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Sparsity based Ground Moving Target Imaging via Multi-Channel SAR

Di Wu, Mehrdad Yaghoobi and Mike Davies

The University of Edinburgh

Outline

- Introduction
- Objectives
- Methodology
- Experiment and Results
- Conclusions and Future Work

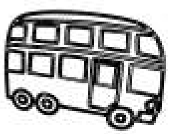
Introduction

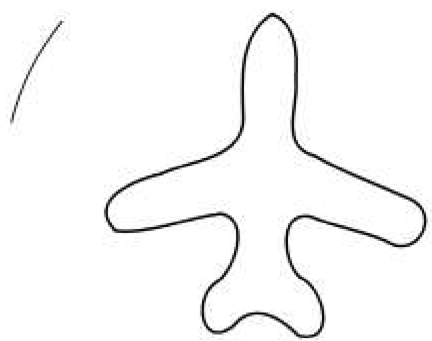
- SAR (Synthetic Aperture Radar)

➢ Developments in SAR can be traced back to 1950s when the military was in need of a remote surveillance device with all-weather, day-or-night capability.

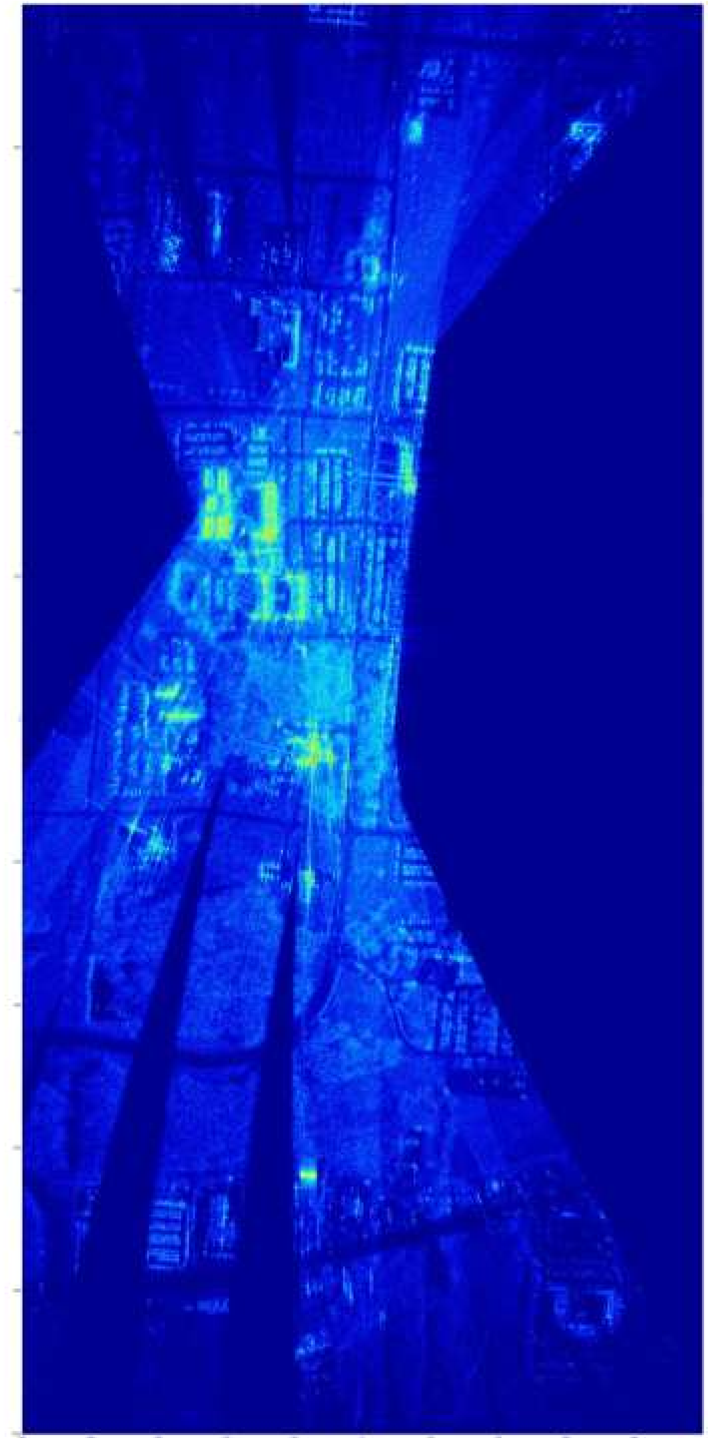
➢ By collecting the received signals along the flight path of the platform, SAR synthesises a long virtual aperture to provide the images with high spatial resolution.

➢ State-of-the-art SAR imaging techniques are capable of forming high resolution (as fine as 0.1 meters) images of the monitored region.





AFRL Gotcha GMTI Data



Introduction

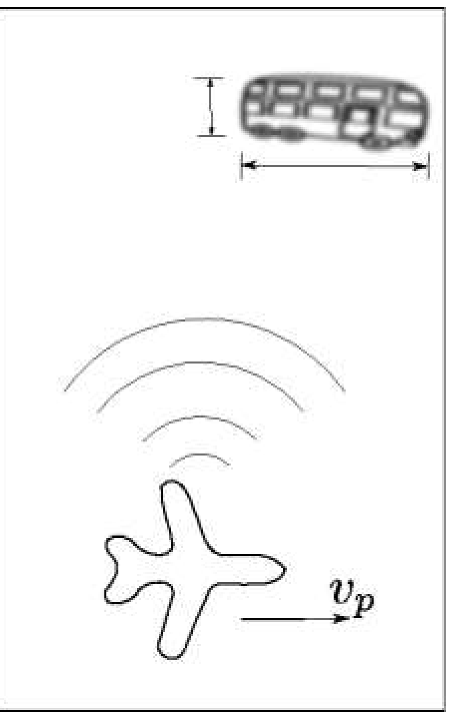
- GMTI (Ground Moving Target Indication)

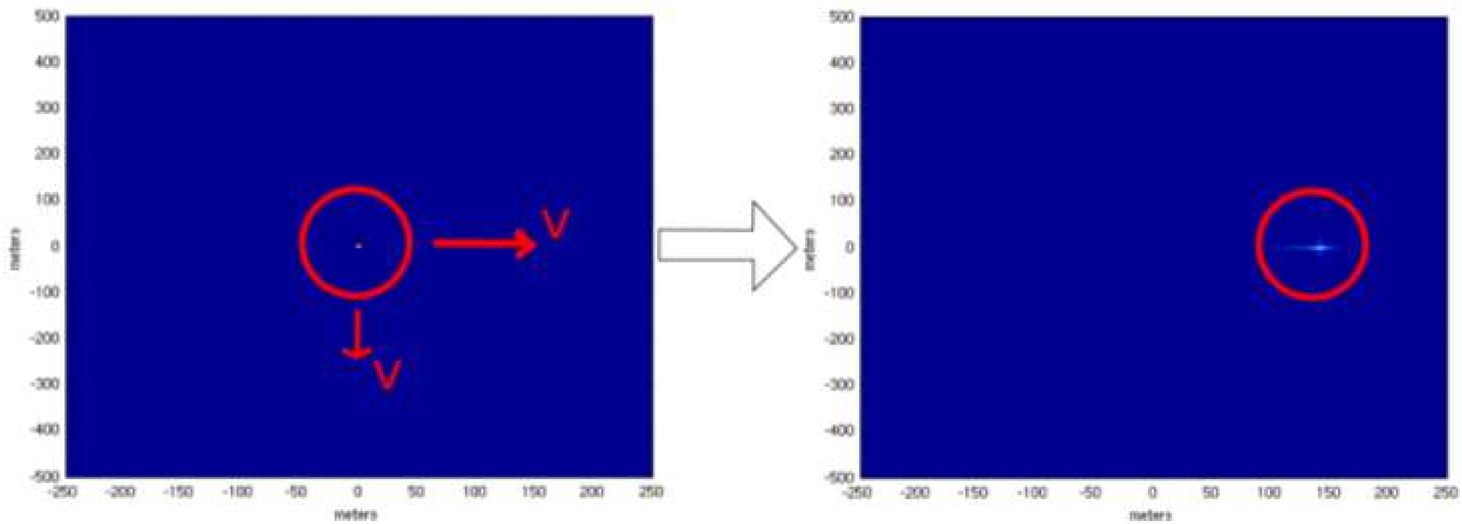
➢ In combination with SAR, GMTI techniques provide the possibility to track vehicles in all weather conditions and locate targets based on the imaging ability.

➢ In particular, multi-channel SAR/GMTI are trying to expose moving targets by exploiting the differences between multiple radar channels. Widely used techniques are subtractive methods such as (DPCA) Displaced Phase Center Antenna and (ATI) Along Track Interferometry.

Introduction

- A typical SAR image assumes the stationary scene.
- It is well known that moving targets will induce displacement and blurring in the image





The formed image of one moving target with conventional techniques in the simulation. (The target is marked with the red circle.)

Objectives/Motivations

Motivated by

- Most of the observed scene is static. Only very few dynamics are of interest.
- Moving targets can be best focused with correct motion parameters.

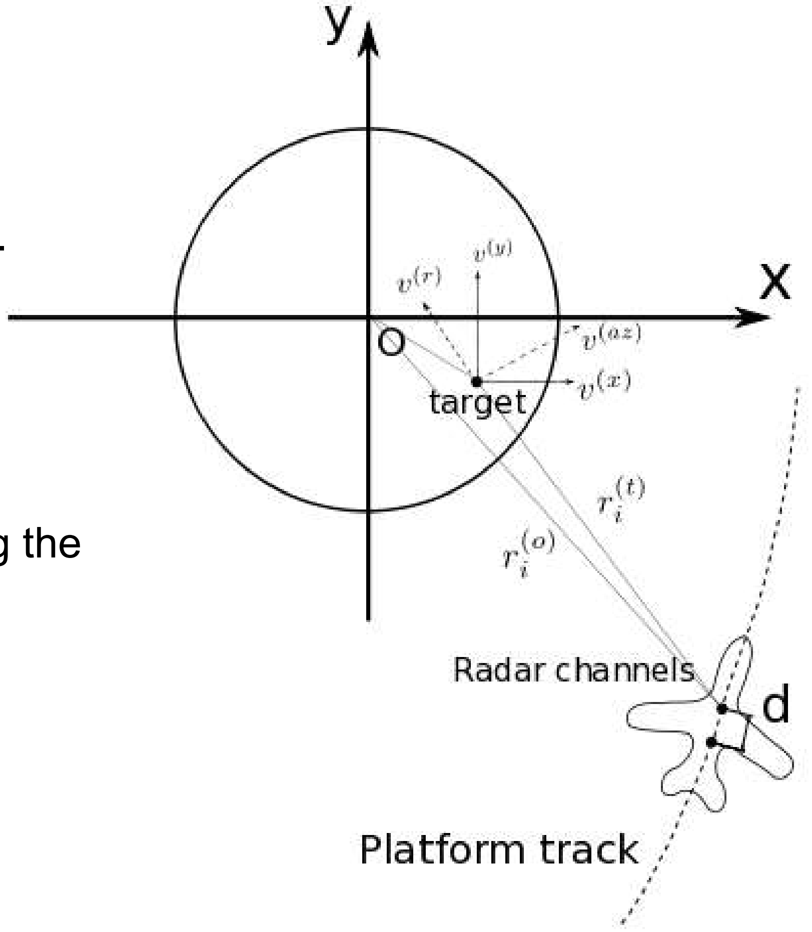
We aim to simultaneously

- Form SAR Images
- Refocus and relocate the moving targets
- Estimate targets’ motion parameters

Methodology

- Geometry

- Approximately far-field model.
- Channels are aligned along the platform track.
- The ‘stop-and-hop’ approximation is applied.
- Sufficiently small sub-apertures imply rapid processing and linear platform trajectory.
- Moving targets have constant velocities during the coherent processing interval (CPI).

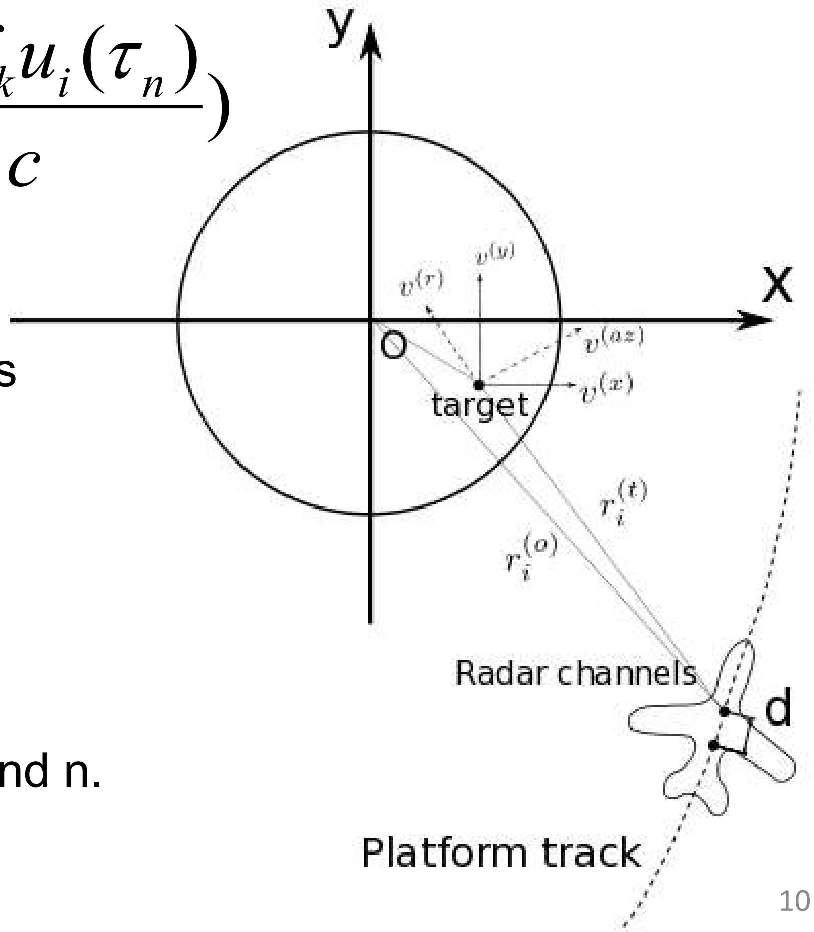


Methodology

- Basics

Given only one target, we denote the compensated discrete received signal of the i-th channel as:

$$Y_i(f_k,\tau_n) = A_i\sigma(\mathbf{r}(\tau_n))\exp(-\frac{j4\pi f_k u_i(\tau_n)}{c})$$



- f_k : range frequencies
- τ_n: azimuth time of the transmitted pulses
- A_i: beam pattern and energy loss
- $\mathbf{r}(\tau_n)$: target position at τ_n
- σ: target reflectivity
- $u_i(\tau_n)$: differential range $r_i^{(t)}(\tau_n)$- $r_i^{(o)}(\tau_n)$
- c: speed of light

* The received data is recorded with entries k and n.

Methodology

- Multi-channel SAR and Channel Balancing

➢ The received echo of the aft-antenna can be viewed as the delayed received signal of the fore-antenna.

➢ With channel balancing, we attempt to retrieve the same responses for stationary targets between different channels. (The responses of moving targets are still different.)

We denote the balanced second channel data as

$$\widetilde{Y}_2(f_k, \tau_n)$$

e.g. If the transfer functions of the two channels have been equalised, then we have

$$\widetilde{Y}_2(f_k, \tau_n) = Y_2(f_k, \tau_n + \Delta)$$

where Δ represents the time delay between the two channels.

Methodology

- Image Forming

We define a grid $(x_m, y_l, 0)$ on the terrain with no heights. The formed image is:

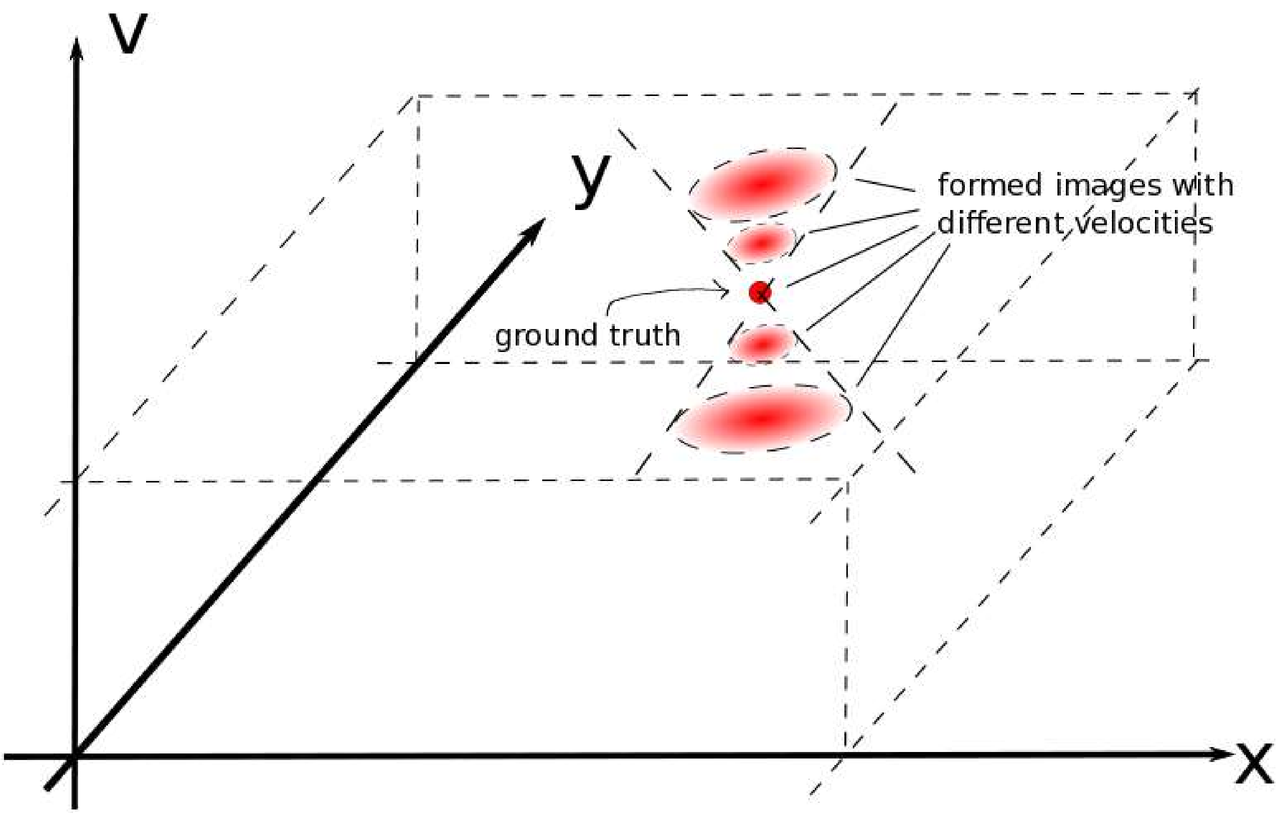
$$X(m,l) = \sum_{k=1}^{K} \sum_{n=1}^{N} Y(f_k, \tau_n) \exp\left(\frac{j4\pi f_k d_{nml}}{c}\right)$$

It can be rewritten as $\mathbf{X} = \Phi_B(\mathbf{Y})$

- d_{nml}: $||\mathbf{r}^{(c)}(\tau_n) - (x_m, y_l, 0)|| - ||\mathbf{r}^{(c)}(\tau_n)||$
- $\mathbf{r}^{(c)}(\tau_n)$: channel position at τ_n
- $\mathbf{Y}$: phase history

Methodology

- Moving Target Imaging



Instead of forming the image in the 2-D physical space (x-y space) directly, we reconstruct the image with additional dimensions which stand for the 'velocity map'.

* We assume that there is only one dominant velocity for each image element.

Methodology

- DPCA and ATI

DPCA:
$$X_1 - X_2 = \Phi_B(Y_1) - \Phi_B(\widetilde{Y}_2)$$

$$X_1(m,l) - X_2(m,l) \approx X_1(m,l)(1 - \exp(-\frac{j4\pi f_0 v_{ml}^{(r)} \Delta}{c}))$$

The image is approximately scaled with a function of the radial velocities.

ATI:
$$X_1 \circ X_2^* = \Phi_B(Y_1) \circ \Phi_B^*(\widetilde{Y}_2)$$

$$X_1(m,l) \times X_2^*(m,l) \approx \left|X_1(m,l)\right|^2 \exp(-\frac{j4\pi f_0 v_{ml}^{(r)} \Delta}{c})$$

The radial velocities can be estimated based on its phases.

Methodology

- Sparsity based SAR/GMTI

A different perspective:

We generalise the ground moving targets imaging as a parameter estimation and an optimisation problem.

$$\min_{\mathbf{X},\mathbf{V}} \|\mathbf{Y}_1 - \Phi_F^{\mathbf{V}}(\mathbf{X})\|_F^2 + \|\widetilde{\mathbf{Y}}_2 - \widetilde{\Phi}_F^{\mathbf{V}}(\mathbf{X})\|_F^2 + \lambda\|\mathbf{V}^{(x)}\|_0 + \lambda\|\mathbf{V}^{(y)}\|_0$$

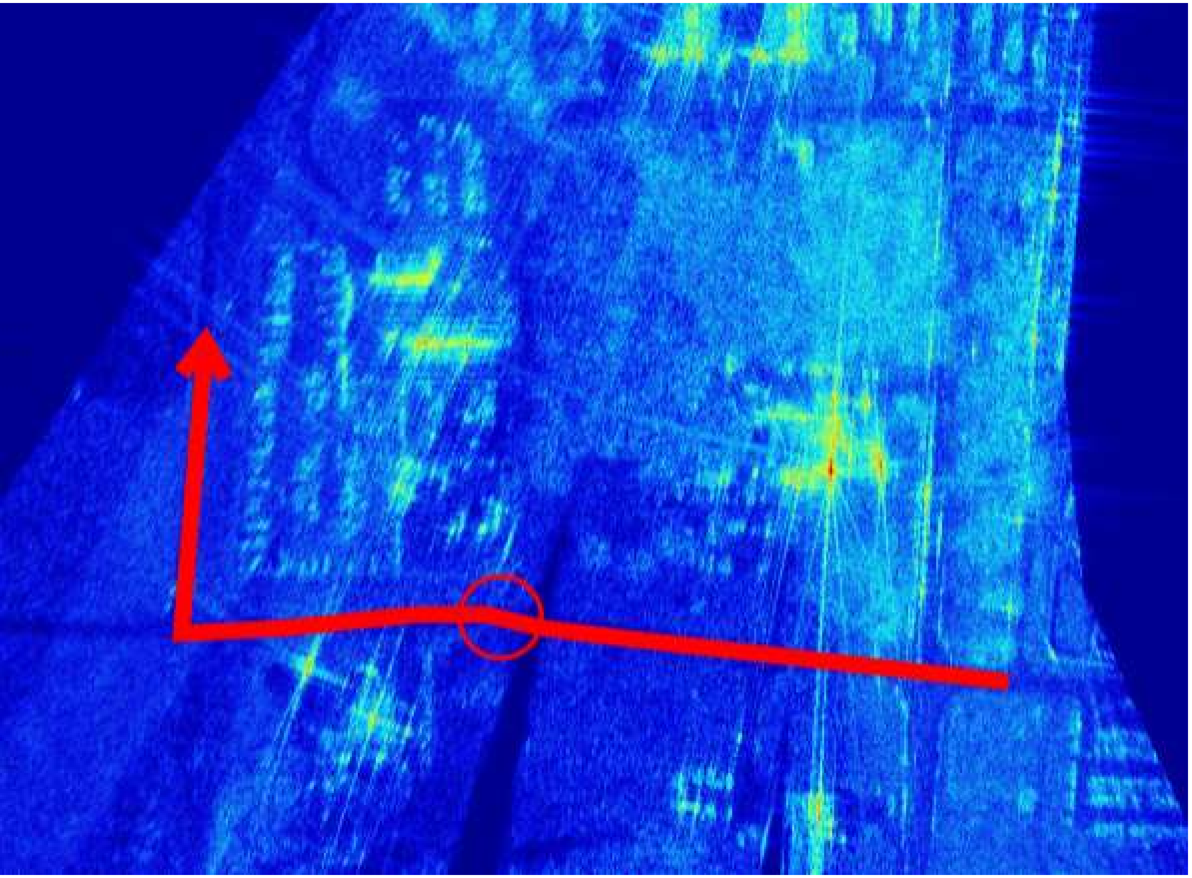
$$s.t. \quad \mathbf{X} \in \mathbb{C}^{M\times L}, \mathbf{V}^{(x)} \in \mathbb{R}^{M\times L}, \mathbf{V}^{(y)} \in \mathbb{R}^{M\times L}$$

$$\text{supp}(\mathbf{V}^{(x)}) = \text{supp}(\mathbf{V}^{(y)})$$

Solving this model is challenging especially with large dataset and large feasible space, thus we currently employ its partial formulation in the experiments.

Experiment and Results

- AFRL GOTCHA GMTI data set.



Three phase centers + urban environment.

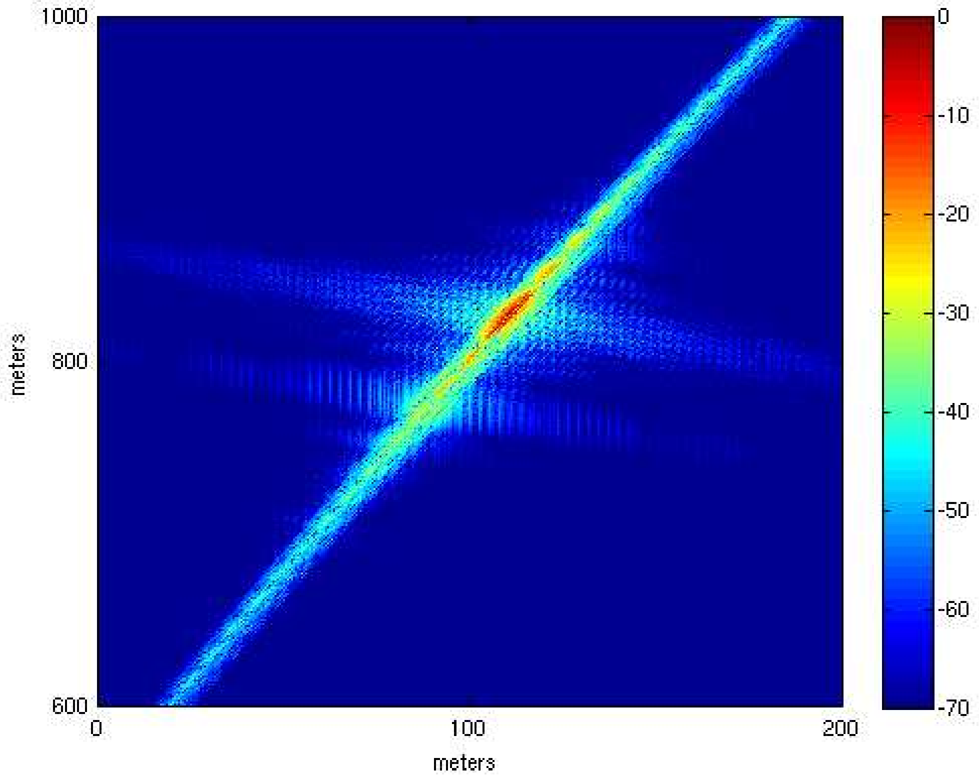
The ground truth data of the target vehicle is given.

The phase history is collected over 71 seconds interval.

The data was range-gated for storage reasons.

We consider the 46-th second snapshot with 0.1 seconds interval.

Experiment and Results



Displayed in dB.

To decrease the computational complexity:

We approximately crop the phase history with a hamming windowed band-pass filter to focus on the target.

Experiment and Results

- Simplified Model

To simplify the problem:

The radial velocities are estimated with standard ATI.
We do optimisation on the azimuth velocities and scene reflectivities.

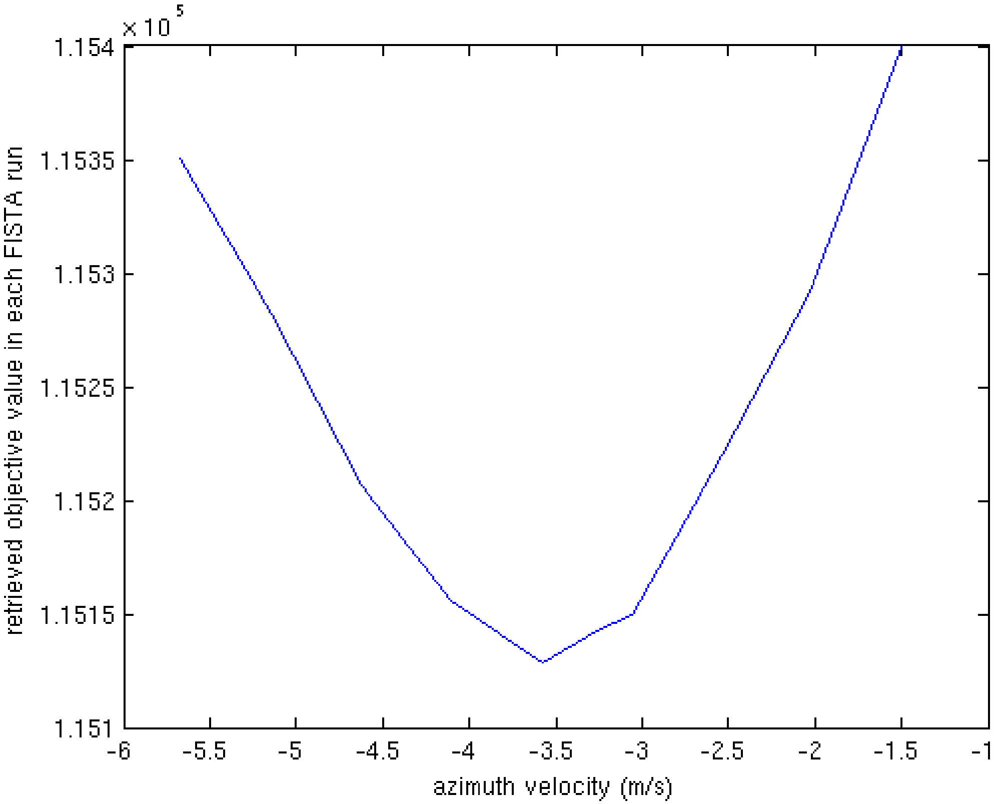
$$\min_{\mathbf{X},\mathbf{V}^{(az)}} \|\mathbf{Y}_1^{(t)} - \widetilde{\mathbf{Y}}_2^{(t)} - \Phi_F^{\mathbf{V}}(\mathbf{X})\|_F^2 + \lambda\|\mathbf{X}\|_1$$

$$s.t. \quad \mathbf{X} \in \mathbb{C}^{M\times L}, \mathbf{V}^{(az)} \in \mathbb{R}^{M\times L}, \mathbf{V} = \Upsilon(\mathbf{V}^{(az)}, \mathbf{V}^{(r)})$$

$$\operatorname{supp}(\mathbf{X}) = \operatorname{supp}(\mathbf{V}^{(az)})$$

* Here the estimated $\mathbf{X}$ is the sparsified image of moving targets.

Experiment and Results

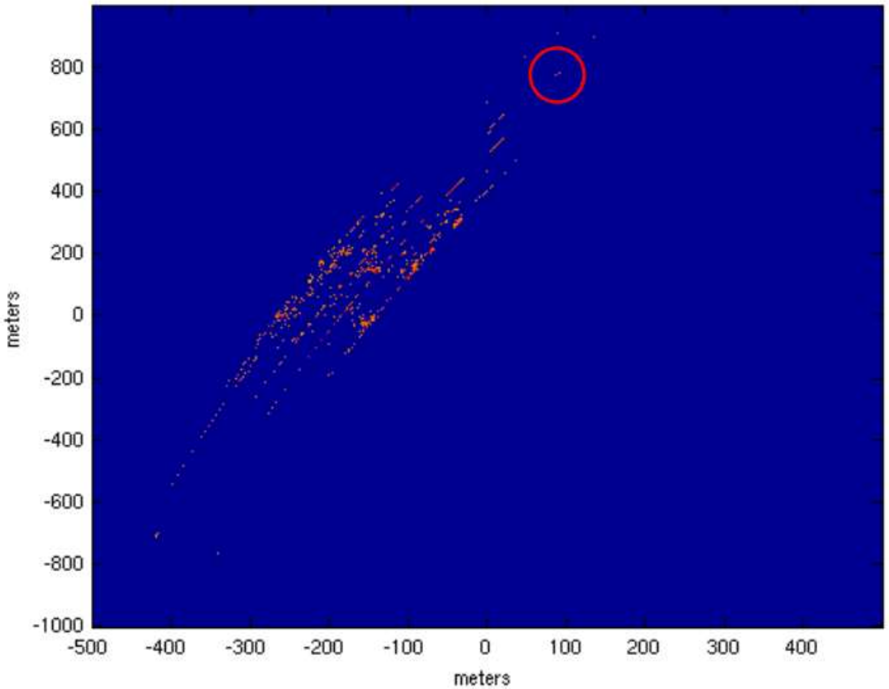


FISTA algorithm is implemented to solve the model.

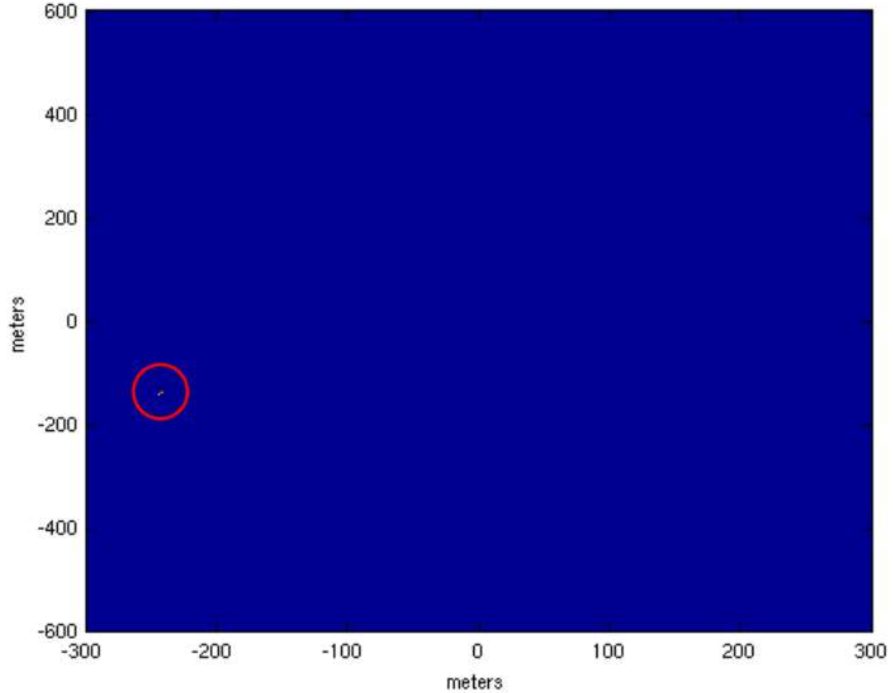
The objective values with different azimuth velocities are recorded.

X are chosen to correspond with the minimised objective value.

Experiment and Results

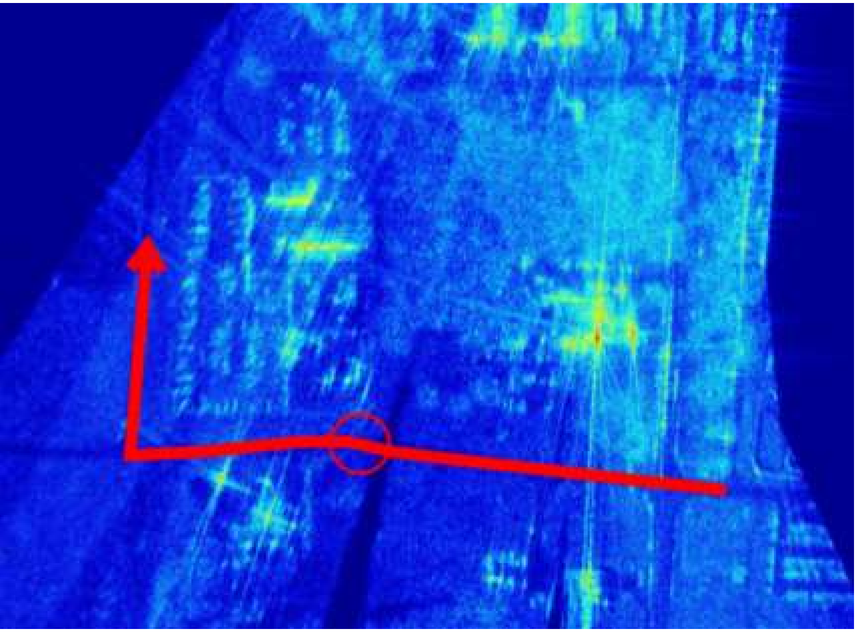


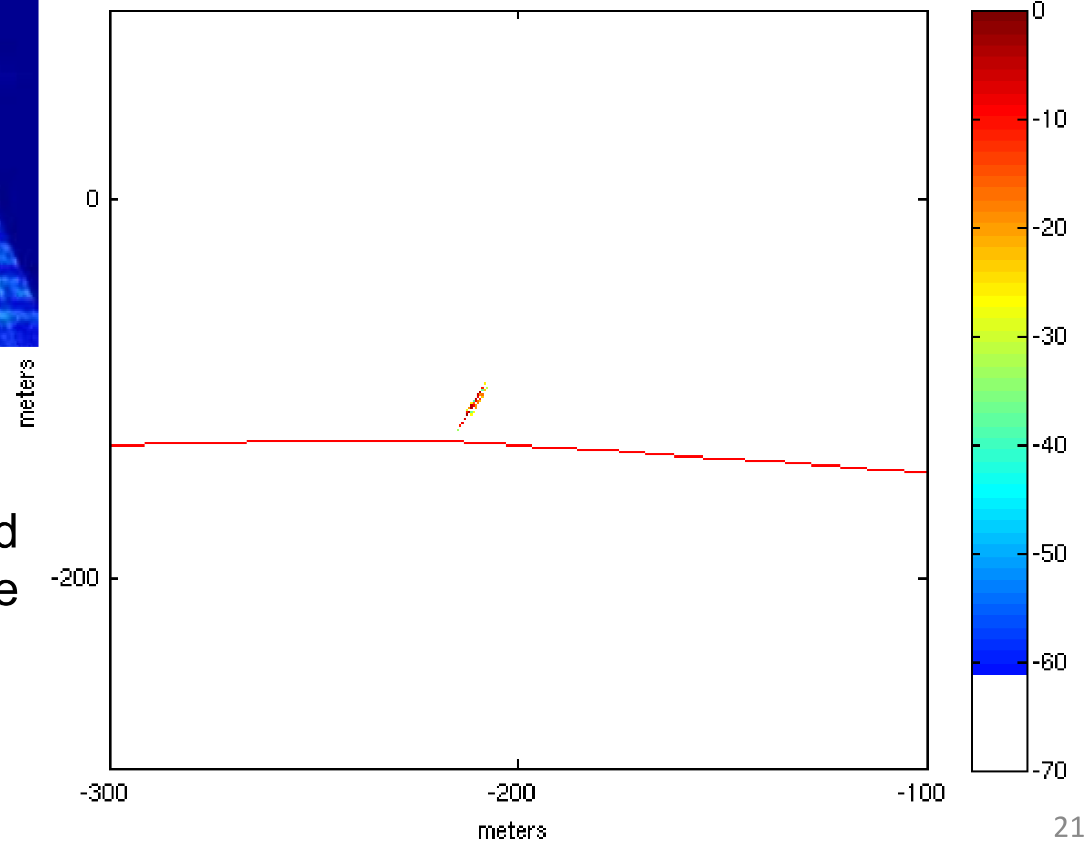
A marked target with conventional imaging technique



The relocated and refocused target

Experiment and Results





The target is refocused and relocated. The red line indicates the ground truth path.

Experiment and Results

	Ground Truth	Estimations
x (m)	-206.7	-211
y (m)	-129.0	-110
z (m)	-3.2	0
range distance to the platform (m)	1.0375e4	1.0380e4
$v^{(r)}$ (m/s)	9.588	9.82
$v^{(az)}$ (m/s)	-2.14	-3.58
overall v (m/s)	13.63	14.32

Conclusions and Future Work

- We generalise the SAR/GMTI task as an optimisation problem and leverage the sparsity to estimate targets' states and form SAR images.
- The moving targets will be refocused and relocated in the formed images.
- Efficient implementations are of interest to us.
- Video SAR processings will be explored.

Acknowledgements

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Thanks for your attention!

Questions?

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