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3D Synthetic Aperture Radar

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3D Synthetic Aperture Radar

SAR is an imaging technique using ultra wideband radio pulses. As the pulses reflect off objects and are received by the radar, the data is converted into distance measurements and used to generate images. In 3D SAR, precise location data, obtained using differential GPS, is used in conjunction with the radar distance measurements in order to create voxels, or three dimensional image pixels. This addition of location data reduces distortions and inaccuracies in 2D SAR imaging.

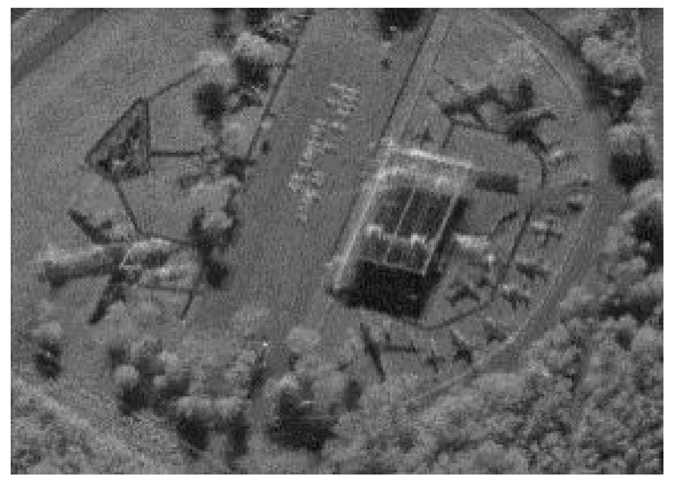


Figure 1: Distortions with 2D SAR

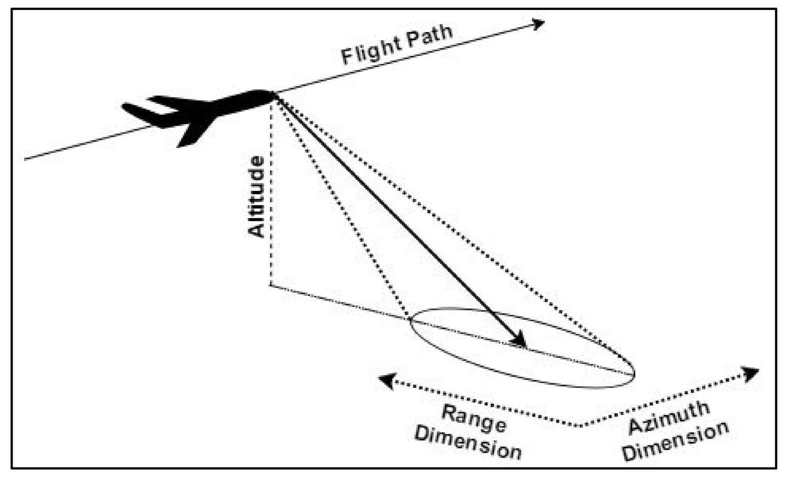


Figure 2: Example of Side looking radar system

A Low-Cost Solution

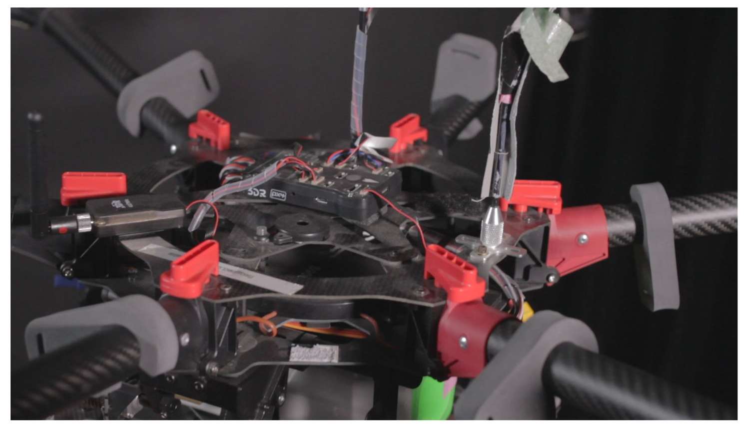
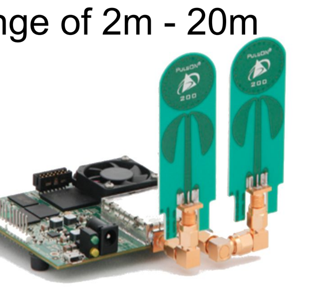


Figure 3: Blue Team's UAV and telemetry

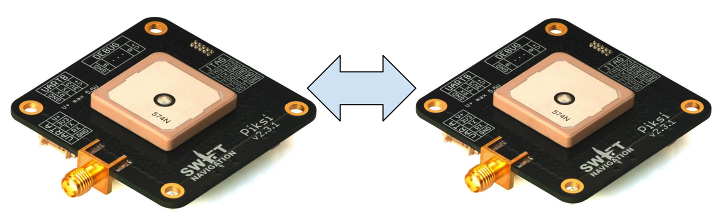
Traditionally SAR imaging is prohibitively costly, and implemented on large aircraft. By using a UAV platform and commercially available components, we were able to reduce the cost of the system, expanding its use in fields such as search and rescue and mapping applications.

System Integration

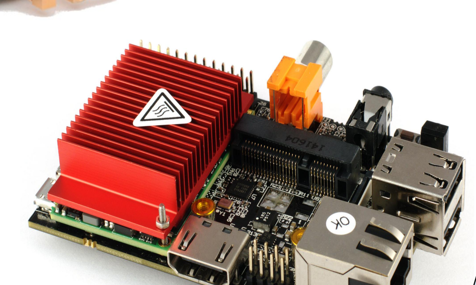
PulseON P410 Radar
- Center frequency: 4.3GHz
- Range of 2m - 20m



Remote   Base



Piksi Differential GPS
- Collects positioning data corresponding to each radar pulse
- Real Time Kinematic (RTK) lock allows for 2.2cm positional accuracy



Hummingboard Pro
- Coordinates radar and GPS data acquisition
- Stores all data collected for image processing

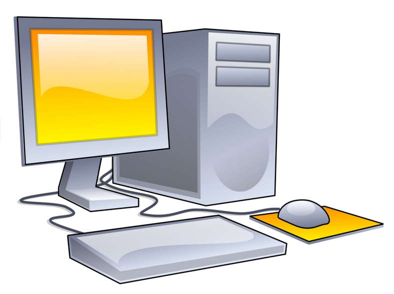


Image Processing
- Aggregate data and performs image formation and autofocusing.

Project Goal

To produce higher resolution voxels (3D pixels) using the data collected from the radar and gps systems on board. Improve data collection by modifying time synchronization between radar and gps systems.

Data Acquisition

Unfortunately due to legal restrictions, our team could not fly the UAV on or near Tufts campus. This issue, along with cold and wet weather, hindered our ability to obtain aerial image data.

Using the native Piksi GPS software (Piksi Console) we are able to observe that the differential GPS base station and remote receiver were connecting to satellites (fig. 4). For the next step, we will incorporate the GPS to work alongside the radar to collect and aggregate data via the Hummingboard.

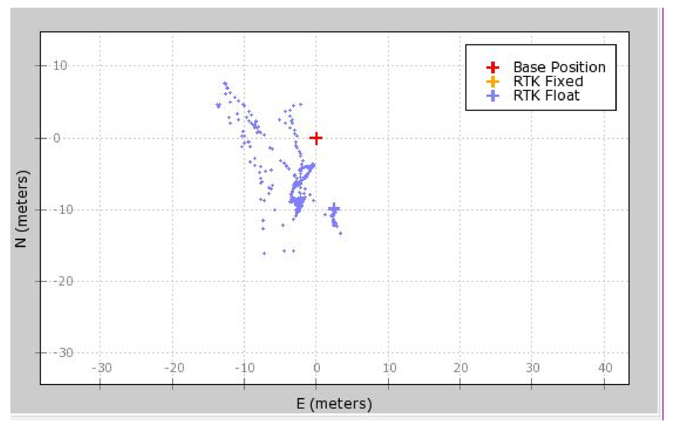


Figure 4: Differential RTK data from Piksi Console

Due to noise inherent in the radar amplification as well as the antenna system, there is significant noise in the obtained radar data between 2-4m, as seen in fig. 5 below, therefore distance measurements with this system are only accurate over long distances.

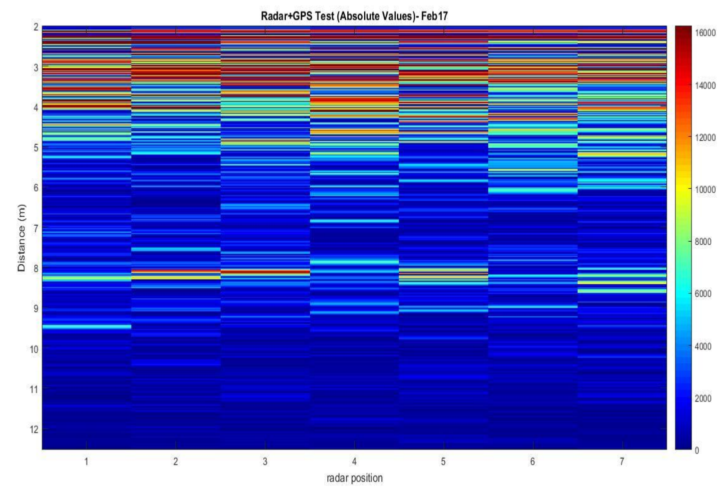


Figure 5: Distance measurements across radar sweep

Future Goals

For future 3D SAR measurements, data from an Inertial Navigation System on the UAV could be used in conjunction with the differential GPS system to obtain more accurate positioning data.

To speed up the image formation process, the MATLAB image processing code can be ported to C to use the Cuda API, increasing processing speed and efficiency.

Finally, additional work can also be done to improve the interpolation of GPS data in order to more accurately synchronize the timing of the radar and GPS data collected on the Hummingboard.

Image Formation

Once radar and location data has been collected, each vector of radar data corresponding to each pulse, as well as the location for each pulse, can be combined to generate image pixels. However, due to the random and jittery movement of the UAV, each pulse will have a phase error which will appear as blurriness in the image, and must be removed via autofocus algorithms.

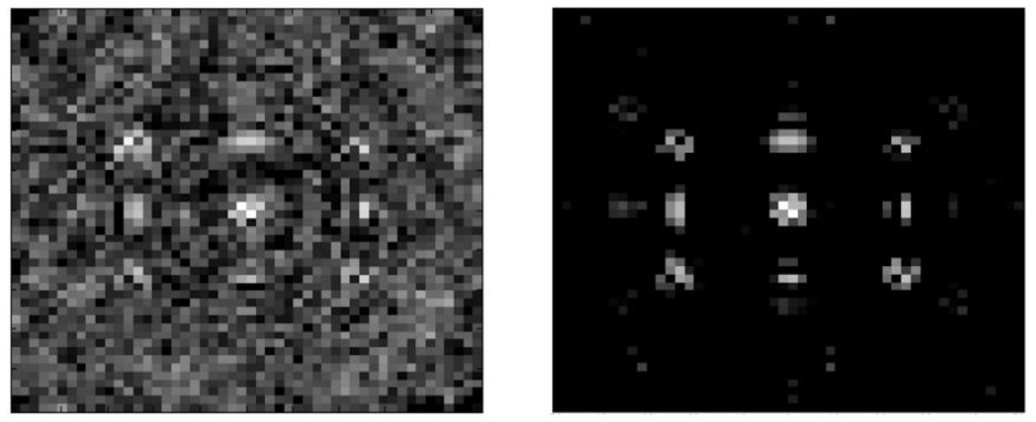


Figure 6: Nine defocused point scatterers (left), and same scene autofocused using the Minimum Entropy algorithm (right).

The minimum entropy algorithm used in our project for autofocusing involves minimizing the entropy S of the image. The gradient descent optimization algorithm was used to find the phase error correction vector ϕ(k) that minimized the entropy of the image S:

$$\hat{\phi}(k) = \arg\min_{\phi} S(\phi)$$

This optimization is done over k = 1 ... K dimensions, where K is the total number of pulses used to form the image. Since K is very large in typical SAR usage, our goal this year was to speed up autofocus by reducing the dimensionality of the gradient descent algorithm. We did this by using the Discrete Cosine Transform (DCT) to map the K dimensions to P coefficients of the DCT, where P can be fixed at as a constant at 20-50 orders. This method is effective because the UAV has inertia in the real world, and its movement can be modeled by a continuous and smooth function.

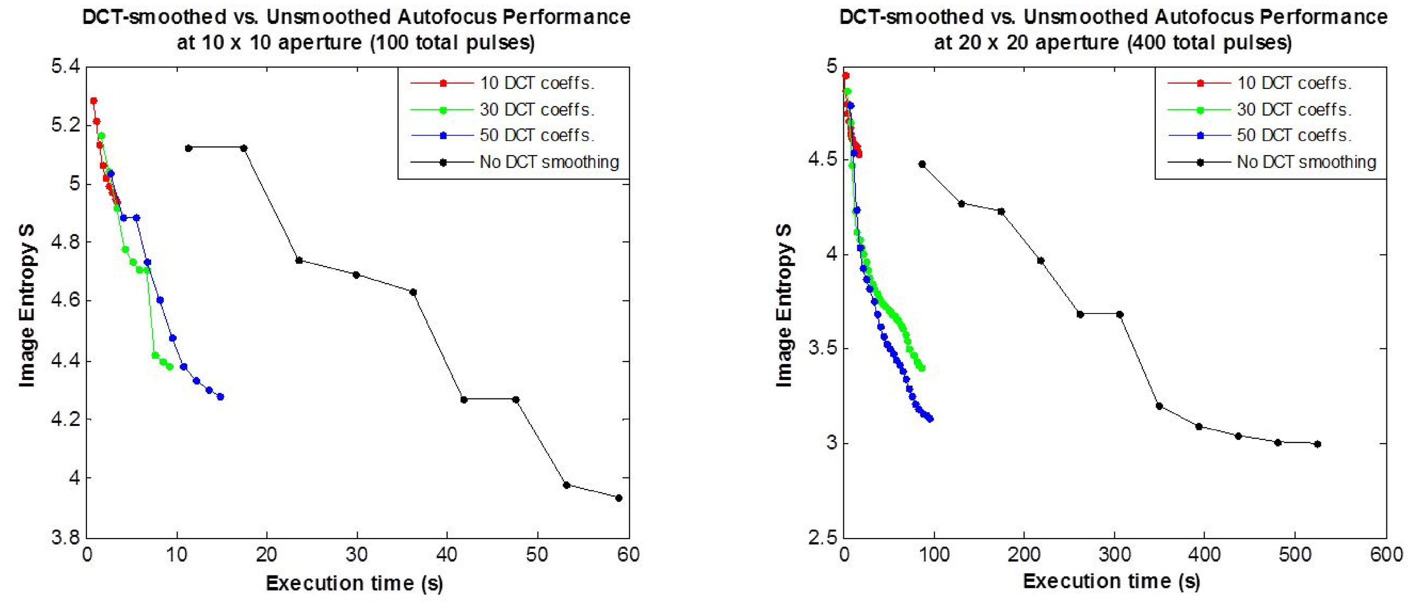


Figure 7: Reduction in execution times for a 10x10 and 20x20 aperture

For apertures with lower pulse count (e.g. 100), DCT smoothing significantly improved runtime speed but did not always minimize entropy. As the pulse count increased (e.g. >400), DCT-smoothed autofocus achieved closer to minimum entropy, while runtime speed decreased even more relative to unsmoothed autofocus. Further improvements can be made to the autofocus algorithm by using the unsmoothed autofocus to 'fine-tune' the DCT-smoothed autofocus algorithm during later iterations.