A Challenge Problem for 2D/3D Imaging of Targets from a Volumetric Data Set in an Urban Environment

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ABSTRACT

This paper describes a challenge problem whose scope is the 2D/3D imaging of stationary targets from a volumetric data set of X-band Synthetic Aperture Radar (SAR) data collected in an urban environment. The data for this problem was collected at a scene consisting of numerous civilian vehicles and calibration targets. The radar operated in circular SAR mode and completed 8 circular flight paths around the scene with varying altitudes. Data consists of phase history data, auxiliary data, processing algorithms, processed images, as well as ground truth data. Interest is focused on mitigating the large side lobes in the point spread function. Due to the sparse nature of the elevation aperture, traditional imaging techniques introduce excessive artifacts in the processed images. Further interests include the formation of high-resolution 3D SAR images with single pass data and feature extraction for 3D SAR automatic target recognition applications. The purpose of releasing the Gotcha Volumetric SAR Data Set is to provide the community with X-band SAR data that supports the development of new algorithms for high-resolution 2D/3D imaging.

Keywords: Synthetic Aperture Radar (SAR), Circular Synthetic Aperture Radar (CSAR), autofocus, 2D/3D imagery, X-band

1. INTRODUCTION

This document presents a challenge problem and a data set for 2D/3D image formation from sparse aperture X-band SAR data as well as data-driven autofocus collected using SAR data. In linear SAR systems, a user could face a complicated matching algorithm in the aspect angle domain when determining a target type and orientation due to the angular orientation of the target. As a result, the matching algorithm may be unreliable and produce false alarm rates as well as low detection rates due to the limited radar look angle data. However, this problem can be addressed by using circular SAR (CSAR) data collection of a spotlighted target region over 360 degrees (full rotation) [1].

In the process of CSAR data collection, an aircraft flies circular flight paths at a determined elevation around a fixed scene center and aluminates the scene of interest while collecting returned energy radiated from the ground to the aircraft. Due to the inherent nature of full azimuth coverage, SAR signal processing uses magnitude and phase of the received signals over successive pulses from elements of the synthetic aperture to create an image. Thus, full azimuth coverage and phase history allows for the formation of unique 3-dimensional imagery. Data presented for this challenge problem has been analyzed and smaller target areas of interest extracted through spotlight SAR data collection. The purpose of spotlight data is to obtain high-resolution imaging information for use in identifying targets [2]. As a result, a scene consisting of nine personal-owned-vehicles (POVs), one case tractor and one forklift have been spotlighted for high-resolution imagery formation. Also, a calibration array consisting of a tophat, numerous dihedral and trihedral targets exists for extensive groundtruthing. However, in realistic world environments, calibrated ground truth data may not be feasible or attainable. In a typical SAR application, image formation errors beyond the measurement capabilities of inertial measurement units or for propagation induced errors, it is necessary to use data-driven autofocus techniques [3]. Therefore, there exists the need to coherently align the aircraft radar from pass to pass by analyzing and formulating data-driven autofocus techniques.

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2. AUTOFOCUS

A single prominent point processing algorithm [2] was applied to the data to provide a sample coherent calibration between the eight passes. The large tophat in the scene is large enough that its return is brighter than benign clutter in a single pulse and it is visible from all aspect angles which makes it an ideal target for this algorithm. A slight modification of the algorithm is needed as the location of the tophat response varies with aspect angle. In a SAR image, the return from the tophat appears at the intersection of the vertical and horizontal plates. Since the radius of the cylinder is one meter, the return appears one meter away from the center of the tophat in the radial direction.

The algorithm is implemented by the following steps:

1. Loop through every pulse in the dataset.
2. Range compress the pulse to form a range profile of the scene.
3. Identify the range location of the peak corresponding with the tophat return.
4. Calculate the phase corrections needed to adjust the range to correspond with the actual location of the tophat.
5. Apply the phase corrections before image formation.

3. PROBLEM DEFINITION

As the military mission on the global war on terror changes, so does the method and approach that the warfighter must endure. Conventional war fighting methods such as open field combat and identifiable targets are no longer the norm since the battlefield is turning more to urban environments. As a result, urban asymmetric warfare requires increasingly difficult functions on smaller targets within tougher environments. Increased ground clutter, more specific identification and tracking techniques and minimized targets are the obstacles that new age warfighters must assess. AFRL/SNAS seeks to address these issues by addressing two significant problems associated with imaging and autofocus techniques.

3.1 Problem 1: Sparse aperture and 2D/3D images

Previous research has addressed traditional imaging in 2D and 3D image formation techniques that use nonlinear, non-coherent combinations of subaperture data [4, 5]. First, we seek to make the best possible 2/3-dimensional SAR image from a sparse aperture. Targets of interest include calibrated targets such as a tophat reflector and numerous dihedral/trihedral corner reflectors, 9 privately owned vehicles, 1 tractor, and 1 forklift. All data was collected in an urban environment located in a parking lot and adjacent grass area. Interest is focused on mitigating the large side lobes in the point spread function. Due to the sparse nature of the elevation aperture, traditional imaging techniques introduce excessive artifacts in the processed images.

3.2 Problem 2: Data-driven autofocus

Second, we seek to address data-driven autofocus techniques of using SAR data to coherently align the radar from pass to pass. An autofocus solution is provided for the HH and VV polarizations based on the returns from the large tophat reflector. One of the chief causes of defocus in airborne spotlight-mode imagery is uncompressed errors in the measurement of the aircraft position as it traverses the synthetic aperture [6]. In real-life imaging scenarios, calibration targets will not be available, so robust autofocus algorithms are needed for coherent alignment of the data from pass to pass.

4. DATA DESCRIPTION

The full public release data set, referred to as the “Gotcha Volumetric SAR Data Set, Version 1.0”, consist of SAR phase history data collected at X-band with a 640 MHz bandwidth with full azimuth coverage at 8 different elevation angles and full polarization. The imaging scene consists of numerous civilian vehicles and calibration targets. Figure 1 displays a spotlighted 2D SAR data image of the vehicle staging center and calibration target array from a single pass with 360 degrees full aperture. Figure 2 displays a digital picture of the targets assembled in the vehicle staging center. Upon comparison analysis of the vehicle staging center SAR image to the staging center digital image, two vehicles are missing due to scripted scenarios being orchestrated during the time period selected for the SAR image data to be processed. Figure 1 was selected only as a reference and example of imagery processed from the collected data.

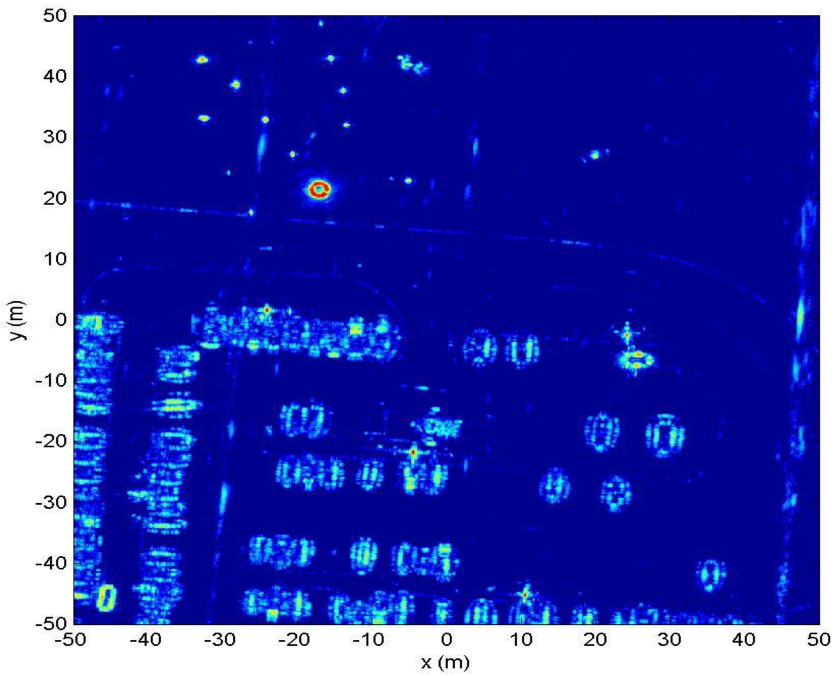

Figure 1. 2-dimensional SAR Image of the spotlighted scene center from a single pass with 360 degrees full aperture

Figure 2. Digital picture reference of parking lot consisting of vehicle staging center. All nine personal-owned-vehicles, case tractor and forklift displayed.

Figure 3 displays one POV (Ford Taurus Wagon) used to demonstrate problems associated with current autofocus techniques as noted by the example image results in Figures 4-5 of 3D volumetric images using all eight passes with 360 degrees full aperture. Of significant concern are the excessive artifacts produced in the processed images. It should be noted that these images are examples only and not a benchmark for analysis. An example of the extensive calibration target ground truth is displayed in Figure 6 as a digital image of the tophat reflector. Further detail of the calibration site layout is displayed in Figure 7 and a data description of the calibrated targets is listed in Table 1.

Figure 3. Digital Picture reference of Ford Taurus Wagon used in the 3-dimensional SAR imaging of figures 4 and 5.

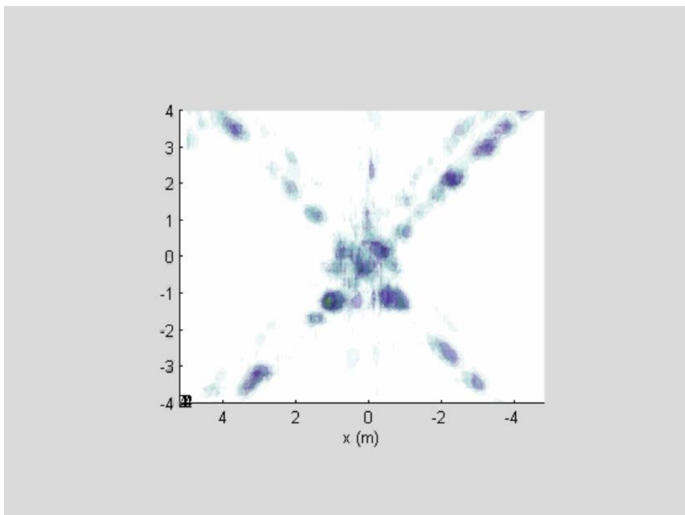

Figure 4. 3-dimensional volumetric SAR image from the front end view of the Ford Taurus Wagon using all eight passes with 360 degrees full aperture.

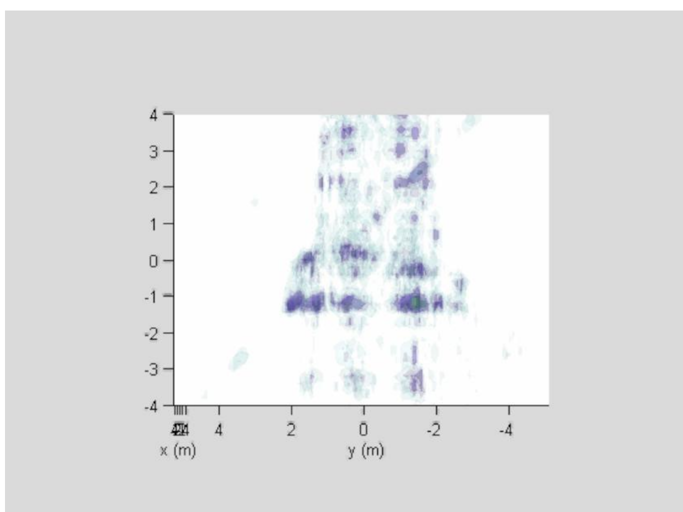

Figure 5. 3-dimensional volumetric SAR image from the side view of the Ford Taurus Wagon using all eight passes with 360 degrees full aperture.

Figure 6. Digital picture reference of the calibrated tophat reflector used in the calibration array of the spotlighted scene center.

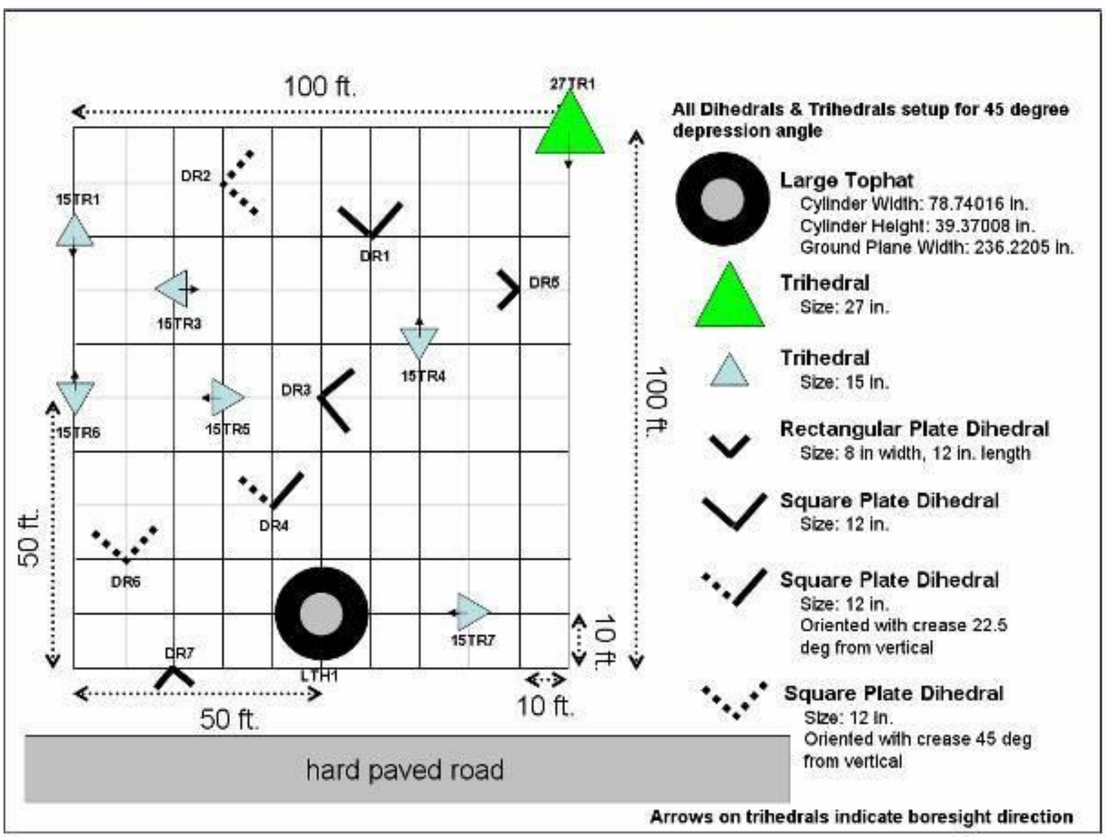

Figure 7. Layout diagram of the calibration array used in the spotlighted scene center.

Table 1. Calibration Array Data Descriptions

Calibration Target	ID#	Point	X (m)	Y (m)	Z (m)	Heading (degrees)
15 in Trihedral	15TR-01	C	-32.14	42.54	-0.53	180
15 in Trihedral	15TR-03	C	-28.09	38.67	-0.42	90
15 in Trihedral	15TR-04	C	-13.86	37.70	-0.05	0
15 in Trihedral	15TR-05	C	-24.39	32.96	-0.33	270
15 in Trihedral	15TR-06	C	-32.50	33.41	-0.57	0
15 in Trihedral	15TR-07	C	-5.12	22.98	-0.05	270
27 in Trihedral	27TR-01	C	-7.51	51.47	-0.09	180
12 in 12 in Dihedral	DR-01	C	-15.55	42.96	-0.13	0
12 in 12 in Dihedral	DR-02	C	-26.16	45.64	-0.43	90
12 in 12 in Dihedral	DR-03	C	-18.58	33.53	-0.18	90
12 in 12 in Dihedral	DR-04	C	-20.88	27.10	-0.23	0
12 in 8 in Dihedral	DR-05	C	-13.24	32.09	-0.09	270
12 in 12 in Dihedral	DR-06	C	-29.27	24.48	-0.48	0
12 in 8 in Dihedral	DR-07	C	-26.15	17.50	-0.44	180

The collected data for the challenge problem is stored in MATLAB binary format (*.mat files). Each file contains the phase history collected over one degree of azimuth for a single pass and a single polarization. With 8 passes and 4 polarizations per pass, the total number of files is 11,520 (360 * 8 * 4). The filenames are coded with the pass number, polarization, and azimuth angle. For example, file "data_3dsar_pass1_az001_HH.mat" contains the data for all pulses from 0 to 1 degree azimuth from pass 1 operated at HH polarization. Loading a file gives a single MATLAB structure with fields containing the k-space data, frequencies, x,y,z-coordinate antenna locations, range to scene center, azimuth angle (degrees), and elevation angle (degrees). In addition, a simple autofocus solution is provided for the HH and VV polarizations.

To request a copy of the full data set, visit the AFRL/SNA Sensor Data Management System (SDMS) Public Website https://www.sdms.afrl.af.mil/main.php.

5. SUMMARY

This document presents a challenge problem and a data set for 2D/3D image formation from sparse aperture X-band SAR data as well as data-driven autofocus collected using SAR data. The full public release data set, referred to as the "Gotcha Volumetric SAR Data Set, Version 1.0", consist of SAR phase history data collected at X-band with a 640 MHz bandwidth with full azimuth coverage at 8 different elevation angles and full polarization. The imaging scene consists of numerous civilian vehicles and calibration targets. The challenge problem associated with the data set consists of the formation of high quality 2/3D imagery from a sparse aperture, as well as data driven autofocus in the absence of ground truthing. All images, digital pictures, phase history data, ground truthing, target locations, challenge problem statement and data description are included on a 2 disc set available upon request.

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