Project 2

Radar Imaging

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UAV-SAR Imaging with Time Domain Back Projection

Introduction

The goal of this project is to process and analyze UAV-based Synthetic Aperture Radar (SAR) data using Time Domain Back Projection (TDBP) for high-resolution image reconstruction and evaluation.

The radar system onboard UAVs captures echoes from the environment. The aim is to process these echoes to form a detailed image of the scanned area.

Time Domain Back Projection (TDBP)

The TDBP algorithm uses multiple radar pulses to generate an image from the radar data. Each pulse's echo is processed, and by integrating these over different time samples, a coherent image of the environment is obtained.

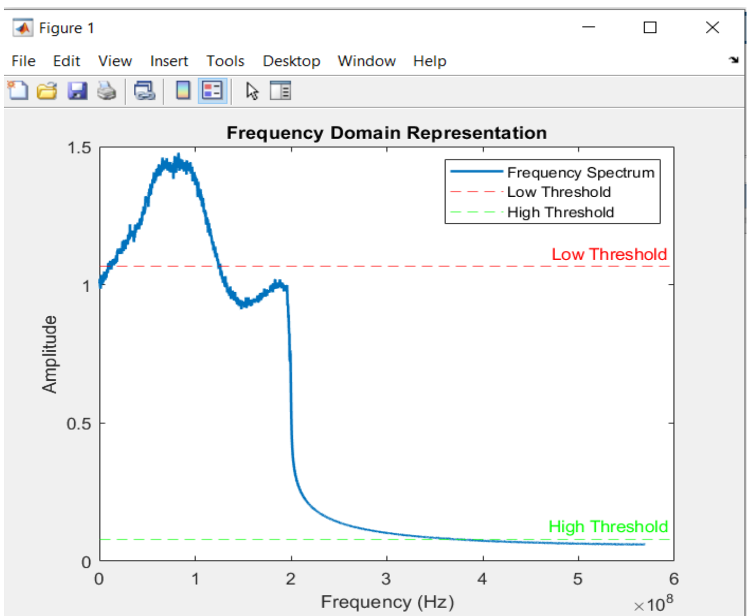
1) Range Resolution Assessment

In this part of the project, we focused on assessing the range resolution of the radar system, both with and without the knowledge of the bandwidth value. The range resolution defines the ability of the radar to distinguish between two objects that are close together in range. We followed a two-step approach to calculate the resolution.

Range Resolution without Known Bandwidth

we aimed to estimate the range resolution without knowing the bandwidth. The first step was to calculate the sampling frequency based on the data provided. Once we obtained the sampling frequency, we performed a Fast Fourier Transform (FFT) for each radar pulse to convert them into the frequency domain. From this, we calculated the average frequency and used it to estimate the bandwidth. As you can see, this is the result for this part.

```
The computed bandwidth is: 358478484.25 Hz
Range Resolution Estimate: 0.42 meters
>>
```



Range Resolution with Known Bandwidth

The first method assumes that the bandwidth (B) is known. Using this value, we applied the standard formula for range resolution:

$$\Delta R = \frac{C}{2B}$$

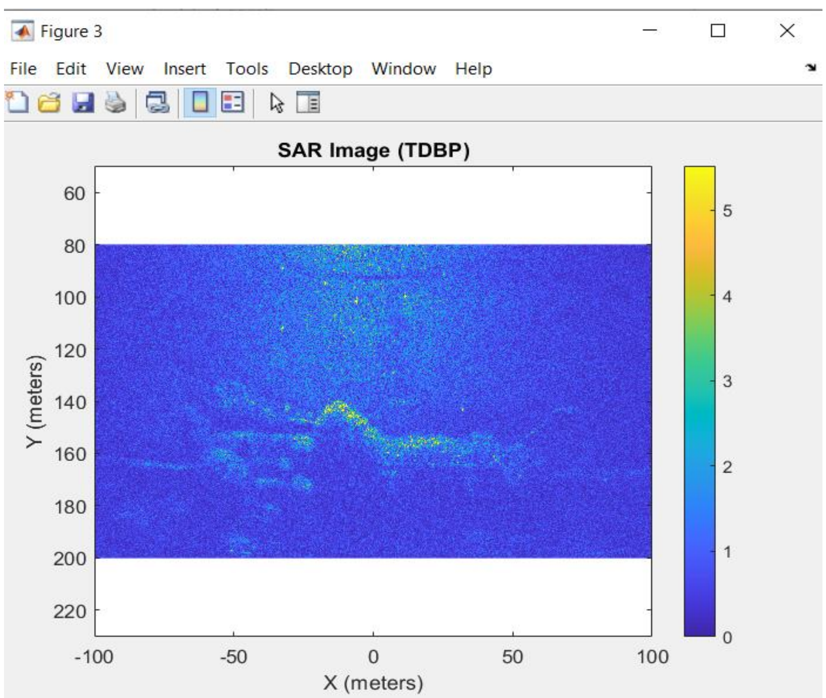
where c is the speed of light, and B is the bandwidth. After performing this calculation, the range resolution was estimated to be 0.38 meters.

```
>> Range_Resolution_with_Bandwidth
Range Resolution: 0.38 meters
fx >>
```

2) Time Domain Back Projection

In this part we Want to form the SAR image by implementing a TDBP. The initial radar image, generated from TDBP, showed significant detail about the environment under observation. The reconstructed SAR image was displayed with the X and Y axes representing meters.

```
Processing trajectory sample 4001 of 4001...
Execution Time: 78.41 seconds (1.31 minutes)
fx >>
```



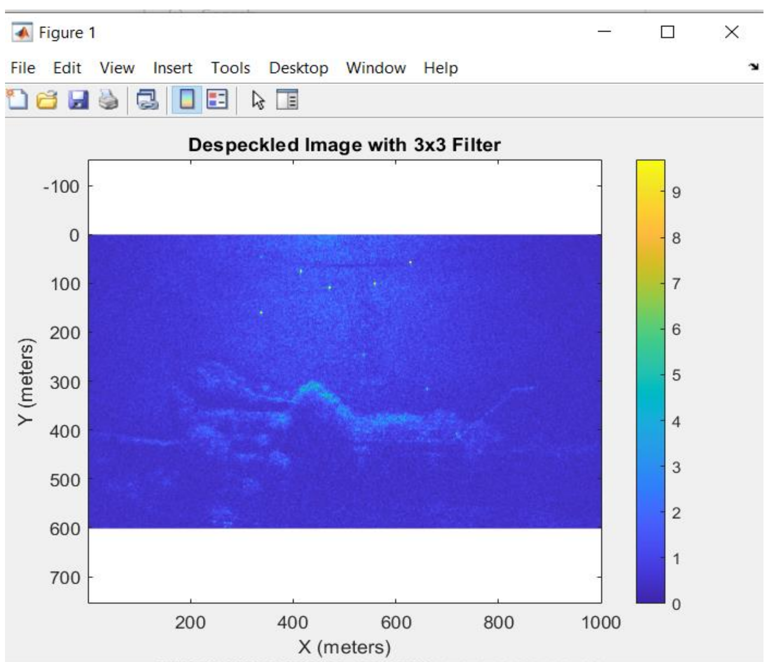
- The SAR image by radar image

- The image of the environment under observation

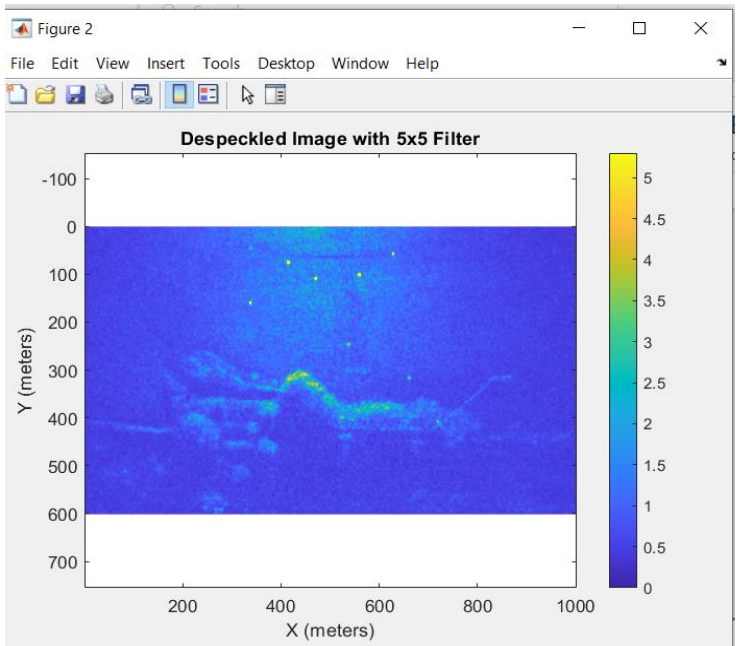
As you can see, the radar is able to slightly distinguish the image of the environment under observation.

3) Despeckling

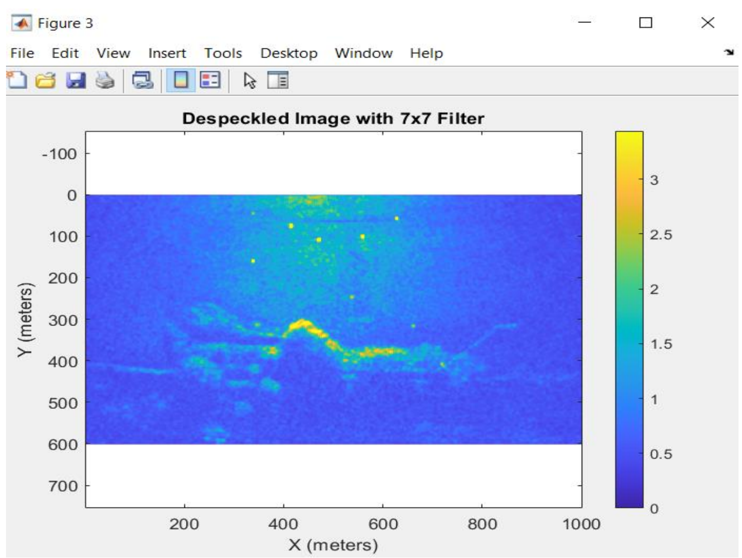
In this section of the project, the goal was to reduce the speckle noise present in the SAR image, which interferes with identifying image features. Different sizes of **2D moving average filters** (3x3, 5x5, and 7x7) were applied to the image to assess their impact on noise reduction.



3x3 Filter: A clear image with minimal noise reduction.



5x5 Filter: Slight improvement in image clarity.



7x7 Filter: Noticeable enhancement in image quality, with better noise reduction.

The despeckling process effectively reduced the speckle noise in the SAR images, improving the clarity and visual quality.

5) Resolution assessment using corner reflectors

Corner reflectors are strong reflectors in SAR images used to assess system resolution. By focusing on a small region around the corner reflectors at x = −6m and y = 101m, we can evaluate two types of resolution:

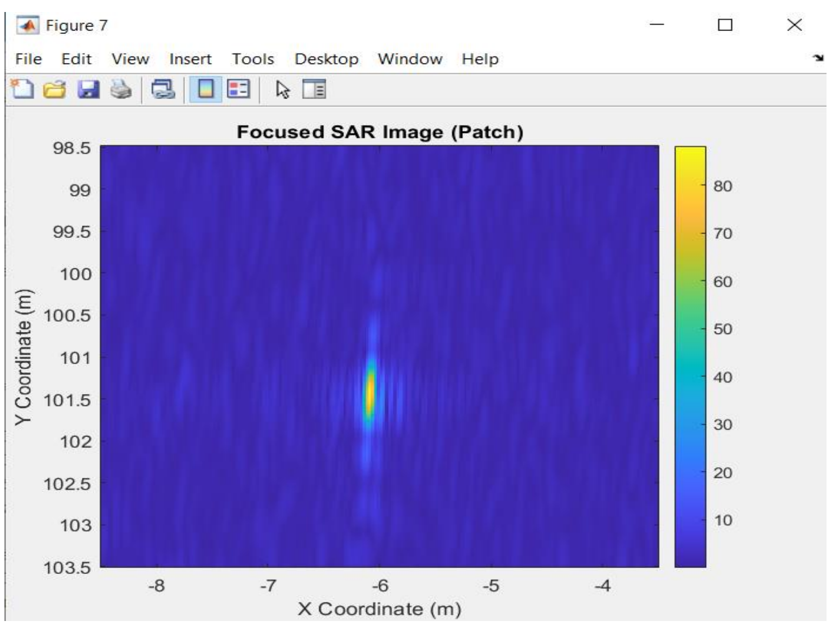
1) **Range Resolution (Y-direction)**:
   The range resolution was calculated by applying **FFT** on a focused patch in the Y-direction.
   Result: 0.4762 meters.

2) **Azimuth Resolution:**
   The azimuth resolution was determined using the formula:

$$Azimuth\_Resolution = \frac{\lambda . r_{P}}{2. L_{s}}$$

   Result: 0.3802 meters.

```
>> Corner__Reflectors
Azimuth Resolution: 0.3802 meters
Resolution in Y direction (FFT-based): 0.4762 meters
>>
```

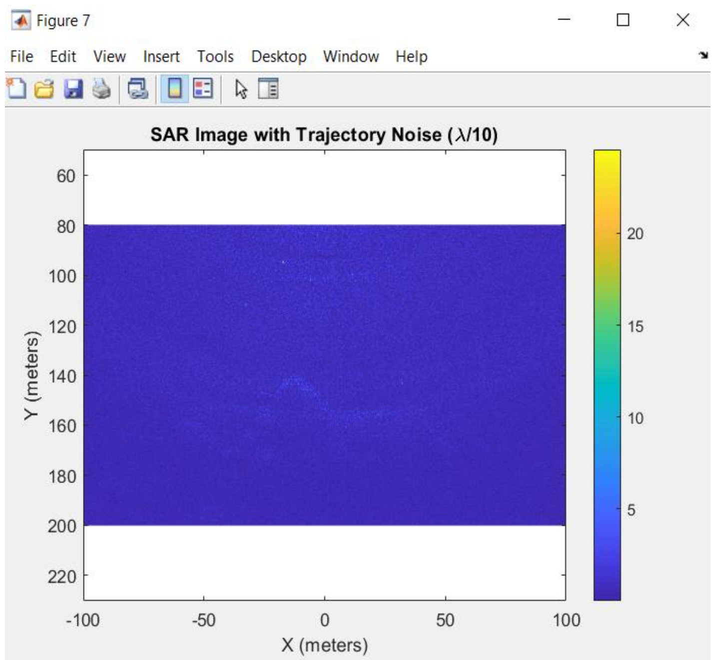


- SAR Image (patch)

6) The effect of trajectory errors:

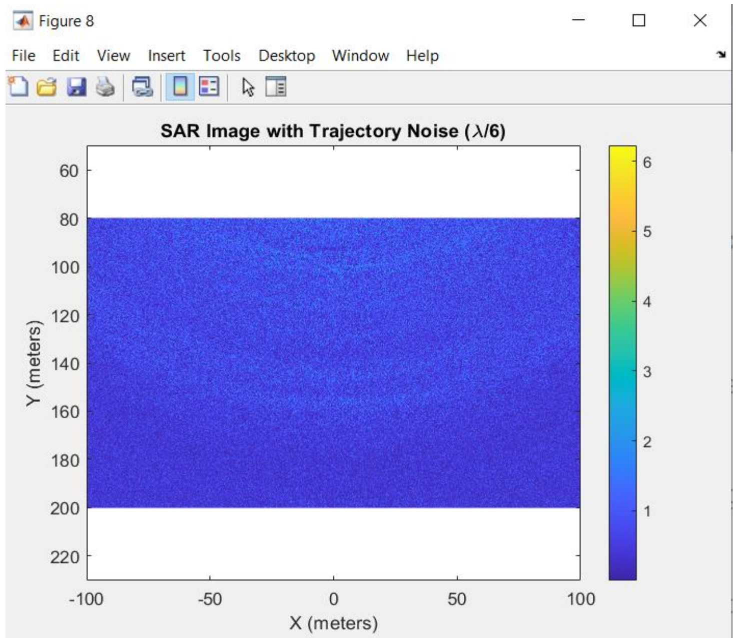
In this part of the project, we explored the impact of trajectory errors (caused by inaccuracies in the UAV's navigation system) on the quality of the SAR images. To simulate these errors, white noise was added to the trajectory data (X, Y, Z coordinates). The noise was introduced with varying standard deviations, such as λ/10, λ/6, λ/4, and λ/2, simulating different levels of inaccurate navigation.

Low Noise Levels: When the noise was minimal (λ/10), the SAR image remained mostly clear with minor distortions.

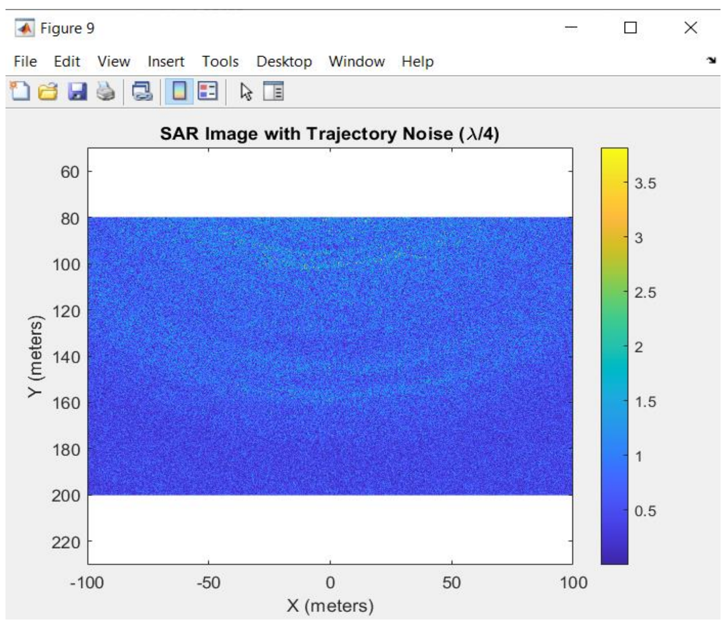


- SAR image with standard deviation $\lambda/10$

Higher Noise Levels: As the noise increased (λ/6, λ/4, λ/2), the image became blurrier and more distorted, with details lost progressively.

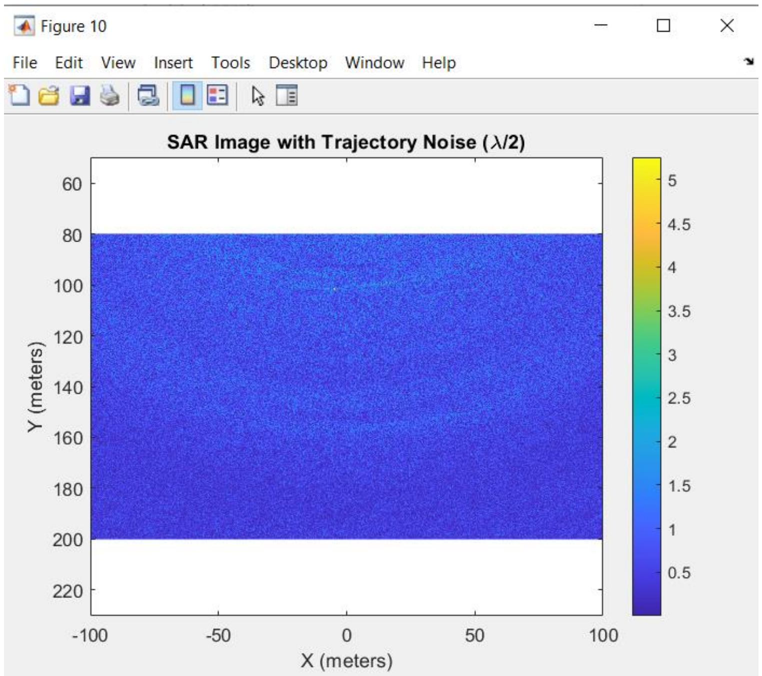


- SAR image with standard deviation $\lambda/6$



- SAR image with standard deviation $\lambda/4$

Maximum Distortion: The most significant distortion occurred when the noise was set to $\lambda/2$, where the image quality severely degraded and fine details were lost.



- SAR image with standard deviation $\lambda/2$

The processing time for generating the SAR images with noisy trajectory data was approximately 231.95 seconds (3.87 minutes). This time remained relatively constant across different noise levels, although higher noise levels slightly increased the computational load.

```
>> Trajectory_Errors
Execution Time: 231.95 seconds (3.87 minutes)
fx >>
```