Sensor, Signal and Information Processing (SenSIP) I/UCRC

Neural Rendering and Motion Correction for Synthetic Aperture Sonar

Presenter: Suren Jayasuriya

Date: November 30th, 2023

Project Overview

Tasks:

Task#	Task Description
1■	Develop simulations of SA images with motion artifacts
2■	Implement ML algorithms for enhanced SA image formation
3■	Enhanced motion estimation for SA imaging
4■	Testing algorithms on real SA data

Project Milestones:

Task#	Planned Completion	Milestone (Deliverable)
1■	09/23	Simulation benchmark in place
2■	12/23	Neural network algorithms in simulation
3■	3/24	Motion estimation algorithm finalized
4■	8/24	Evaluation on real SA data

Research Goals:

1. Develop a framework for joint motion and image formation for synthetic aperture imaging
2. Leverage neural networks to estimate scene from partial measurement/observations
3. Clear documentation of research, lessons learned and recommended approaches

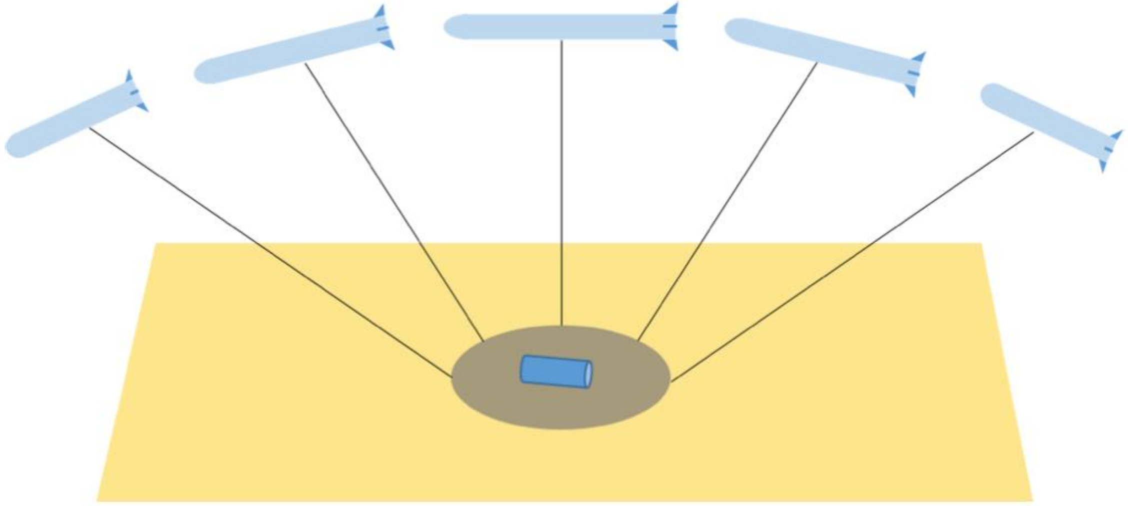
Benefits to Industry Partners:

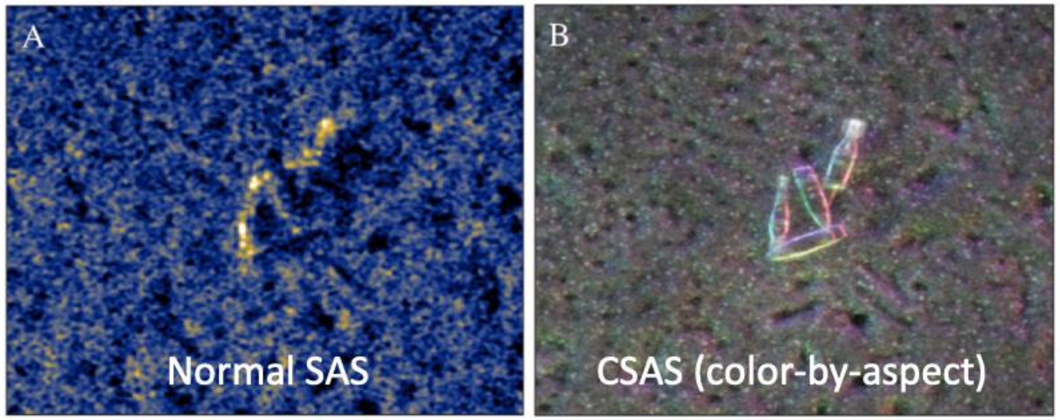
1. Insight into synthetic aperture imaging problems
2. Recipes for neural network applications for these spaces
3. Software simulators and benchmarking/evaluation scripts

[2] ■ Milestone complete or is on track for planned completion date
■ Milestone has changed from original sponsor-approved date (Why?)

Circular SAS

- Many applications (e.g. ATR) can benefit from multiple looks at the target
- CSAS allows for high-resolution imagery leveraging 360 degrees for a large aperture[1,2]
- Data products are high fidelity including less speckle noise and multilook processing[3]

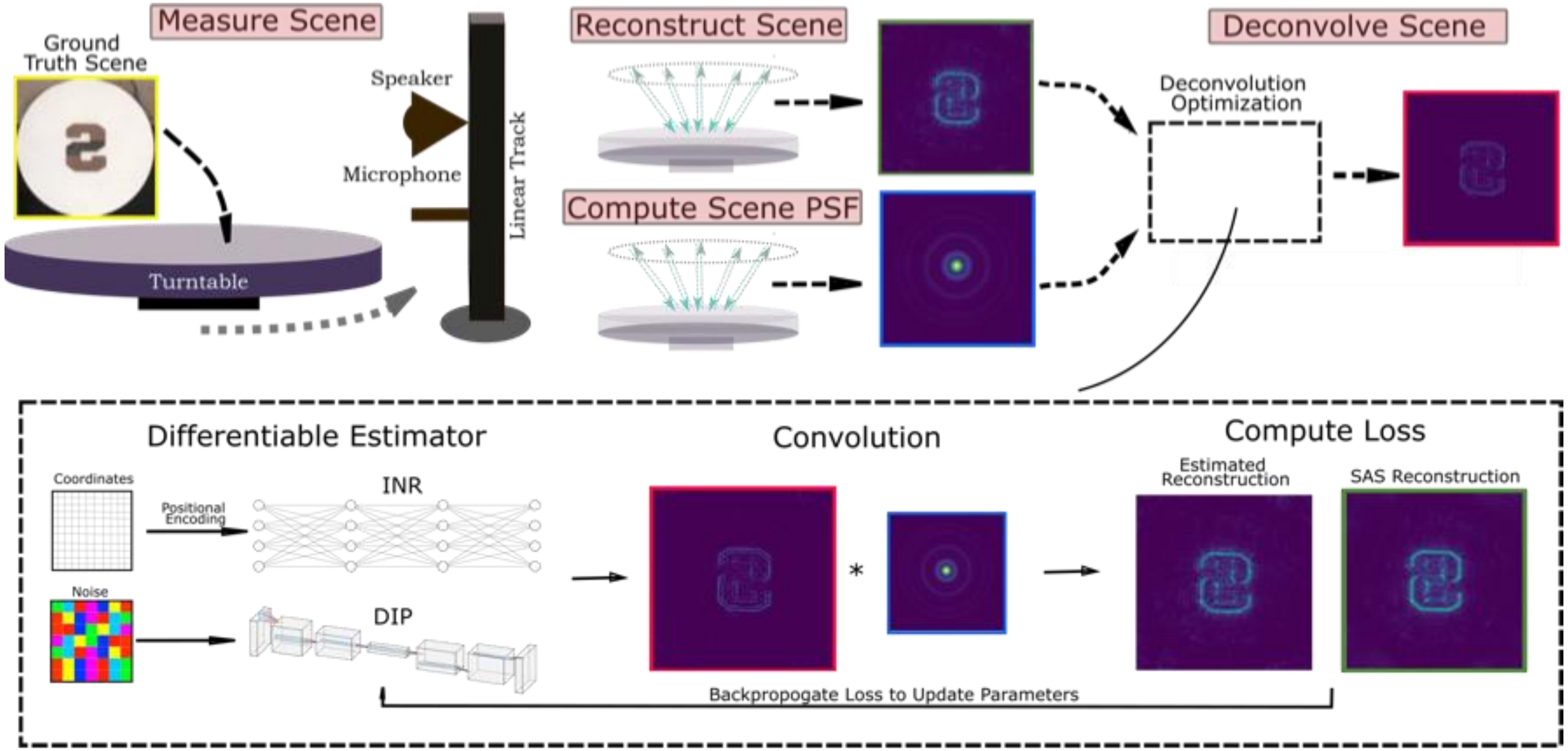




[1] Ferguson and Wyber, Application of acoustic reflection tomography to sonar imaging, JASA 2005
[2] Marston et al., Coherent and semi-coherent processing of limited-aperture circular synthetic aperture (CSAS) data, OCEANS 2011
[3] Marston and Kennedy, Spatially variant autofocus for circular synthetic aperture sonar, JASA 2021

Prior Results: SINR method

› Introduced an analysis-by-synthesis pipeline for CSAS deconvolution



Albert Reed, Thomas Blanford, Daniel Brown, Suren Jayasuriya, SINR: Deconvolving Circular SAS Images Using Implicit Neural Representations, IEEE Journal of Selected Topics in Signal Processing (special issue) 2023

Motion artifacts

- Unaccounted motion in either the platform or the object can result in degradation of the image

- Beamforming relies on precise estimates of the imaging platform

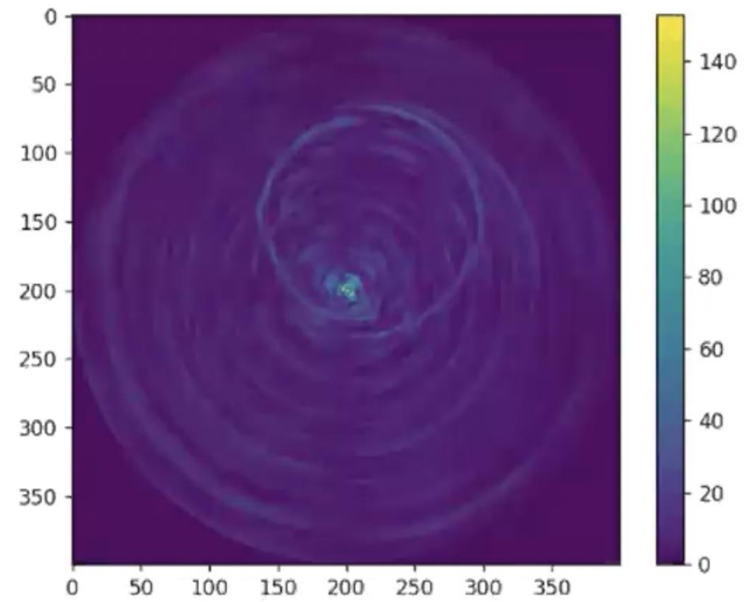


Image with Positional Uncertainty

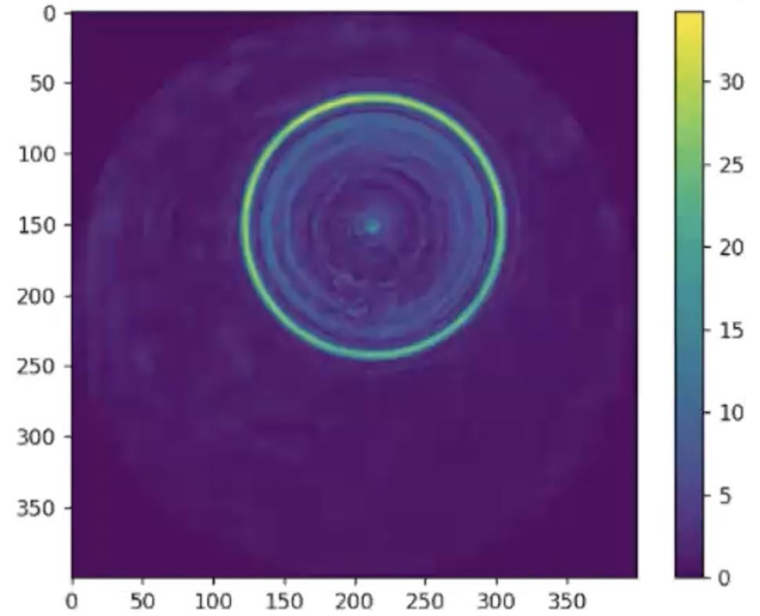
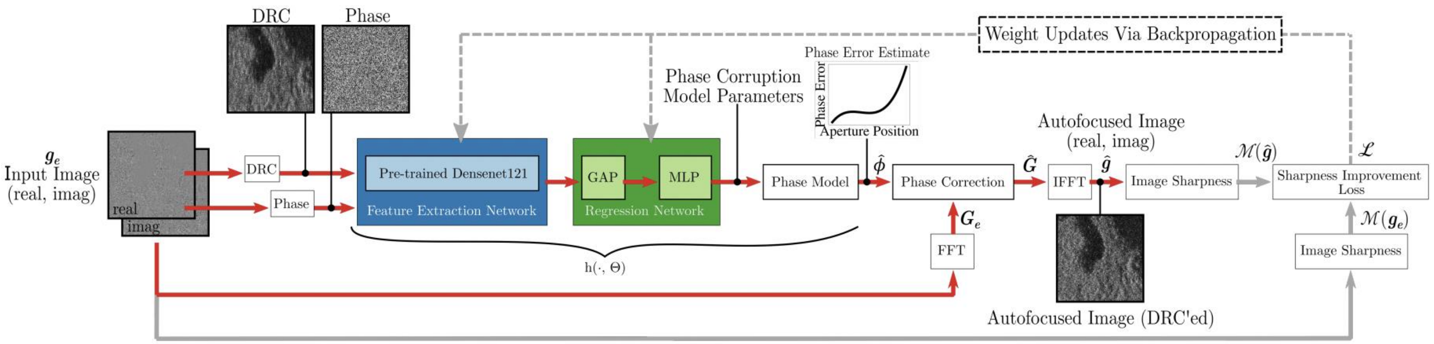


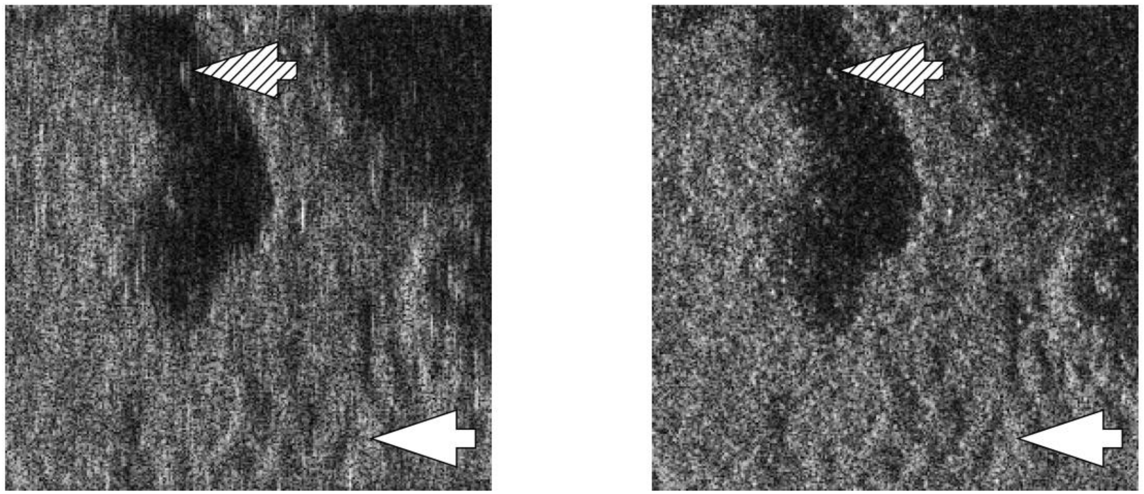
Image with no Positional Uncertainty

Autofocus to handle time-of-flight errors

- Method by Gerg et al. 2021 to perform deep autofocus



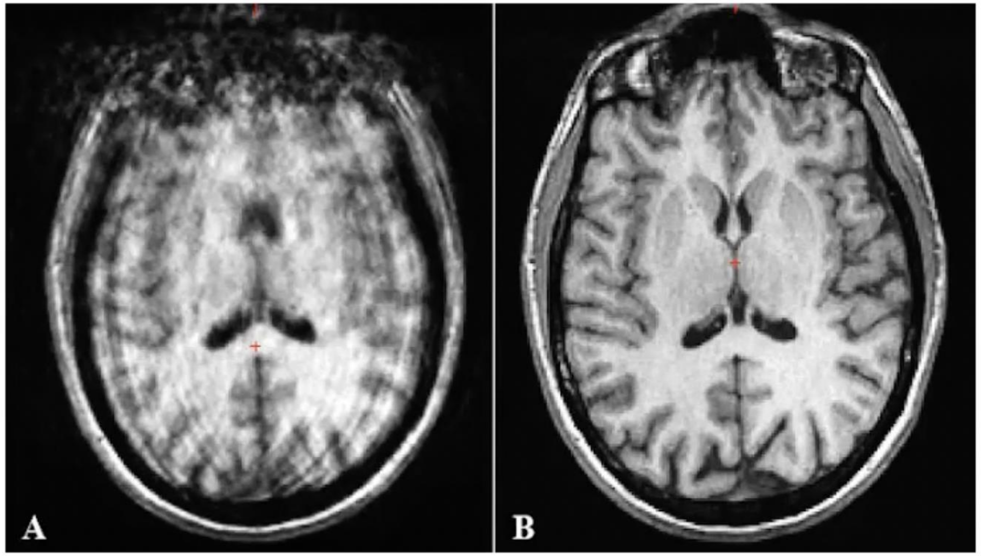
- Correct phase errors that occur in the image due to mis-estimated time-of-flight returns



(a) Original Defocused Image (b) Autofocus Result

Our approach: Image-to-image transformation

- Train a neural network to do image-to-image correction
- Has been shown successfully in medical imaging domains



Motion Correction in MRI Image

Datasets

Dataset 1: Simulated CSAS dataset using regular images modeled as point scatterers

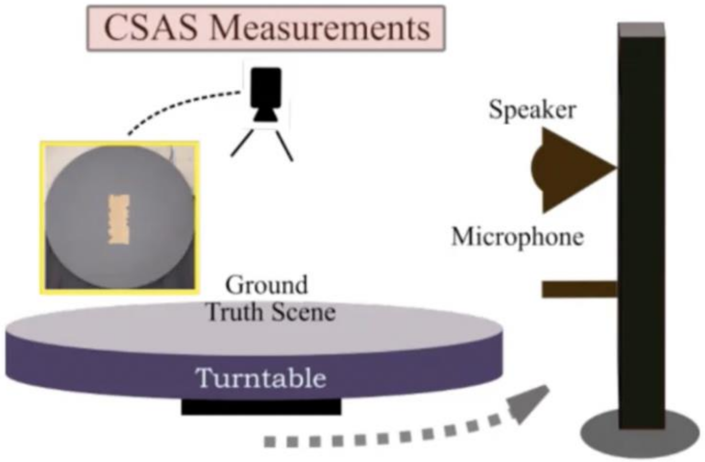
- The transducer's position will have noise added to its position during the collection process

Dataset 2: Real-world CSAS measurements with phase shifts applied to recorded audio signal

- An AirSAS turntable will be used to collect measurements with no positional uncertainty
- The recorded waveforms at each degree in the aperture will be randomly delayed

Dataset 3: The AirSAS transducer's position will be manually moved during the collection process

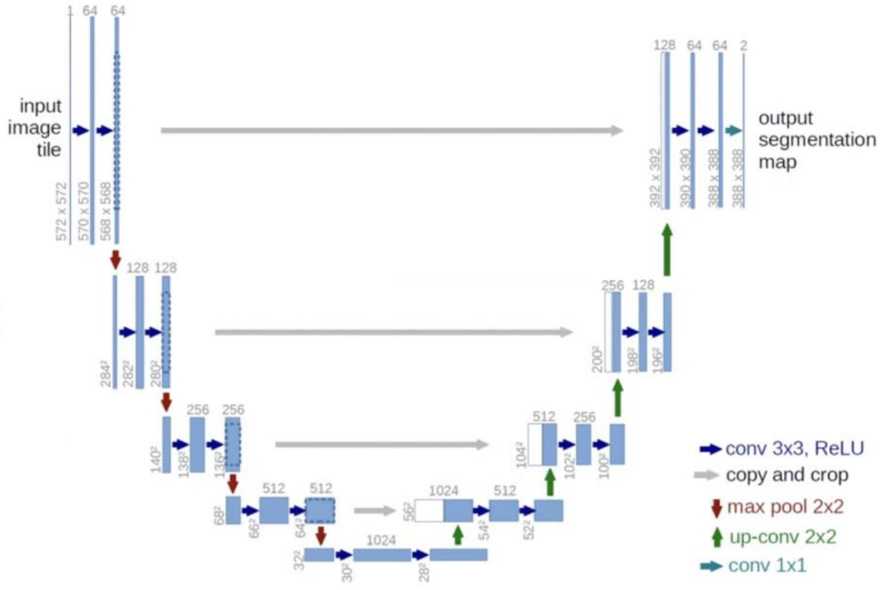
- This dataset will only be used for evaluating our model's performance on real-world data



AirSAS Turntable

Network architecture

- A UNET model will be used to perform image-to-image translation
  - A modified architecture was adopted from an online example of a UNET
- The UNET model have the bulk of its training completed on the simulated dataset
- Transfer learning will be used to fine tune the model on the phase-delayed real-world dataset
- The model's performance will be verified using the manually moved transducer dataset

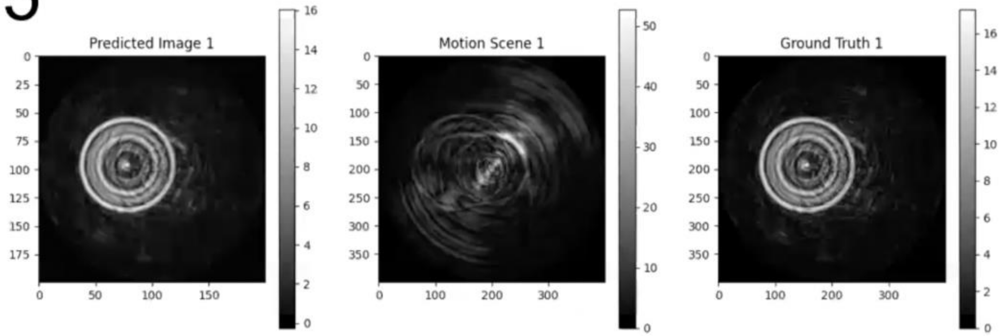


UNET Model Architecture

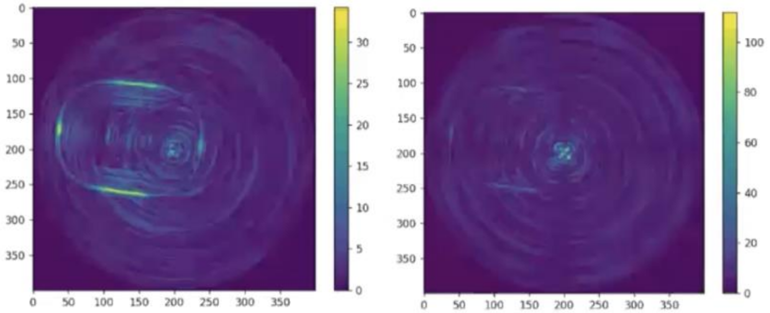
Also looking into more advanced models such as transformer-based networks

Preliminary Results

- Created a dataset containing 5 objects totaling about ~100 examples using the phase-delayed real-world data
- Trained the U-Net model to overfit on one training example
  - Was able to successfully correct the motion artifacts that were present in the image



U-Net Correction of Corrupted Image



Example Image of Delayed Real-World Data

Future work

› Handling generalization error going from a simulated dataset to testing on real AirSAS measurements

› Investigating unsupervised/self-supervised methods to reduce the reliance on labeled data

› Positional uncertainty is not just phase error, can also be reflected in the amplitude data -> more than just autofocus

Progress to Date and Accomplishments

Task#/Description	Status	Progress and Accomplishments
Develop simulations of SA images with motion artifacts	■ (green)	- Built simulator in Python for point scattering model (for sonar) - Simulate motion for in-air SAS measurements
Implement ML algorithms for enhanced SA image formation	■ (yellow)	- New SAS algorithm for 3D reconstructions
Enhanced motion estimation for SA imaging	■ (yellow)	- Researching inverse SA pipelines, adapting it for our problem
Testing algorithms on real SA data	■ (yellow)	- Constructed AirSAS system, collecting measurements for objects for small real-world dataset - Also acquired some real SAS data from the Sediment Volume Search Sonar (ARL-PSU) in water
5. Documentation of research and development	■ (yellow)	- Paper on sonar deconvolution published in the IEEE Journal of Selected Topics in Signal Processing (special issue on synthetic aperture imaging) - Paper on 3D SAS published to Siggraph 2023

■ (blue) Significant Finding/Accomplishment ■ (green) Task Complete ■ (yellow) Task Partially Complete ■ (red) Task Not Started

Efforts to Seek Additional Sponsorships and Collaborations

- Raytheon
- PSG

Objective Evidence Supporting NCSS Value Proposition

Category	Objective Evidence
Papers, Publications, Presentations/Venue	1. Albert Reed, Thomas Blanford, Daniel Brown, Suren Jayasuriya, ”SINR: Deconvolving Circular SAS Images Using Implicit Neural Representations” IEEE JSTSP 2023 2. Albert Reed, Juhyeon Kim, Thomas Blanford, Adithya Pediredla, Daniel Brown, Suren Jayasuriya, “Neural Volumetric Rendering for Coherent Synthetic Aperture Sonar”, ACM Transactions on Graphics (Siggraph) 2023
Products (Software, Data, Designs, etc.)	1. Open-source code for sonar SA simulations and deconvolution code available: https://github.com/awreed/CSAS_Deconvolution_INR 2. https://github.com/awreed/Neural-Volumetric-Reconstruction-for-Coherent-SAS
Student Placements	1. Albert Reed, graduate research assistant 2. Gregory Vetaw, graduate research assistant 3. Christopher Voelkel, graduate research assistant