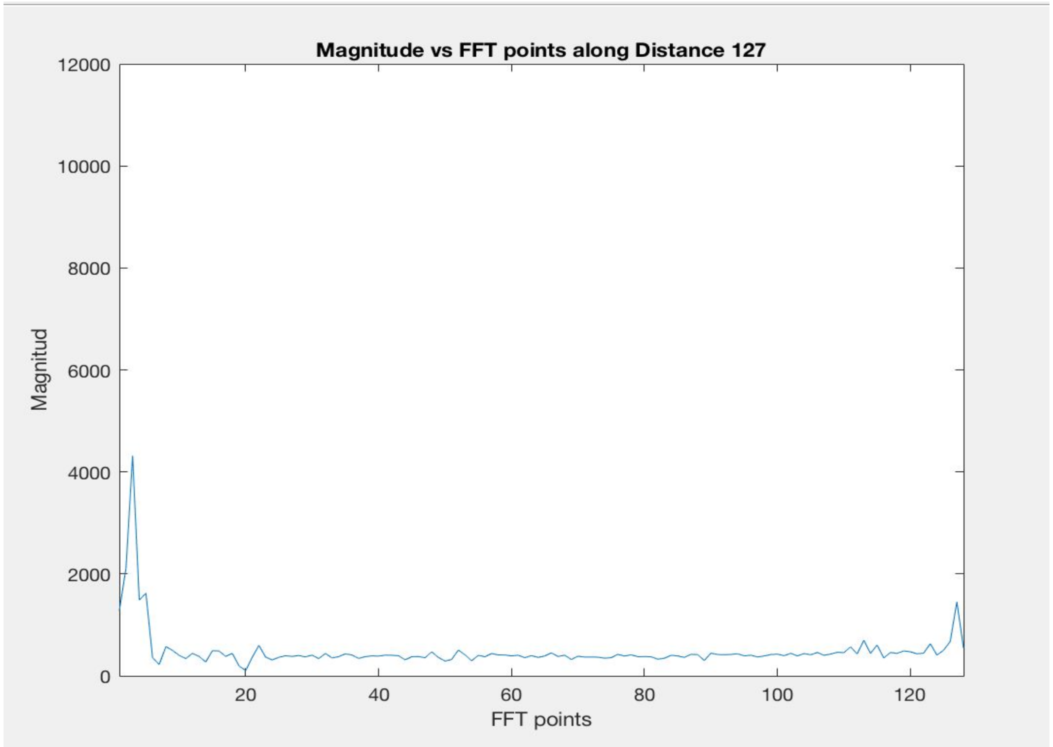
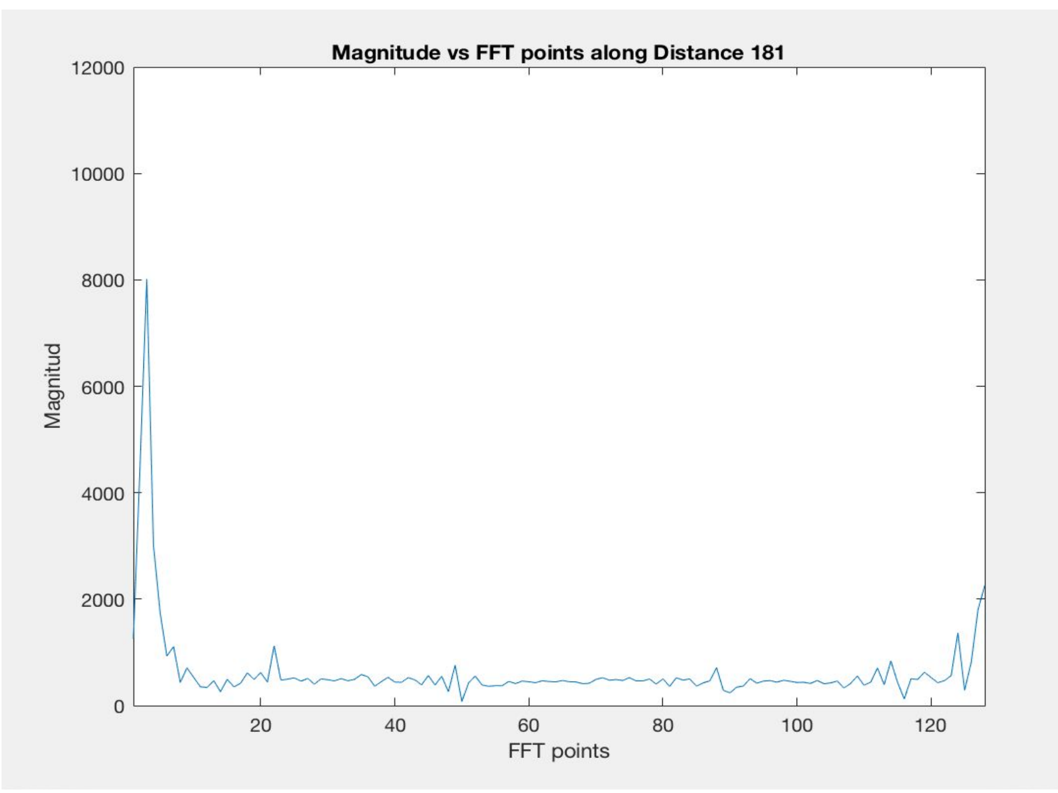
10000
8000
6000
4000
2000
0
20
40
60
80
100
120


Magnitude vs FFT points along Distance 127
12000
10000
8000
6000
4000
2000
0
Magnitud
20
40
60
80
100
120
FFT points


Magnitude vs FFT points along Distance 181
12000
10000
8000
6000
4000
2000
0
Magnitud
20
40
60
80
100
120
FFT points

Discussion:

From completing this assignment, I have acquired a better understanding of the range estimation method and have gotten insight into the duality present between this application and the bearing angle estimation. I have demonstrated in this method how to work from the frequency spectrum and work backwards to get the time delay and range of objects underground. This method has a couple advantages than attempting impulse response techniques. For one, you are able to control the resolution of the output by adjusting the bandwidth of signal to transmit and it is a less disruptive approach than a massive impulse.