BIG PROJECT II: Performance Modeling of Airborne Side-Looking Stripmap SAR with Backprojection Image Reconstruction

ECE 430/530

Spring 2017

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Process and Reporting:

I. **SAR History** (A brief review of the technology and its development)

The early beginning to SAR started in the 1960's when NASA initially started to gather imaging data using passive imaging devices. Early military radar had been around for a period as well; however, this type of technology could not provide the global level of imaging found in the SAR. The technology for SAR enables it for good capability to resolve long-range dynamic systems due to the high-powered pulse and the antenna synthetization that allows for two-dimensional image generation. Before the 1950's most radar was denoted as side looking airborne radar, which could not provide good resolution due to the deterioration of the pulse at range. Due to these range constraints, military interest gave birth to SAR technology to attempt and improve upon the current radar technology. The first actual synthetic aperture radar was not developed until 1978 with the SEASAT. Throughout the 1980's, there was not significant development to SAR technology, and the primary advancements were in the derivatives to the SEASAT space borne satellite technology. Then, the 1990's created several different bands of SAR space borne satellites coming from countries like Canada, Japan, and Europe. Some of these developments included the polarimetry and interferometry for improving the quality of the resolution topology and the data return from the pulses. In the previous decade, several other major advancements have continued to propel the technology behind SAR. These techniques include the usage of tomography and advanced interferometry, which has further improved the imaging capabilities of the modern SAR in aspects of 360 degree imaging for volume scatters. Future SAR technology continues to push improving the standard characteristics of the radar like the range / azimuth resolution, multi-channel radar, and other aspects. From a space borne perspective, a SAR system may eventually be developed that could continually monitor the Earth's surface for different phenomena.

II. SAR Fundamentals

a. What is “SAR” (what gets “synthesized” and how an aperture is formed)?

SAR stands for synthetic aperture radar, and it still operates under the same underlying principles that standard radar uses for detection and transmission. Electromagnetic waves are pulsed through a transmitter, and the return pulses are detected and processed by the receiver. The main difference with SAR comes from the method of transmitting and collecting pulses. Essentially, SAR places an antenna on a moving object and transmits along the path. Each different transmission time corresponds to a different position point due to the movement of the object, and the processing of the returned signals allows for a synthetization of a much large antenna aperture than the aperture of the actual onboard antenna. Using this method of radar allows for imaging of the desired scene.

b. Resolution dependence

The resolution of the return imaging depends on several factors throughout the process of creating the SAR image. For the range compression, the sampling time for creating the vector of potential return times from targets determines from the start if targets will be distinguishable from each other. The max of the time vector depends on the size of the scene itself, whereas the time step to determine proper target resolution depends on the expected minimum distance possible between two targets. Smallest values for the time step in sampling should ensure proper target resolution. Another factor to consider with resolution is the grid size used when calculating the backprojection algorithm. Similar to the time step used in the range compression, the grid size is essentially the two dimensional time step used in resolving and compressing targets within the cross range Depending on the size of the scene, an appropriately large grid size is required to ensure that targets can be appropriately identified within the cross range. If too small of a grid size is picked, then the potential of not properly resolving a target exists. Another factor for range resolution comes from the antenna spacing used for synthetization. Changing the amount of points sampled for the antenna positions will impact the final results of the backprojection, even though it may not have a significant impact on the resolution.

c. Signal design and matched filter (MF) processing

For the signal design, the primary goal is to achieve an approximate 16-bit signal that will provide correlation for the matched filtering. These desirable characteristics include having low side lobes, high peak, and quick transition width with the main beam. There are several options when generating a good transmit signal for a SAR imaging simulation. One proven example of signals with good correlation comes from the barker codes. For most odd values less than 13, there exists a barker code that exhibits strong correlation properties for an application like SAR imaging. However, due to the length limitation, the barker code can be limited for only certain applications. Another option for signals with good correlation is the gold code, which involves using a left bit shift register and the logic gating circuits to generate the signals of arbitrary length that can have decent correlation. The desire for good correlation comes from the matched filtering process that will be required to achieve range compression. Matched filtering involves correlating the raw data from the return receiver with the transmit signal to generate a peak where the max peak amplitude occurs. In order to get good matched filtering, the signal must have good correlation properties. This will help ensure that the side lobes do not obscure any information during matched filtering and will help with maintaining good resolution within the scene.

III. Setup Outline

a. Target scene arrangement (show image of the created target scene) with all relevant dimensions

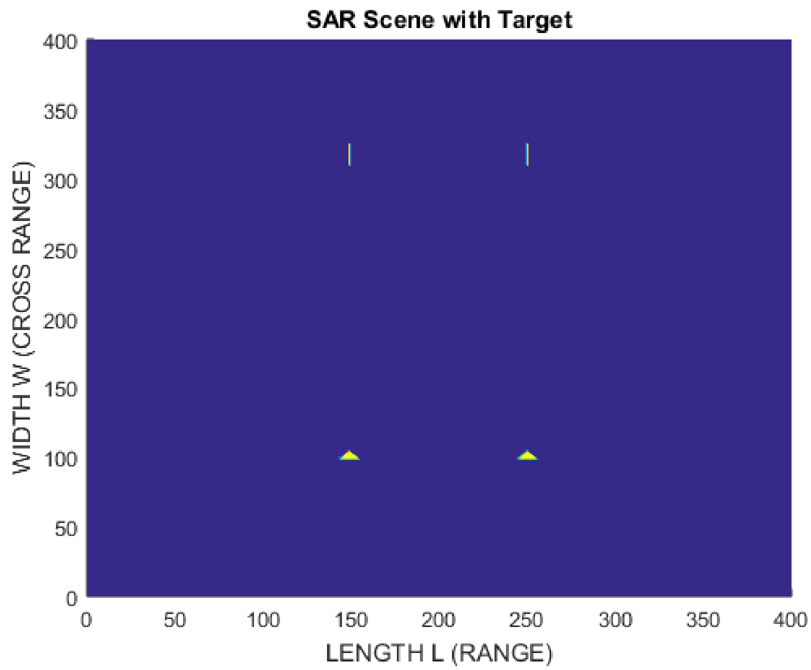

Figure 1 (2D Image of Scene with Target)

Figure 2 (3D Image of Scene with Target)

The scene consists of a 400 meter by 400 meter square that has 104 targets concentration, with the scene consists of two triangles and two beams emitted from the triangles. The synthetization utilized eight antennas when performing the algorithm.

b. Selected antenna pattern (show polar plot and the expression for your P(Θ))

$$P(\theta) = \cos(\theta) * \sin(\theta)$$

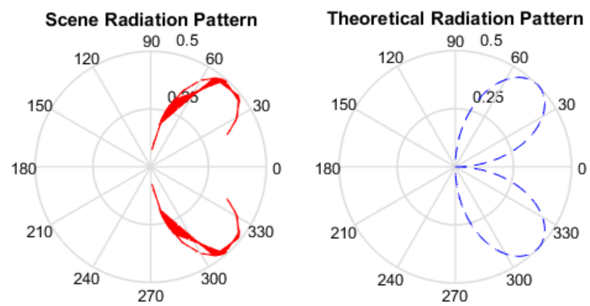

Figure 3 (Antenna Radiation Pattern)

The antennas pattern played an important role by affecting how the signal propagated. Depending on the angle that the transmit signal was incident upon the antenna determines how much of that transmit signal power is seen by the antenna. This can potentially obscure targets and hurt the imaging results that are generated by the backprojection, which means that the noise levels used will depend somewhat on the radiation pattern used on the transmit signal.

IV. Signal Design for Correlation

a. Design and plot your 16-sample SAR signal along with its autocorrelation function (ACF).

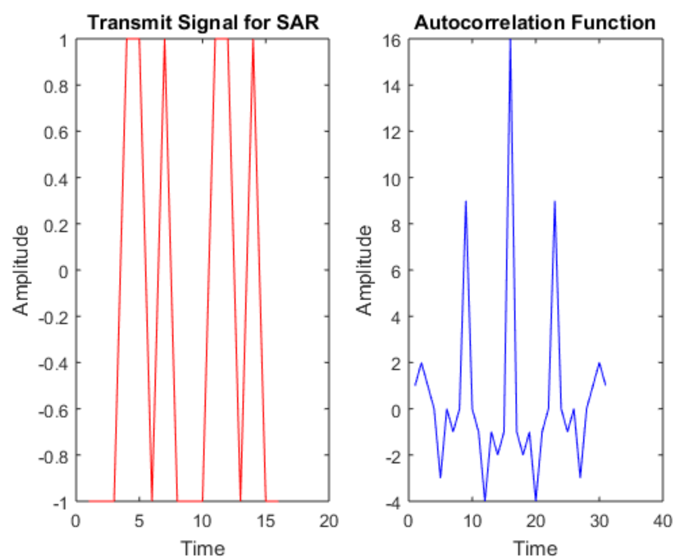

Figure 4 (Transmit Signal Based off Barker Code)

V. **Backprojection Algorithm** (Briefly describe the algorithm and show its block diagram)

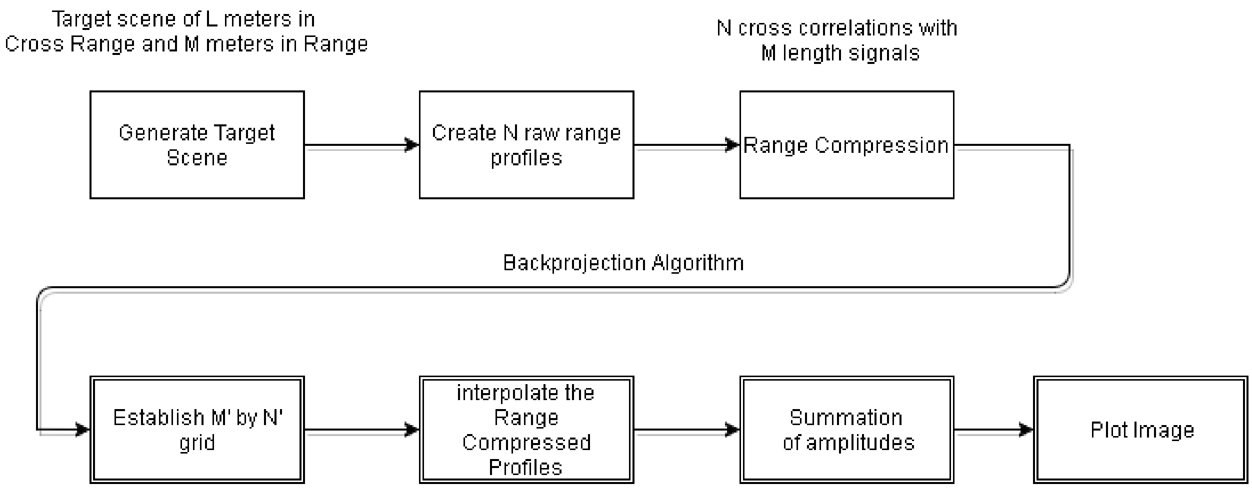

Figure (Block Diagram Demonstrating Backprojection Algorithm)

The backprojection algorithms primary goal is to provide cross range compression for the targets within the scene. To perform the backprojection algorithm, the requisite number of range-compressed profiles must be generated as a comparison library for the algorithm. Then, a grid of size M’ x N’ must be generated over the previously analyzed scene. Preferably, the grid should be finer than the dimensions of the scene. However, depending on the quality of resolution desired, this might be unnecessary. A potential middle step before performing the actual backprojection would be to interpolate the data so that the time range profiles are sufficiently populated with points when performing the backprojection. After interpolation, the primary step of backprojection involves iterating through the theoretical grid points and performing partial range compression. The partial range compression involves finding the max amplitude indexes for each range profile, and comparing those indices to a range profile library of the original targets. The theory is that as the theoretical grid points approach the actual target, the range profiles will become more and more similar. This will correspond to an overlap with amplitudes and the points closer to the targets will generate a larger heat map value. Then once all the comparison in the grid have been made, and the values for each grid point have been summed based on the range profile libraries, a two dimensional or three dimensional heat map can be generated. Due to the nature of the algorithm, there can be imaginary ghosting that will reflect imaginary returns that have equal return times to different antennas. However, the main targets should have rather noticeably larger peaks in comparison. The ghosting can also be eliminated by thresholding the image to ensure that the ghosting at partial locations can be partially reduced

VI. Simulation Results (Show the resultant reconstructed images of the target scene with

a). No noise;

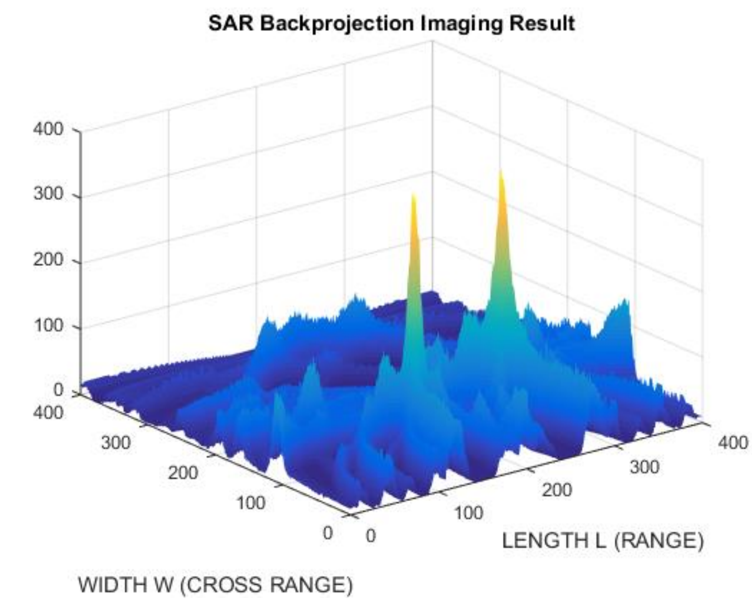

Figure (Noiseless Backprojection 3D Results)

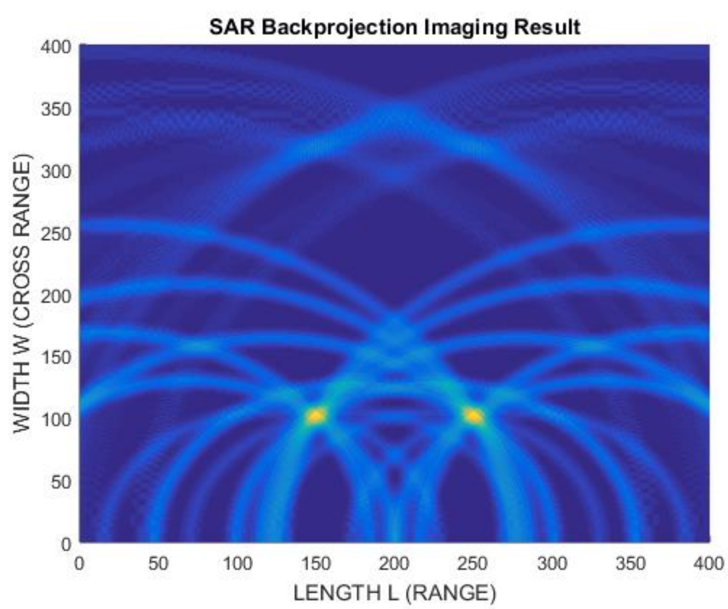

Figure (Noiseless Backprojection Results 2D) b). Low noise (AWGN);

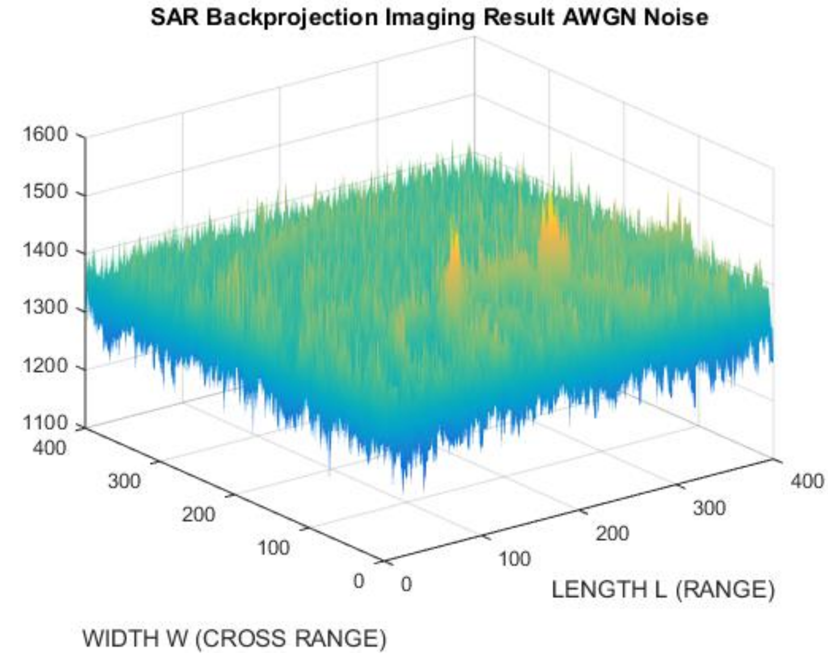

Figure (AWGN 3D Back Projection Results)

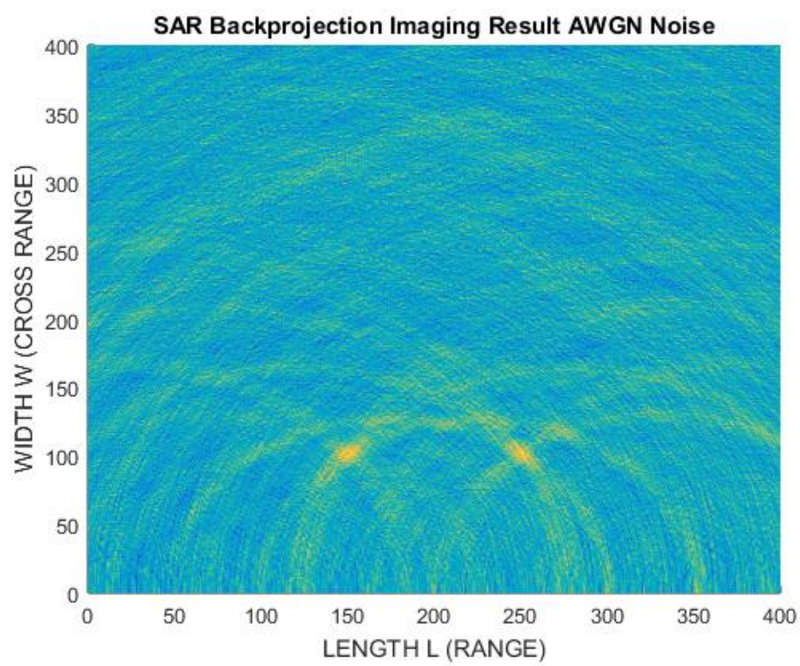

Figure (AWGN 2D Backprojection Results

c). Strong noise;

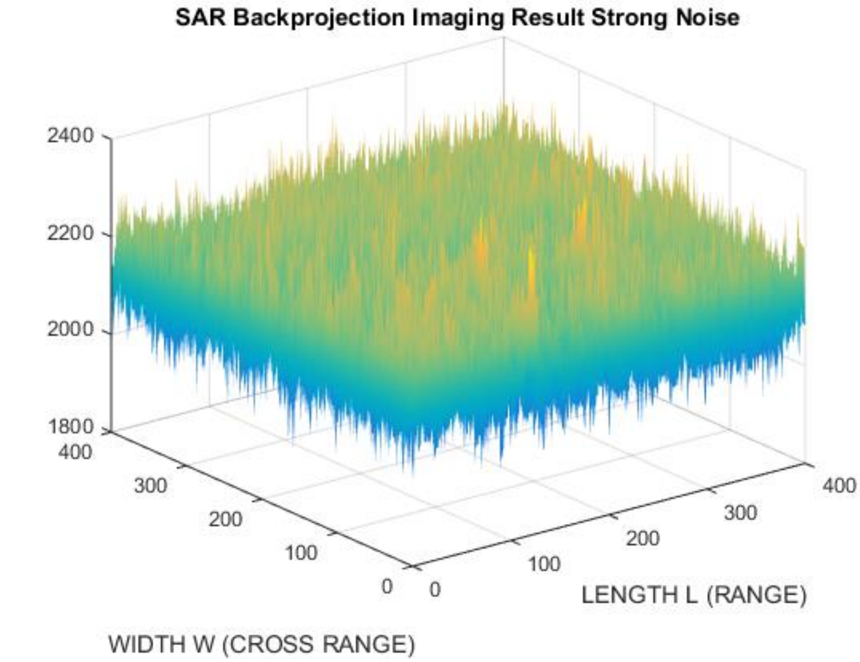

Figure (Strong Noise 3D Backprojection Results)

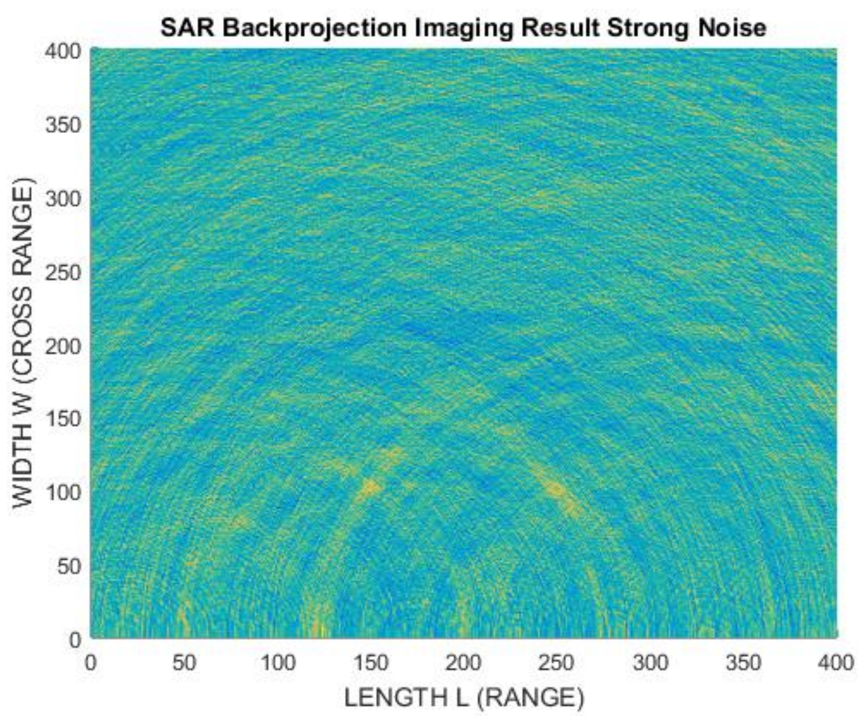

Figure (Strong Noise Backprojection 3D Results) d). Overwhelming Noise;

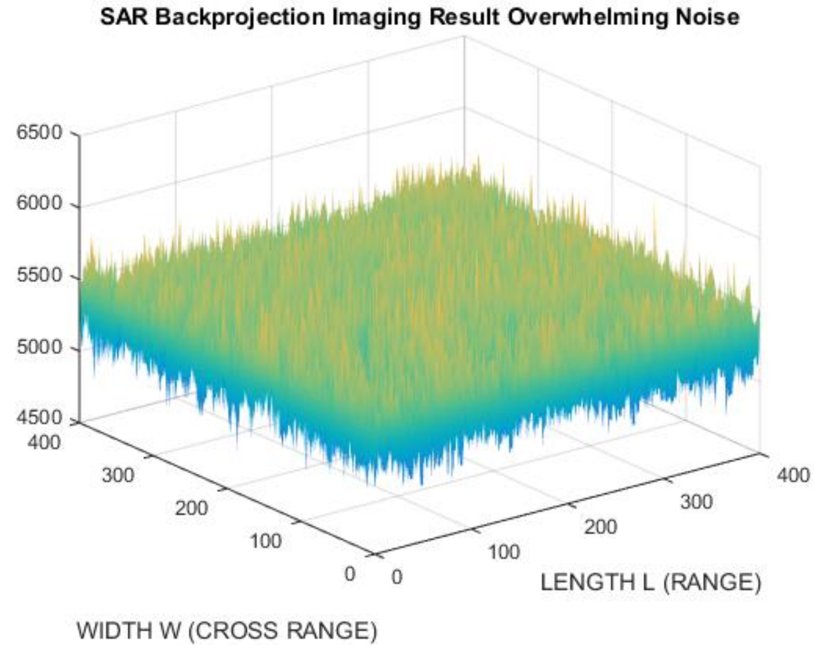

Figure (Overwhelming Noise Backprojection 3D Results)

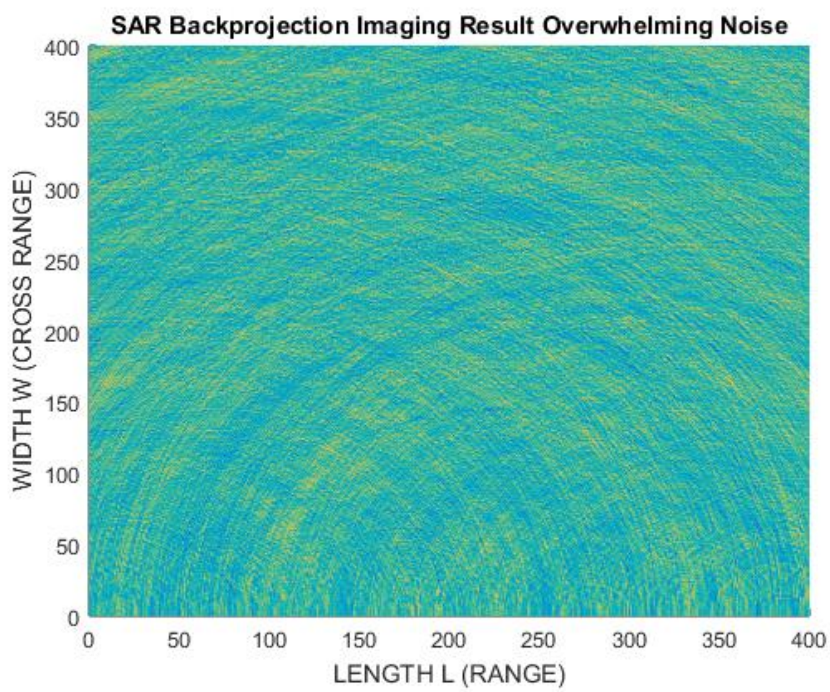

Figure (Overwhelming Noise Backprojection 2D Results)

VII. Conclusion and discussion

Starting with the noiseless results from the backprojection, the algorithm seems to perform fairly well at identifying potential targets. The scene was composed of several different types of targets, and was able to resolve the majority of the scene. The two main triangles returned with quite good resolution due to the high grid size and time sampling of the inverse of the speed of light. However, the difficulty in resolution came from the two beams further in the scene. Due to both the distance and partially due to the angle of the antenna location relative to the radiation pattern, the two beams were much less resolved compared to the triangles. This could also be due to the separation from the two main triangles, which may have also contributed to a pseudo ghosting that hurt the resolution of the two beams. Next, looking at the noisy profiles, only one profile had any recognizable scene still intact after the random corruption due to Gaussian noise. With regular AWGN, the two main triangles were still resolvable, but the beams were no longer distinguishable from the generated noise floor. The triangles were also much less defined compared to the noiseless environment. To improve upon the quality of the resolution in noise, the best solution appears to be having a signal with decent correlation to ensure the best matched filtering possible to try to get clear peaks from the noise floor. Obviously, matched filtering has limits, as both the strong and overwhelming noise prove to be too strong for the backprojection and range compression algorithms to surmount. With much larger coefficients, the noise floor is too large for the peaks to be distinguishable with matched filtering. Overall, the simulation seemed effective at resolving the targets. After generating the scene, the antenna radiation pattern determines how much of the signal actually is incident upon the antenna. Then the initial range profiles are generated as a comparison for the backprojection algorithm that would complete the compression imaging through SAR. With moderate noise, the algorithm was still able to resolve the stronger target returns.

References

[1] McCandless, Samuel, and Christopher Jackson. “Chapter 1. Principles of Synthetic Aperture Radar”. http://www.sarusermanual.com.N.p., 2017. Web. 15 June 2017.

[2] Moreira, Alberto et al. “A tutorial On Synthetic Aperture Radar”. Www2.geog.ud.ac.uk N.p., 2017. Web. 15 June 2017