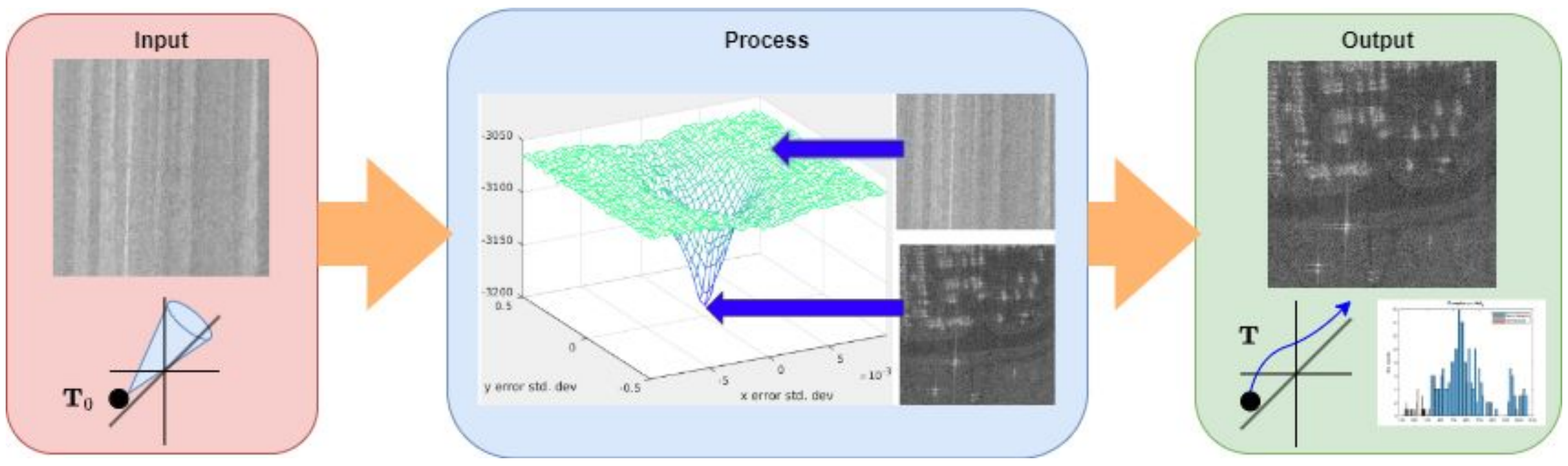
Deep Learning for GPS-Denied SAR Image Focusing and Vehicle Trajectory Estimation

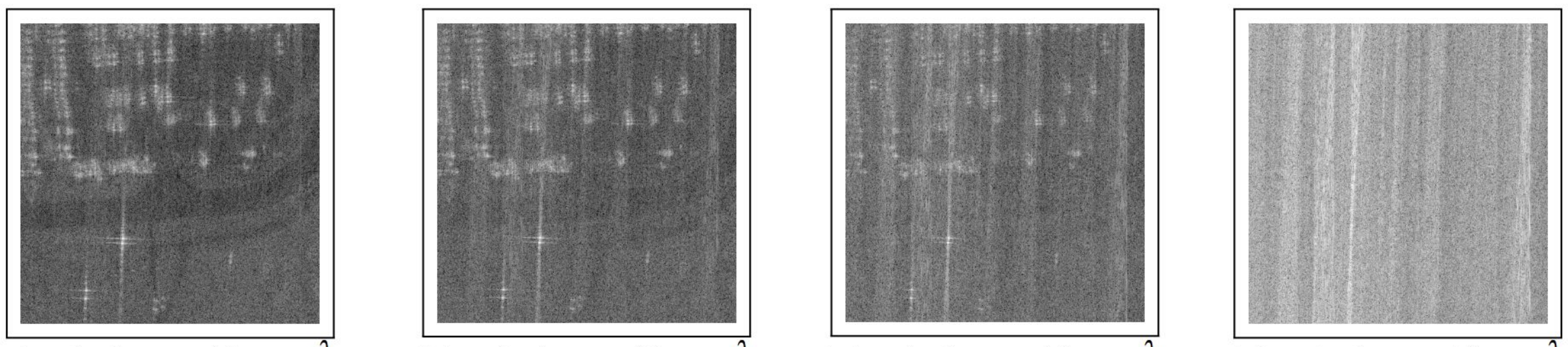
Chris Beam, Andrew Willis ({cbeam18,arwillis}@charlotte.edu), Kevin Brink (kevin.brink@us.af.mil)

Overview

Synthetic Aperture Radar (SAR) uses Radio Frequency (RF) radiation pulses to capture backscatter signals from Earth's surface. A major problem with SAR systems is that they are highly sensitive to errors in positioning where focusing fails at position errors above 10% of the wavelength λ [1,2]. This article builds upon prior work described in [3] by:

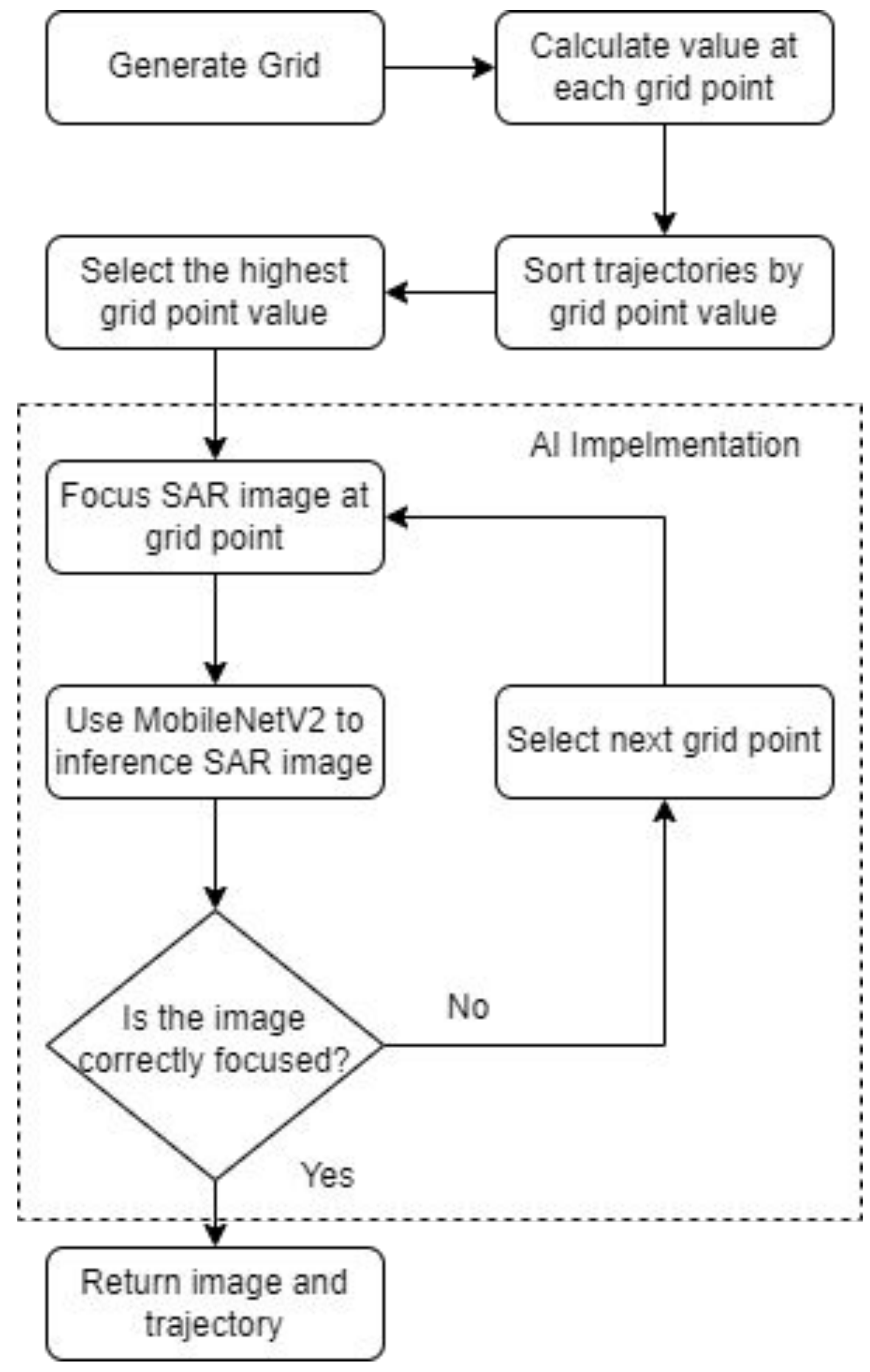
1. Defining a new performance functional to improve detection of "real-world" and "invalid" SAR images.
2. A new AI approach for classifying "real-world" and "invalid" SAR images.





(a)$\sigma(\varepsilon(x,y,z))=\frac{\lambda}{100}$ (b)$\sigma(\varepsilon(x,y,z))=\frac{\lambda}{20}$ (c)$\sigma(\varepsilon(x,y,z))=\frac{\lambda}{10}$ (d)$\sigma(\varepsilon(x,y,z))=\frac{\lambda}{2}$

Method

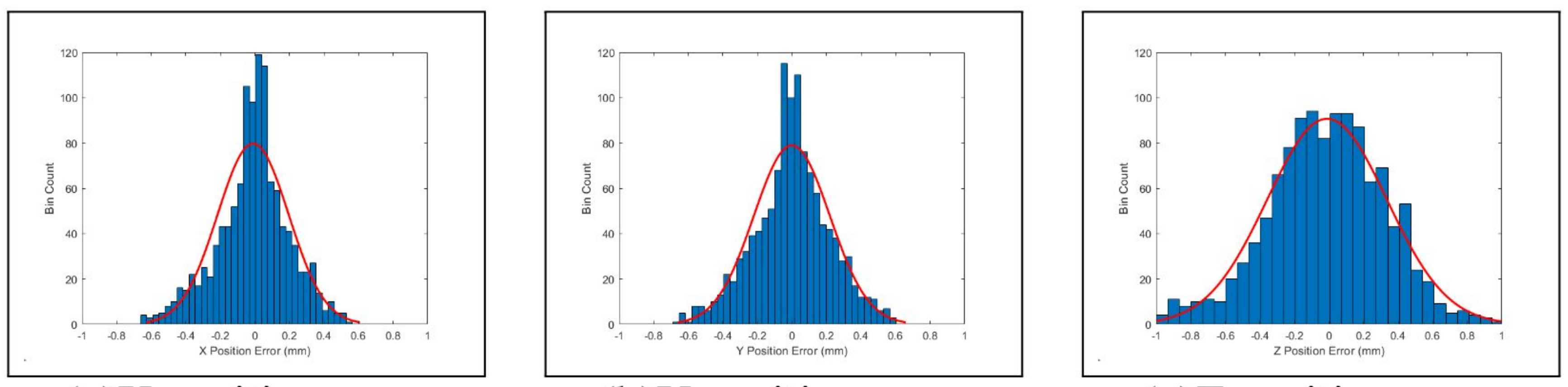


$$\mathbf{F}_{\mathcal{D}}(m,n|\mathbf{T}=\mathbf{T}_i)=\sum_{x=0}^{X-1}\sum_{y=0}^{Y-1} e^{-j2\pi xm/X}e^{-j2\pi yn/Y}\mathbf{I}_{\mathcal{D}}(x,y|\mathbf{T}=\mathbf{T}_i)$$

$$\mathbf{Q}(\mathbf{T}=\mathbf{T}_i|\mathcal{D})=\sum_{m=-M_0}^{M_0}\sum_{n=-N_0}^{N_0}|\mathbf{F}_{\mathcal{D}}(m,n|\mathbf{T}=\mathbf{T}_i)|$$

Results

- Histogram of trajectory position errors



(a)X position error (b)Y position error (c)Z position error

- Tables of MobileNetV2 training and trajectory position errors

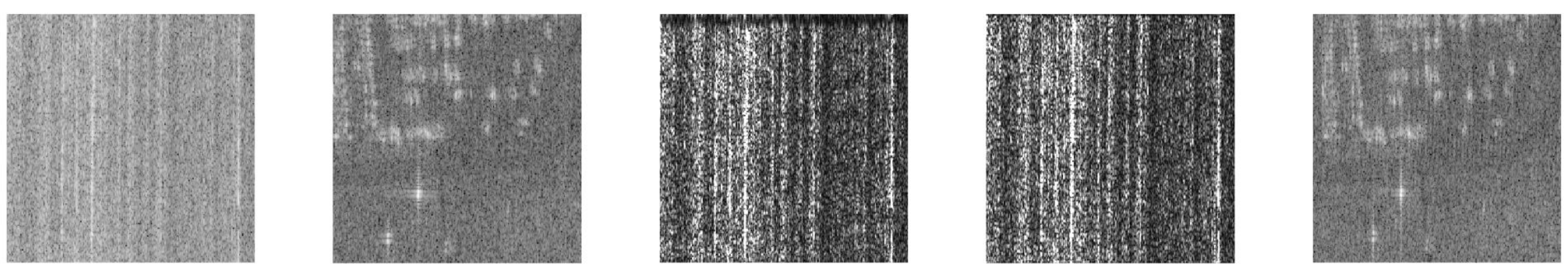
Input Size	Accuracy	Precision	Recall	AUC
224^2x3	0.9962	0.9962	0.9962	1
128^2x3	0.9821	0.9821	0.9821	0.986
64^2x3	1	1	1	1
32^2x3	0.9954	0.9954	0.9954	0.9967
16^2x3	0.9996	0.9996	0.9996	1

Table 1: Test dataset metrics for the different MobileNetV2 input sizes.

Component	Mean Error (mm)	Std. Dev. Error (mm)
X	-0.0076	0.2402
Y	-0.0044	0.2356
Z	-0.0286	0.3569

Table 2: Error metrics between the relative ground truth trajectory and the estimated trajectory endpoints obtained using our proposed method.

- Comparison against state-of-the-art autofocus algorithms



Input Ground Truth [4] [5] Proposed

Conclusion

This article presents a new approach to accurately estimate the trajectory of a radar platform from radar backscatter measurements. This is made possible by two new components: (1) a new performance functional and (2) an AI-based method to identify the correct solutions. MobileNetV2 is used as the CNN model to detect "valid" and "invalid" candidate results. The results show low bias and high accuracy (≤ 1 mm) in trajectory estimates and improved SAR images. Though the estimator is not real-time, it could be deployed to airborne platforms for GNC feedback. The SAR images have potential applications beyond navigational aiding.

References

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[2] Aaron Evers and Julie Ann Jackson. A comparison of autofocus algorithms for back-projection synthetic aperture radar. In 2020 IEEE International Radar Conference (RADAR). IEEE, apr 2020. doi: 10.1109/radar42522.2020.9114579.
[3] Andrew Willis, Christopher Beam, Garrett Demeyer, and Kevin Brink. Gpu-accelerated sar image formation in the presence of very large motion error. In IGARSS 2023 - 2023 IEEE International Geoscience and Remote Sensing Symposium, pages 7906–7909, 2023. doi: 10.1109/IGARSS52108.2023.10281891.
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