ECE 278C Assignment 6: Multi-frequency GPR Imaging

Tyler Hattori
University of California, Santa Barbara
thattori@ucsb.edu

Abstract

In this assignment, the backward propagation methods demonstrated in Assignments 4 and 5 are applied to FMCW GPR data. The method from Assignment 4 highlights the effect of bandwidth, while the method from Assignment 5 highlights the effect of the aperture. I show that either reconstruction process results in an accurate depiction of the rebar beneath the ground where the data was measured. Only the phase term in Green's function is considered.

1. Introduction

In Assignment 4, I saw that the backward propagation technique reconstructs a source region more accurately when a wide band of operating wavelengths is considered. In Assignment 5, I extended this concept to the realization of range profiles at each individual point along the receiving aperture. I saw that overlaying these range profiles yielded the same reconstruction as in Assignment 4. In this assignment, I consider FMCW data taken at even intervals along the walkway outside Broida Hall. By treating these data measurement points collectively as a receiving aperture, the rebar locations can be found through backward propagation. In the following sections, the reconstruction methods from Assignments 4 and 5 are individually explained and applied to the FMCW data.

2. Assignment 4 Method

I first perform 128 individual reconstructions by back propagating the FMCW data at every data point for $n = 128$ different operating frequencies. By overlaying each of these 128 individual reconstructions I obtain the wideband sum reconstruction. In this section I denote n as the number of overlayed reconstructions—or the number of operating frequencies in the band.

I define the y location of my aperture as the ground, $y = 0$. I space the data points of the aperture according to the measurement procedure in the assignment prompt by placing them from $x = 0$ to $x = (200)(0.0213cm) = 4.26m$. Because I want to determine the locations of the rebar underground, I define the source region as the space beneath the aperture. Applying the reconstruction technique with this setup allows the y axis to denote the depth of the rebar locations underground, where the rebar locations appear as peaks in the source region. Figure 1 shows the gradual reconstruction of the source region as n increases. Figure 2 shows the corresponding spectrum.

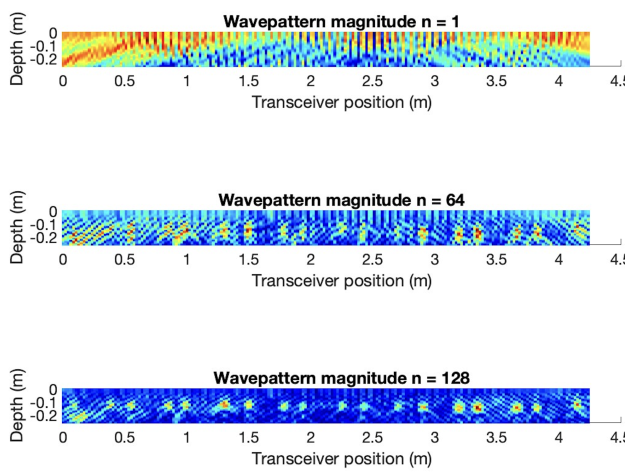

Figure 1. Sum reconstruction for $n = 1$, $n = 64$, and $n = 128$ from the top

The plots in Figure 1 can be thought of as diagrams representing the ground directly underneath the aperture. The 200 data points on the aperture evenly span the top of each source region at $y = 0$, which represent the 200 locations on the ground where data was gathered. I see that the determined locations of the rebar gradually become more precise as n increases. Moreover, I see that the rebar appears at a depth of about 12cm.

The spectrum of the reconstruction is characterized by a peak along the y axis that grows in length as n increases. This makes sense because for any given n every data point along the aperture is back propagated, so the spectrum retains its angular shape but grows radially as the number of

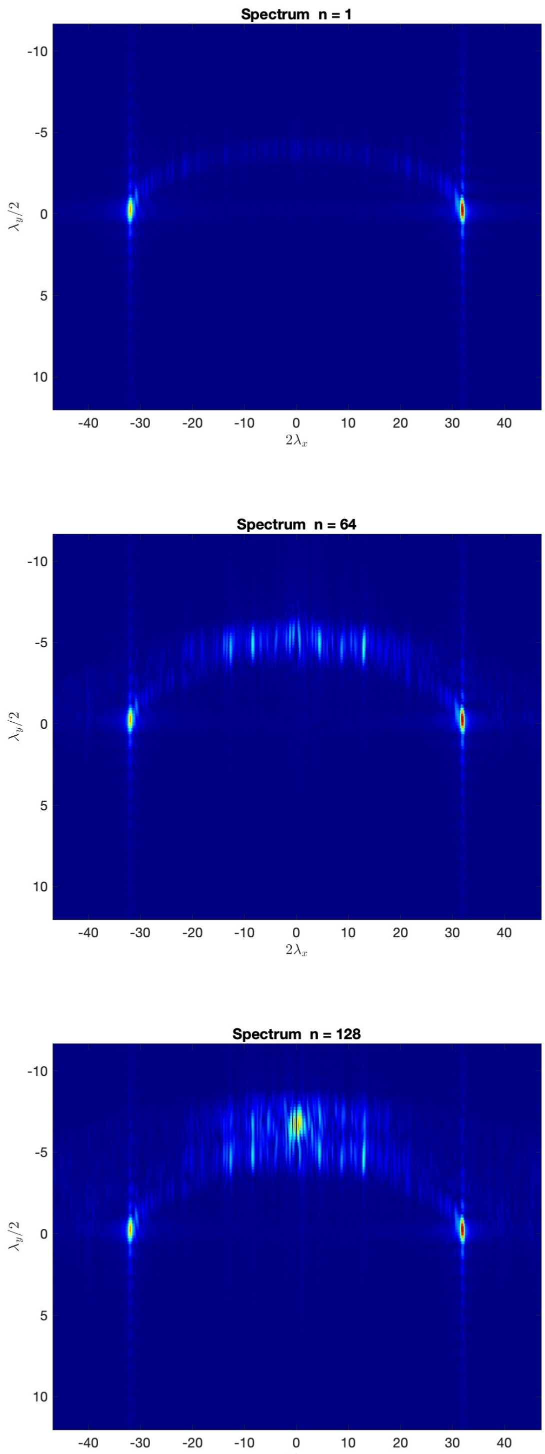

Figure 2. Sum reconstruction spectrum for $n = 1$, $n = 64$, and $n = 128$ from the top

operating wavelengths increases. The "arc" from earlier assignments has peaks only at certain points because of the unique distribution of the rebar source locations. However, the arc lightly spans the entire upper half of the circle. This is because the source region is directly under the aperture, so the plane waves are coming from a wide range of directions but are all travelling downward.
The spectrum at the final value of n spans from about $\lambda = 8$cm to $\lambda = 16$cm. This aligns with my expectation, as the range of operating frequencies during the measurement process was 0.976GHz to 2GHz. The conversion from frequency to wavelength is shown below.

$$\lambda = \frac{0.976GHz}{c\sqrt{6}} = 7.97cm$$
$$\lambda = \frac{2GHz}{c\sqrt{6}} = 16.34cm$$

3. Assignment 5 Method

I now perform the reconstruction by computing the range profile at each individual data point along the aperture and gradually overlaying these profiles from the left-most data point to the right. A data point's range profile is created by backward propagating the data 128 times using 128 different operating wavelengths. The resulting reconstruction forms a ring (i.e. a band) of potential source locations that could have resulted in the received data. By overlaying the range profiles of each of the $n = 200$ data points, the peaks in the sum reconstruction naturally occur at the intersections of the rings from each individual range profile. I follow the same physical setup for the aperture as in the last section. In this section, n denotes the number of data points on the aperture that are included in the reconstruction. Figure 3 shows the sum reconstruction as n increases. Figure 4 shows the corresponding spectrum.

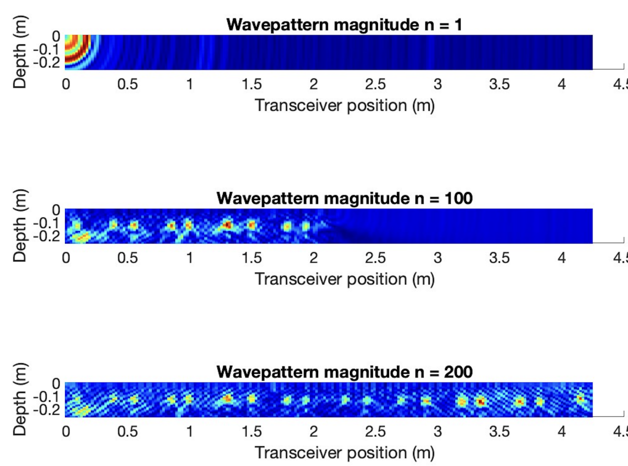

Figure 3. Sum reconstruction for $n = 1$, $n = 100$, and $n = 200$ from the top

I see that the range profiles gradually add together to create

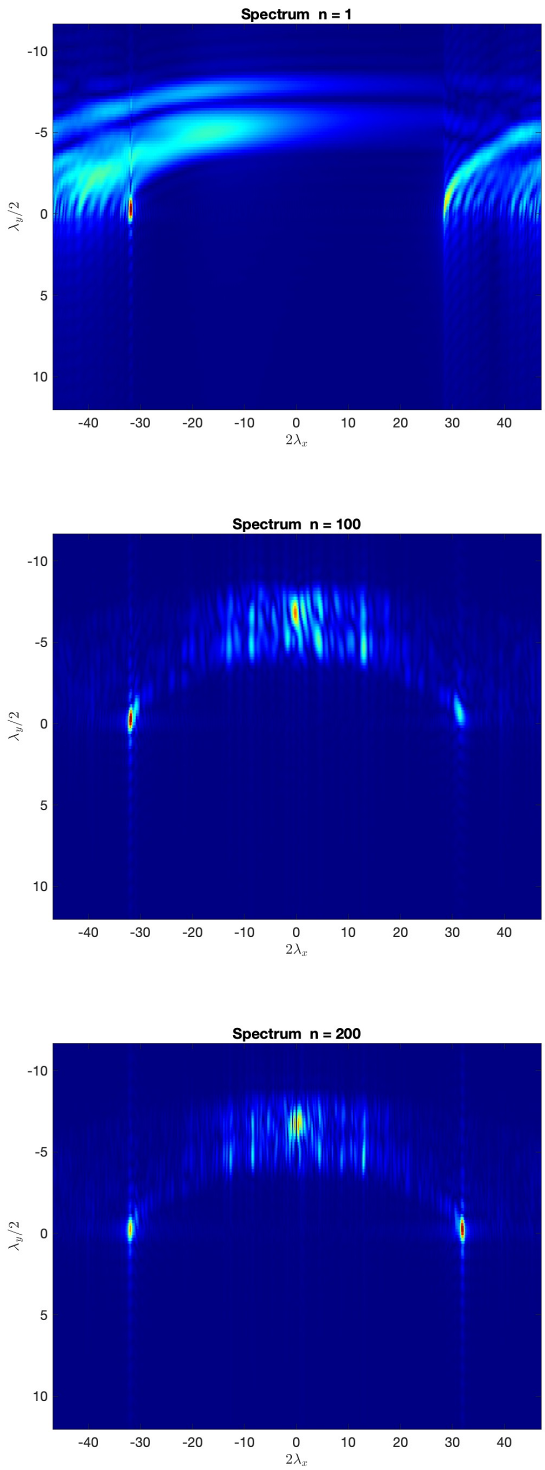

Figure 4. Sum reconstruction spectrum for $n = 1$, $n = 100$, and $n = 200$ from the top

peaks at the rebar locations. Moreover, I see that the final reconstruction and its corresponding spectrum are the same as the results from the last section. Again, I see that the rebar appears at a depth of about 12cm.

The spectrum of this reconstruction maintains its radial length for all n. This is because the range profiles contain wideband content, so the band of operating wavelengths is apparent even for the initial values of n. This spectrum also becomes symmetric about the y axis only as n approaches its final value. This reflects the process of gradually overlaying the range profiles from left to right across the aperture as n increases. These observations match my results in Assignment 5.

4. Conclusion

I have shown that the backward propagation technique can be used in its wideband form or range profile form to reconstruct a source region. I saw that these methods have their own advangtages. For example, reconstruction by overlaying range profiles allows for a consisent rebar depth estimate for any value of n. Moreover, this method accurately determines the rebar locations before the final value of n has been reached! This makes sense because we could have taken less than 200 data points along the aperture before carrying out the reconstruction.

However, the range profile overlay method has a diagonal spectrum for smaller values of n, which is hard to read (although this issue would be solved by calculating the spectrum on a thinner source region). On the otherhand, the wideband method has a consistent spectrum that is easy to read for all n and reasonably grows as more operating wavelengths are considered. Nevertheless, the reconstructions are the same when all wavelengths and aperture locations have been considered.