Physics-Based GPU-Accelerated SAR Simulator for ATR Database Generation

Alessandro Vetere
MetaSensing – Italy

alessandro.vetere@metasensing.com

Eugenio Pino
MetaSensing – Italy

eugenio.pino@metasensing.com

Adriano Meta
MetaSensing – Italy

adriano.meta@metasensing.com

ABSTRACT

Automatic Target Recognition (ATR) with Artificial Intelligence (AI) plays a key role in modern surveillance and reconnaissance activities. The enabling technology for ATR is the availability of a database that is representative of realistic situations including targets and backgrounds. When applied to radar imaging, the problem of collecting enough data of targets under different configurations and conditions becomes extremely complicated and unaffordable. At MetaSensing we are tackling this problem with a recently developed physics-based SAR simulator (KAISAR) able to estimate the complex 3D RCS (Radar Cross Section) of a target and to model the SAR collection and processing stages to build a synthetic yet realistic database of target-background-images with data augmentation. This paper provides a description of the SAR simulator and some examples of synthetic data generated.

KEYWORDS

Artificial Intelligence (AI); Automatic Target Recognition (ATR); EM simulations; GPU; SAR; Synthetic aperture radar; Simulations; Raytracing

1.0 INTRODUCTION

Synthetic Aperture Radar (SAR) is a critical remote sensing imaging technology which is receiving growing interest thanks to the NewSpace developments. There are multiple applications which can benefit from SAR imaging ranging from Automatic Target Recognition (ATR) in the Intelligence, Surveillance and Reconnaissance (ISR) domain to structural stability monitoring in the geomatics domain. Moreover, SAR can be used for agriculture, forestry, biomass, and generation of Digital Elevation Models.

Within the ISR domain, SAR with its ATR technique plays a very important role providing advanced information about the detected targets in the SAR images. The combination of SAR, ATR and AI is pivotal for the best SAR-based ISR system which allows to identify, classify, and recognize different targets in different conditions. The enabling technology for ATR is the availability of a high-fidelity realistic database of SAR images for backgrounds and targets under different configurations which can be used to match the observed real targets for the recognition purpose.

Although more and more satellite SAR are deployed providing a lot of data, there are still several drawbacks and barriers in the generation of databases of target signatures in SAR images. First, costs are one of the main limiting factors in creating a collection of SAR images with labelled targets to be used as training dataset or ATR database; second, real SAR data are subject to multiple noise sources including system errors and accuracies, position errors, viewing geometries, data processing, uncontrolled scenarios on ground. Besides the above problems, there is also the problem of having access to the real targets and the problem of the amount of data and experiments required. The RCS (or the image) of a target varies drastically due to the characteristics of the radar (resolution, operational band) and the aspect angles (in azimuth and grazing angles). Other complications come from the near background scene surrounding the target that must be added to the database. The configuration space for the ATR database becomes extremely large.

All those barriers make difficult to have a reliable collected data usable for SAR-based ATR and AI applications from different systems hence simulated synthetic data are a much-preferred choice thanks to the possibility to control all the simulation spaces and configurations and generate less resource expensive dataset.

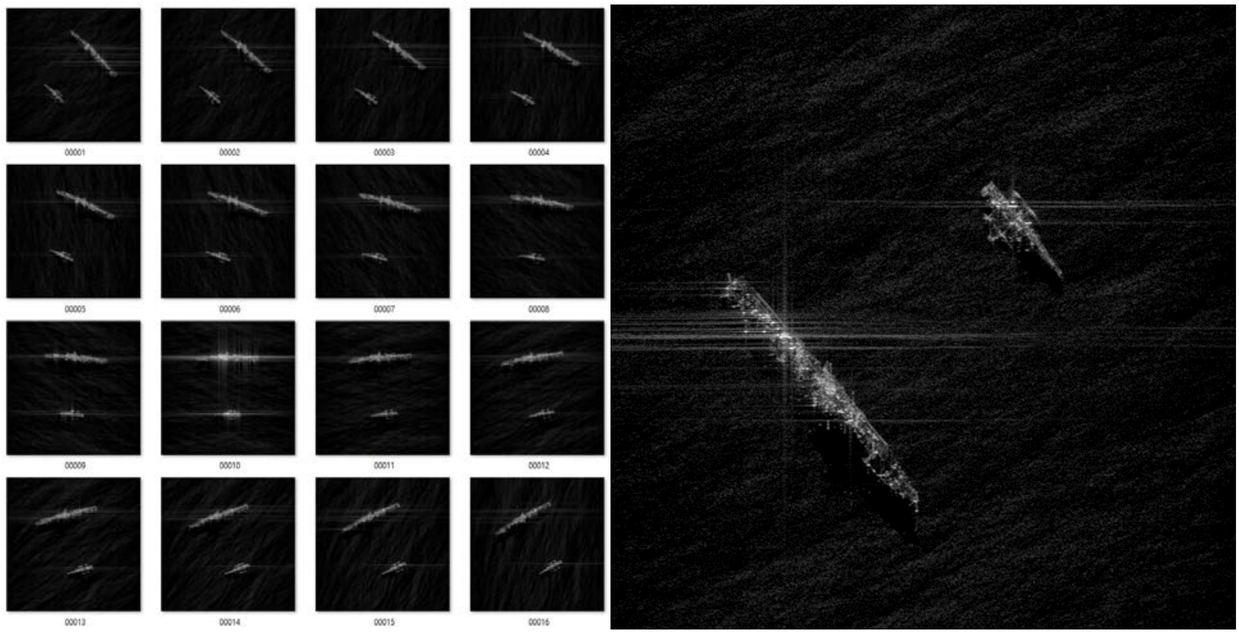

Figure 1-1: Augmented Synthetic SAR image with two ships on sea: some frames left, sample right.

We developed a realistic fast NVIDIA GPU hardware accelerated SAR simulator, called KAISAR, with the goal to support different applications. The first application is to generate large databases of SAR images of targets and backgrounds under different configurations to enable ATR. The second application is to generate SAR images with labelled targets to support deep learning developments for object detection in SAR images. The third application is to provide a fast SAR simulation environment for generation of SAR raw data for system design and new algorithm developments. Figure 1-1 shows some sample synthetic SAR images of two ships on sea taken from a KAISAR generated dataset with 72 different azimuth angles. KAISAR is based on NVIDIA RTX GPU card technology to provide hardware acceleration for the raytracing in the EM-Solver module, and the back-projection algorithm in the SAR raw data and SAR images simulations of the SAR module.

In this paper, the KAISAR simulator developed by MetaSensing is presented along with some examples of simulations.

.

2.0 KAISAR ARCHITECTURE

The KAISAR simulator is based on two cores: an asymptotic ElectroMagnetic Solver (EM-Solver) and a SAR simulator including the image focuser.

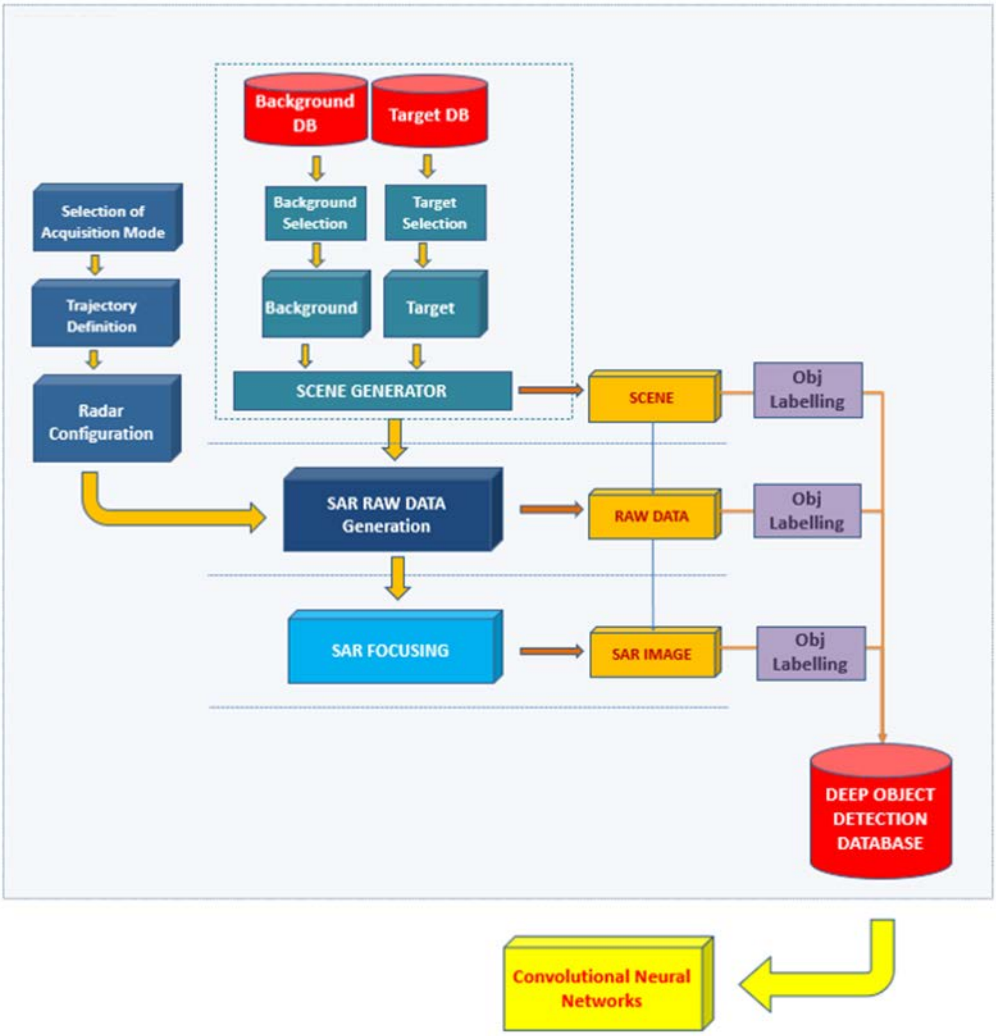

Figure 2-1: Flow chart model of the KAISAR simulator

Figure 2-1 depicts the flow chart of the KAISAR from the two databases of backgrounds and targets, which are used to create a scene to be simulated and included in the deep object detection database which can then be passed to the convolutional neural networks (CNN). The EM-Solver generates the 3D Radar Cross-Section (RCS) maps of a 3D scene composed of user-selected background and targets. The scene is created by the user from high-resolution 3D models of targets placed on 3D realistic background models. The scene is then used by the scene generator module which, by applying the EM-Solver, generates the 3D RCS maps. The 3D RCS maps are passed to the SAR simulator that implements a Reverse Global Back Projection to generate the SAR raw data considering the different configurations set by the user related to the acquisition mode (spotlight, stripmap), the trajectory and the radar parameters. The simulated SAR raw data are then focused with a Global Back Projection to SAR Single Look Complex images. The SAR simulator is all implemented in CUDA on GPU cards to reduce the processing time, while the EM-Solver is based on the

DirectX 12 and DirectX Raytracing (DXR) technologies. All the targets in the three domains (RCS-map, SAR Raw data, SAR images) can be labelled allowing for quick finding and use in training database. All the simulated data are then saved in a database which can be used for ATR or as AI training dataset.

Figure 2-2: Architecture of the KAISAR simulator

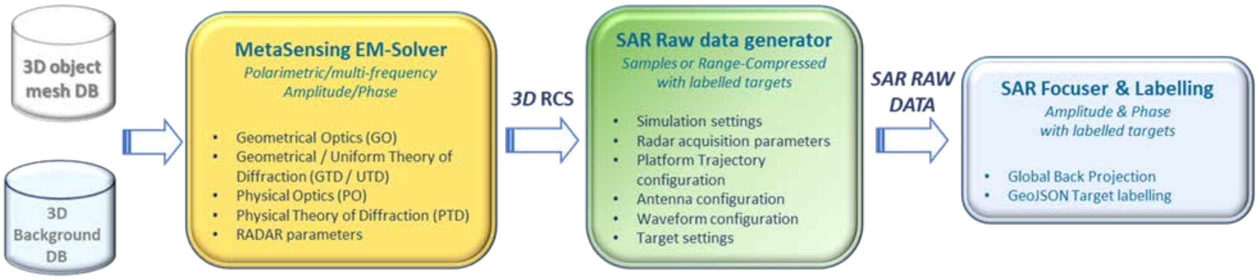

Figure 2-2 depicts the main modules of the KAISAR including the EM-Solver and the SAR simulator. The EM-Solver based on ray-tracing techniques takes care of modelling the real-world scenario composed of realistic background and targets. The EM-Solver generates the 3D RCS maps which are passed to the SAR raw data generation module which accounts for all the configuration parameters related to the platform and the radar. The simulated SAR raw data are focused with the Global Back Projection to SAR images.

This SAR Simulator, thanks to the use of GPU hardware acceleration, can simulate single targets in high resolution in few seconds. A large database of labelled targets and background both in their RCS form, in the SAR raw data and SAR images can be generated in short time.

The paragraphs below will provide a description of the different modules.

2.1 The input database

The input data for the real-world modeling is composed of two separate databases for background and targets. High-resolution high-fidelity 3D models are used for the targets, and they can be obtained from various sources and formatted in standard .obj file also including information about the materials. For AI training dataset purposes, the target models are divided into five different classes: marine, air, ground, weapon (missile), radar. Each class is then divided into different subclasses as reported in Table 2-1. Every target is then identified with its own model name. Currently KAISAR contains around 120 different target models.

Table 2-1: Classes and subclasses of targets

Marine	Air	Ground	Weapon (Missile)	Radar
Warship	Fixed wing	Tank	Surface	Surveillance
Submarine	Rotary Wing	Artillery	Air	
Cargo ship	UAV	Vehicle	Ship	
Motorboat		Car		
		Industrial		

The backgrounds instead are also obtained from realistic 3D models of different areas and are divided into six classes: airport, downtown, forest, harbor, mountain, and sea. Each of the class have different subclasses related to its main class. Currently KAISAR has about 3535 background 3D models with 1x1 km size.

Table 2-2: Classes and Sub-Classes of the backgrounds

Airport	Military base International airport

Downtown	City
Forest	Generic spring forest
Harbour	Seaport with city
Mountain	Forested mountain
Sea	Coastline

Figure 2-3: Quicklook of the scene model generated with five artillery trucks in an urban background.

2.2 The EM-solver

The asymptotic EM-solver used in KAISAR, developed internally by MetaSensing, is based on both the GO-UTD (Geometrical Optics/Uniform Theory of Diffraction) and PO-PTD (Physical Optics/Physical Theory of Diffraction) implementations of Ray Optics. It is well known that the limitations of performance in time come from the ray tracing stage (Shooting and Bouncing Ray - SBR) but modern GPUs equipped with dedicated hardware units (GPU RTX series) can perform billions of ray casts per second reducing the computation time by thousands of times if compared with scalar CPUs. The problem of SBR is solved natively from frameworks like DirectX which drastically reduces the effort of software implementation. The contribution of GPU can also be exploited during the stage of integration for both PO & PTD.

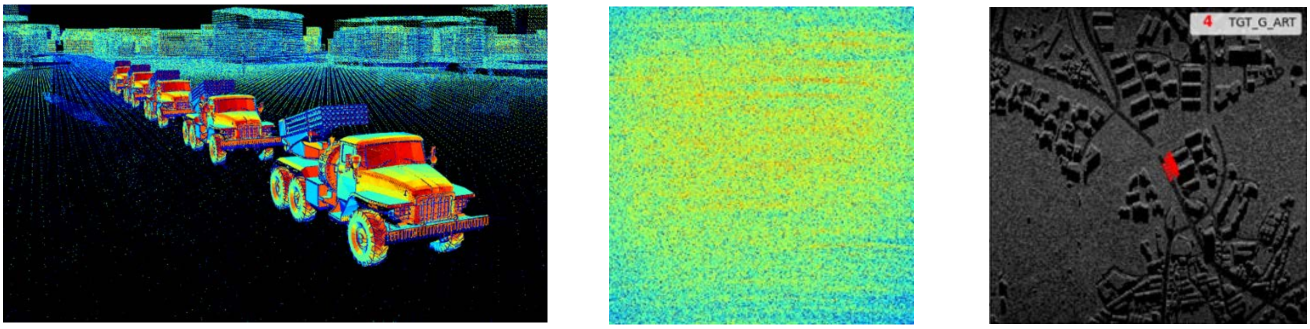

Figure 2-4: Normalized RCS map (left), range-compressed (center) and SLC with labelled target (right) of the scene with five artillery tracks in a downtown background

2.3 The SAR simulator

The SAR simulator is based on a two-stages module: first the SAR raw data are simulated using the Reverse Back Projection technique with the configurations related to the platform trajectory (airborne or satellite), the SAR parameter configurations and the viewing geometry. Afterwards the simulated SAR raw data are focused with the Global Back Projection algorithm to generate the SAR images. Both steps are implemented in GPU-CUDA language to exploit the parallel processing and reduce the simulation time.

2.4 The Target Labelling

As additional feature, the targets in the KAISAR can be all labelled in the GeoJSON file standard to allow an easy-to-use dataset as training dataset for Machine Learning and Deep learning applications. The labelling, besides the location of the target in the images, includes the class, sub-class and model of the target simulated.

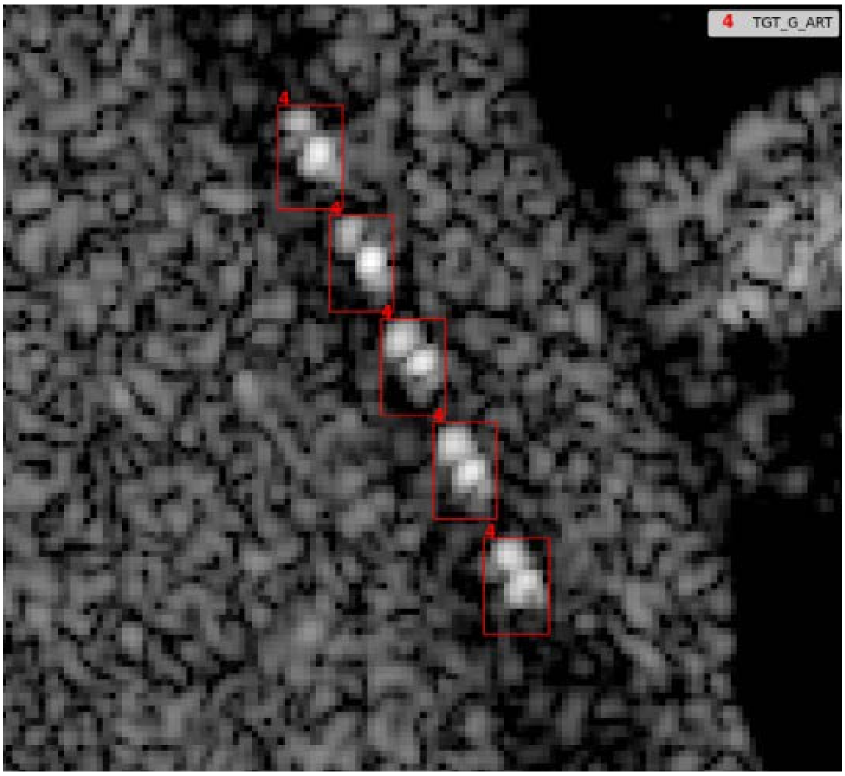

Figure 2-5: Zoom in on the labelled targets in the SAR image.

2.5 Polarimetry and multi-frequency

The KAISAR simulator can simulate polarimetric images including amplitude and phase generating the SAR images in both polarimetric domains: co-polar (HH-VV) and cross-polar (VH-HV). Figure 2-6 shows the polarimetric output of simulated SAR images for a scene with an aircraft carrier and a submarine.

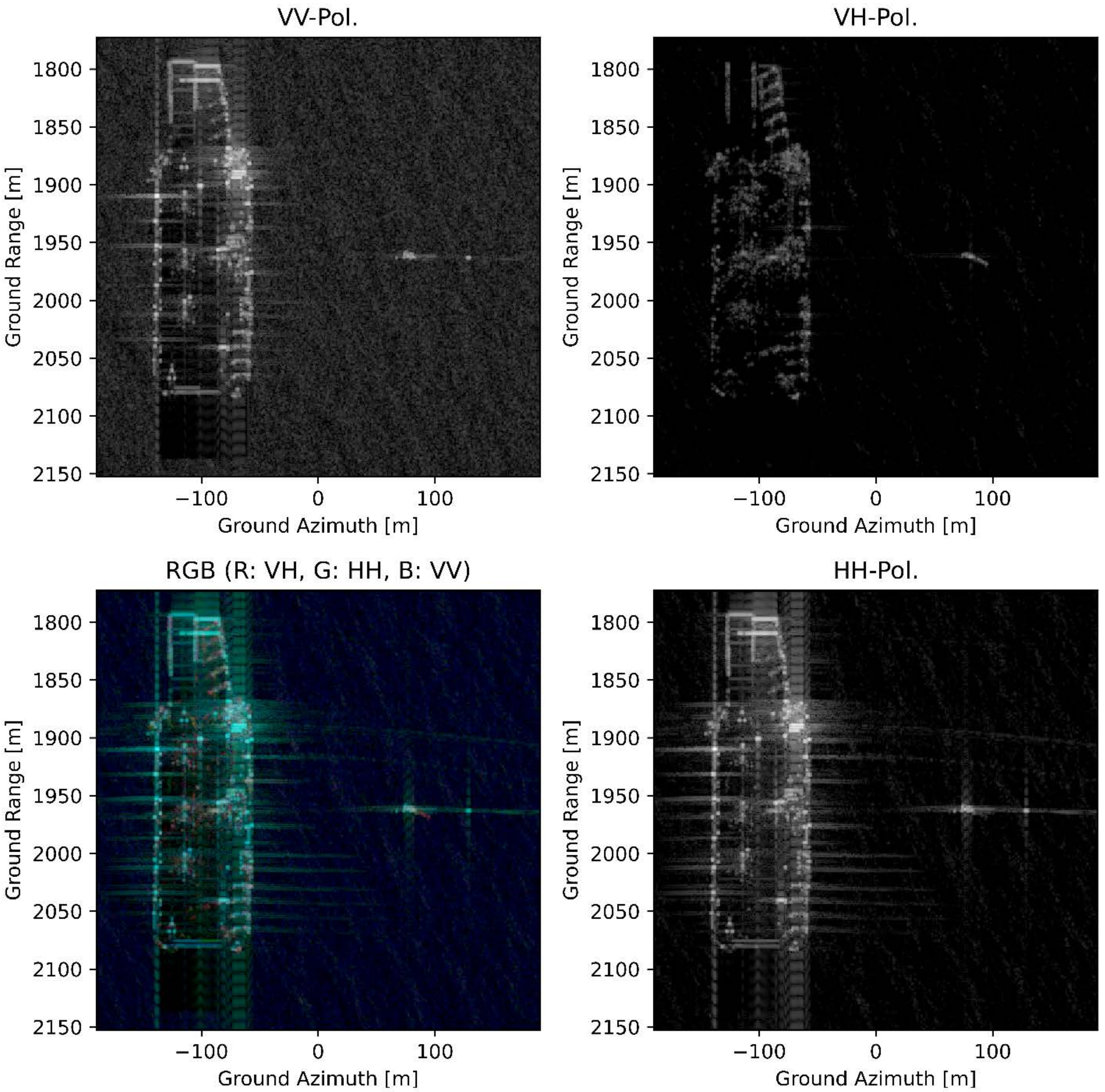

Figure 2-6: Example of polarimetric simulations

Moreover, the KAISAR can simulate RCS, SAR raw data and SAR images for different frequencies from low-frequencies (P-band) to higher frequencies (Ka-band).

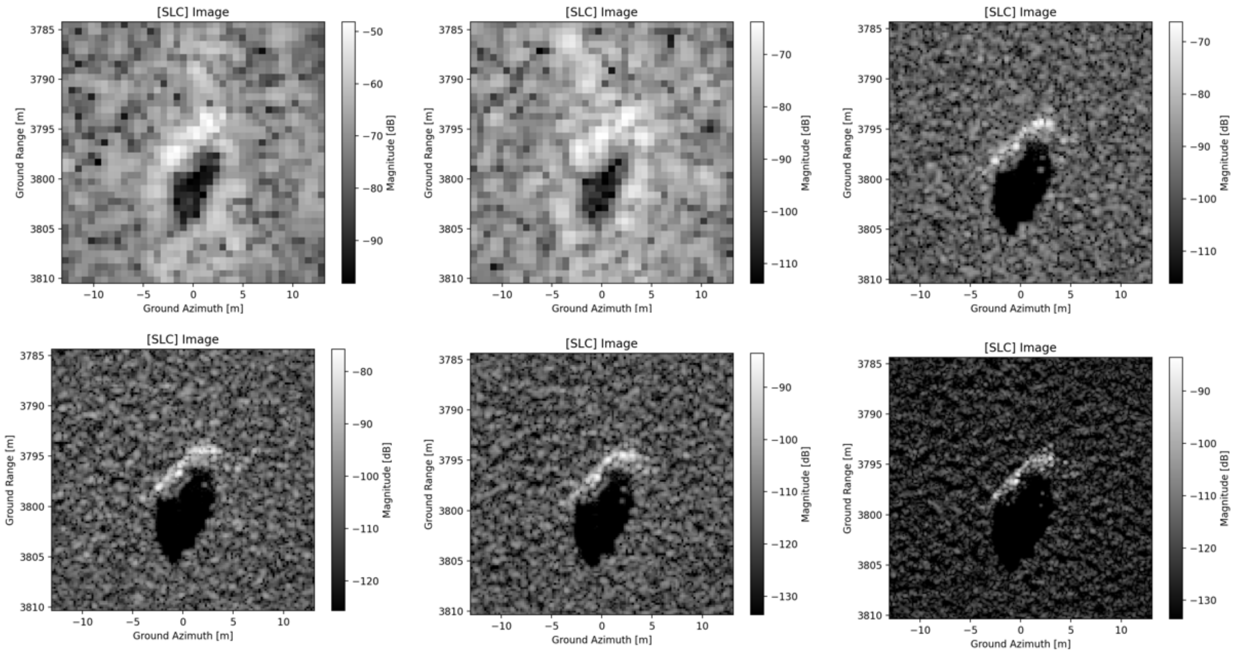

Figure 2-7: Example of simulations from different frequencies (P, L, C top row; X, Ku, Ka bottom row)

3.0 EXAMPLES OF SIMULATIONS

3.1 The MSTAR dataset augmented

KAISAR is being used to simulate some of the targets of the MSTAR dataset [5] and to augment it to provide more information for ATR database. Figure 3-1 shows the optical and related SAR images of the MSTAR dataset. KAISAR simulated different targets, namely the T72, BTR70, BMP-2 and the synthetic dataset were recreated to be used for data augmentation.

Figure 3-2 reports the output of the different simulations for the tank BMP-2 of the dataset showing the RCS map, the range-compressed and the SAR image with the labelled target.Figure 3-3 shows the data augmentation for a synthetic scene where two MSTAR targets are placed next to each other and simulated for 72 different headings.

Figure 3-1: Overview of the MSTAR targets

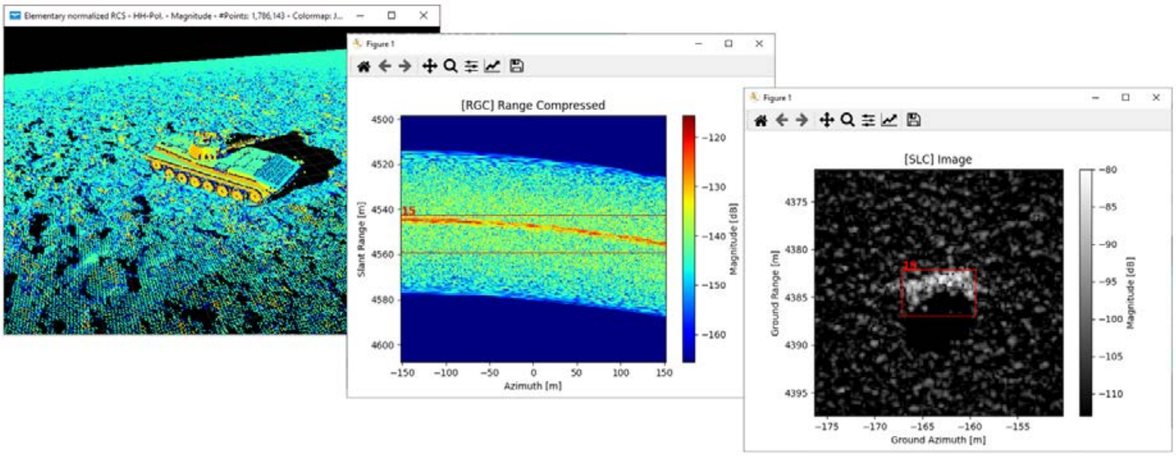

Figure 3-2: Simulated tank (BMP-2) from MSTAR dataset with target labelled on Range-Compressed and SAR image data

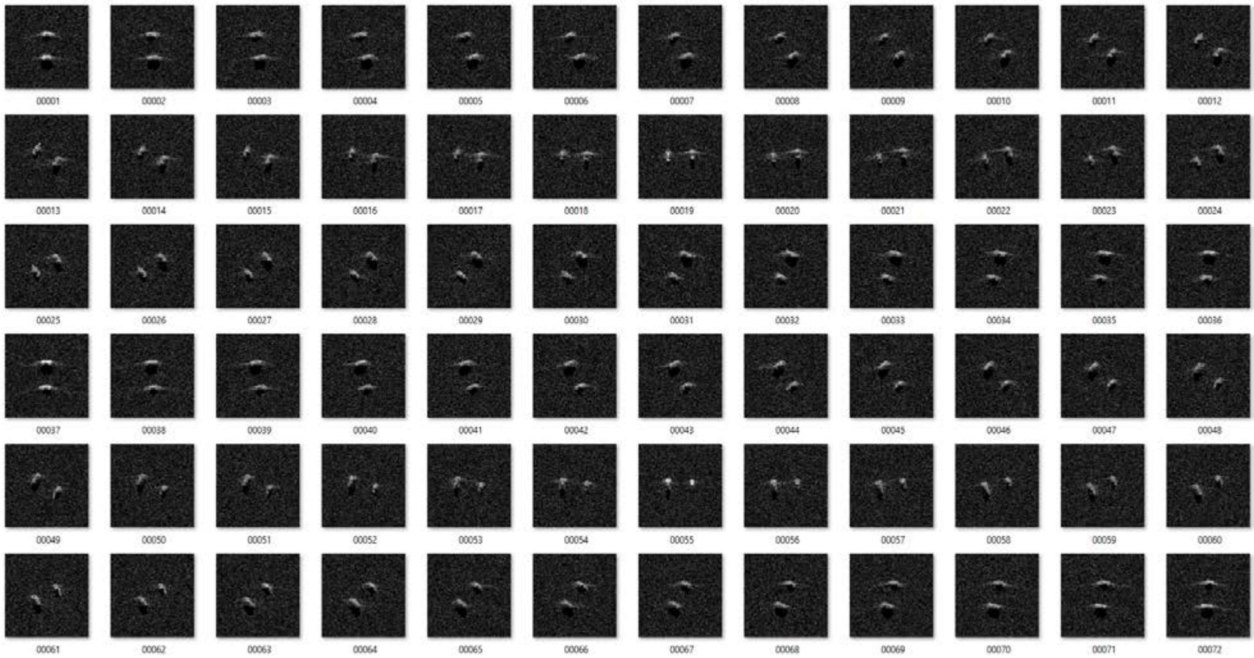

Figure 3-3: SAR images of data augmentation with two targets and multiple look angles to the targets

Within the scope of the simulation of MSTAR dataset, a comparison between the real MSTAR data and the KAISAR synthetic data has been performed.

It is visible that the target can be reproduced with high-fidelity while the background is more difficult to reproduce in the simulator. The main reason is the difficulty of recreating in KAISAR the same configuration and conditions of the real acquisitions.

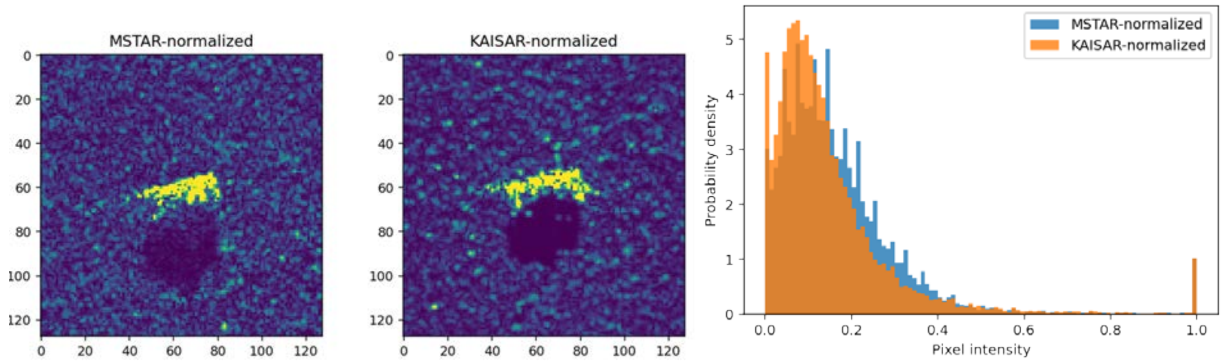

Figure 3-4: Comparison of the real and synthetic SAR images of MSTAR database. Left: SLC image, right: probability density of pixel intensity

3.2 Simulations of different scenes

The two simulations below have been performed by KAISAR emulating one of the configurations of MetaSensing Guardian, which is a real-time airborne multimode SAR sensor at X-band.

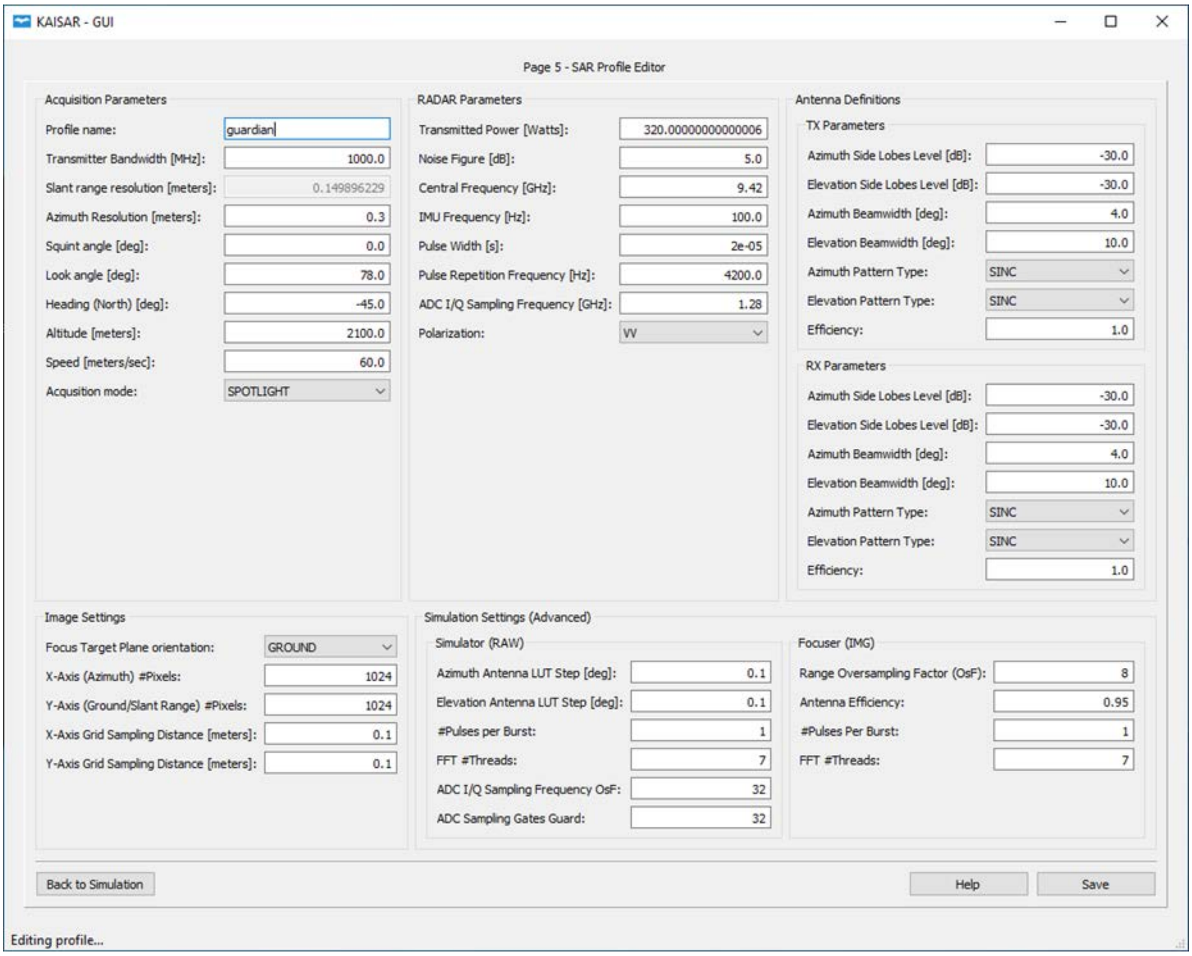

Figure 3-5: KAISAR GUI with the configuration for the SAR simulations

3.2.1 Two targets on the ground

For the development of ATR database, KAISAR has been used to generate augmented synthetic SAR images of different targets under different conditions.

This chapter reports the simulation results for one helicopter and one artillery truck on a ground.

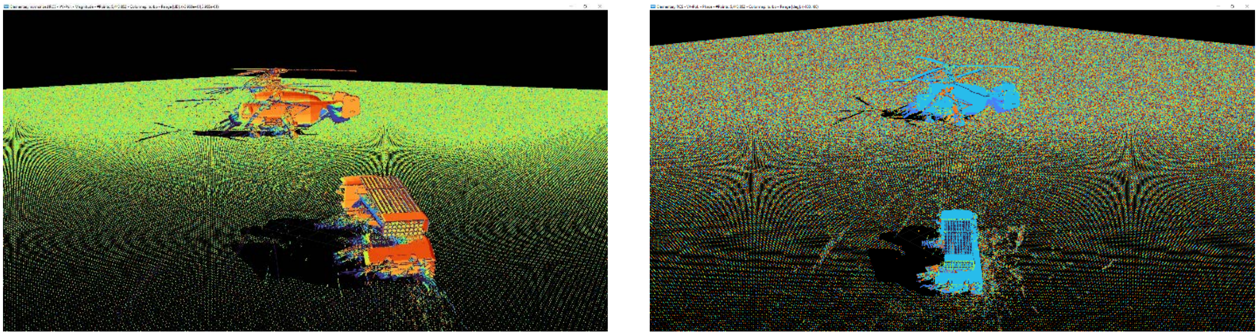

Figure 3-6: RCS of a synthetic scene with helicopter and artillery truck. Amplitude (left) and phase (right).

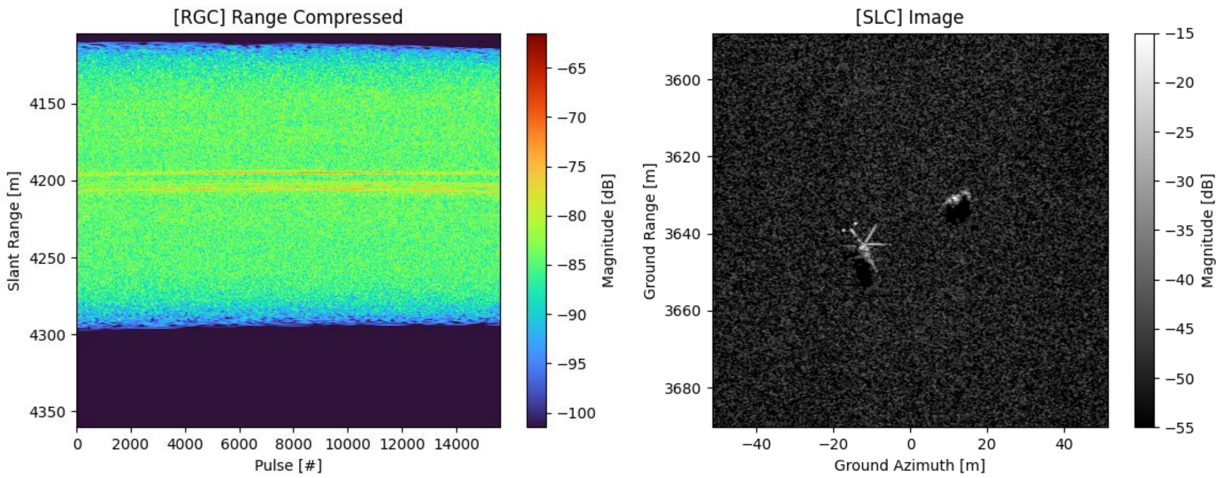

Figure 3-7: Range-Compressed data (left) and SLC image (right) with helicopter and artillery truck

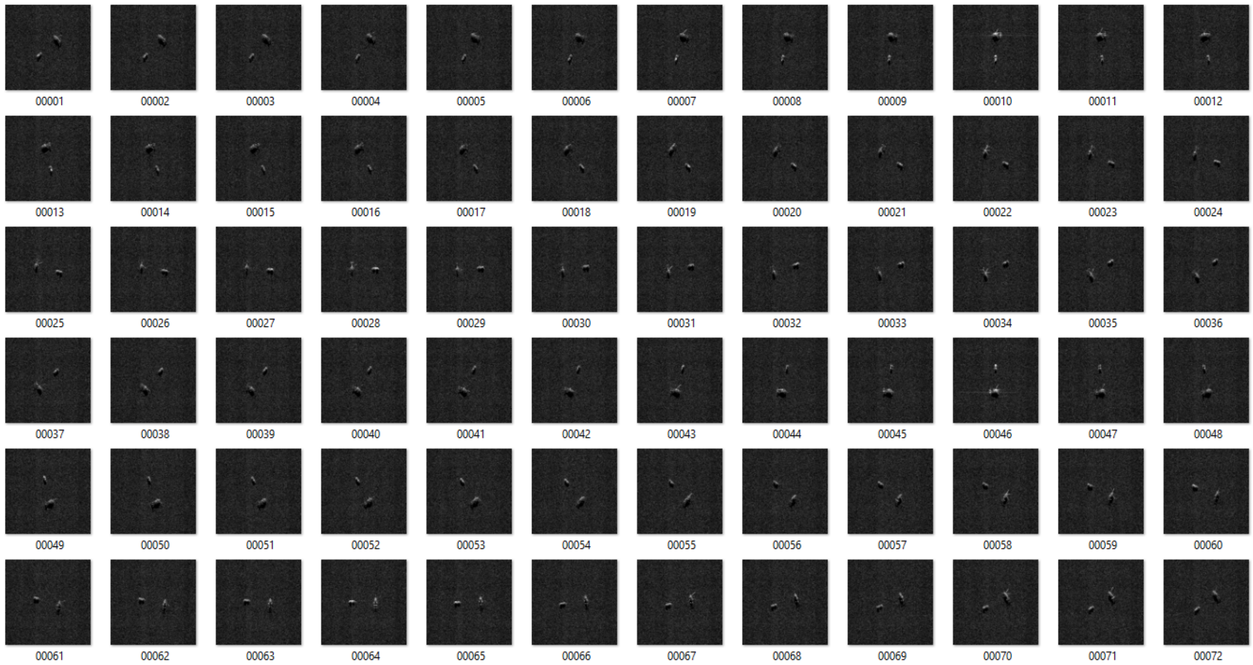

Figure 3-8: SAR images of data augmentation with two targets and multiple azimuth angles to the targets.

3.2 Two targets on sea

In this chapter the simulations result for simulations of two ships over water are presented.

Target motion is not considered in the simulations.

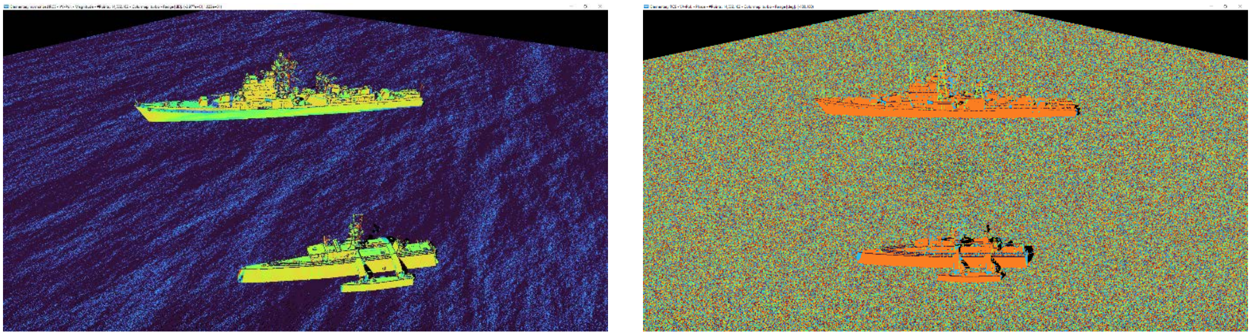

Figure 3-9: Synthetic RCS of two marine targets (military ships) over sea. Amplitude (left) and phase (right).

Figure 3-9 shows the amplitude and phase of the RCS of two military ships over water, while Figure 3-10 shows the range compressed data and the SLC image.

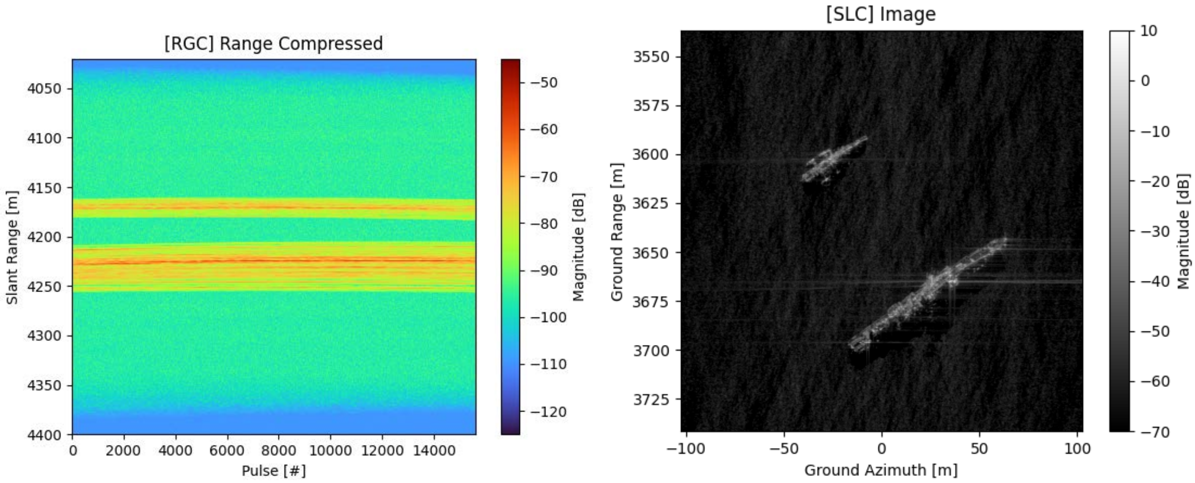

Figure 3-10: Range-Compressed data (left) and SLC image (right) with two military ships on sea

Some sample images of the simulation results for 72 different azimuth angles are reported on Figure 1-1.

4.0 CONCLUSIONS

This paper introduces a new realistic physics-based SAR simulator developed by MetaSensing to provide high-fidelity SAR image databases for ATR as well as large training datasets for AI applications.
The simulator makes use of the new hardware implemented raytracing and hardware acceleration provided by NVIDIA RTX GPU technology.

KAISAR is being used to simulate different targets of the MSTAR dataset and to provide data augmentation for the different SAR images with some of the targets used in the MSTAR experiment. KAISAR output SLC image has been compared with the real acquired SLC image and the results show a good agreement between the synthetic and real data, within a certain known constraints linked to the reproduction of the exact real conditions for the simulations.

5.0 REFERENCES

[1] Carrara, W.G., Goodman, R.S., and Majewski, R.M. (1995). Spotlight Synthetic Aperture Radar:

Signal Processing Algorithms. Artech House.

[2] Curlander, J.C., and McDonough, R.N. (1992). Synthetic Aperture Radar: Systems and Signal Processing. Wiley. ISBN: 978-0-471-85770-9.

[3] Cumming, I.G., and Wong, F.H. (2005). Digital Signal Processing of Synthetic Aperture Radar Data: Algorithms and Implementation. Artech House Remote Sensing Library.

[4] Jakowatz, C.V.J, Wahl, D.E., Eichel, P.H., Ghiglia, D.C., and Thompson, P.A. (1996). Spotlight-Mode Synthetic Aperture Radar: A Signal Processing Approach. Springer Science & Business Media, p. 201.

[5] U.S. Air Force. Sensor Data Management System. https://www.sdms.afrl.af.mil/index.php?collection=mstar