Innovative Project

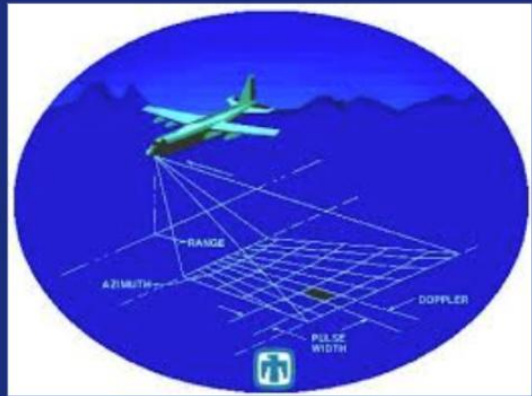
A Novel Framework for integrated GPS-SAR system

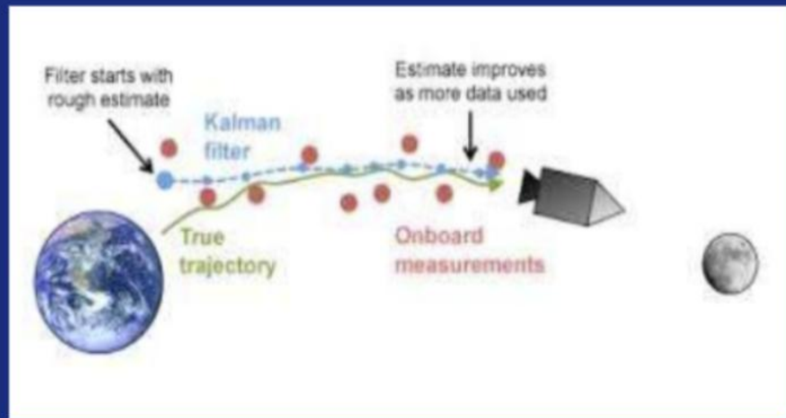
Radar and Satellite Communication
EC438

Anirudh Nakra 2K17/EC/22
Abhijeet Vats 2K17/EC/22
Submitted to : Prof. Avinash Ratre

Introduction

- SAR
- GPS
- Extended Kalman Filter
- SAR RDA and Back Projection





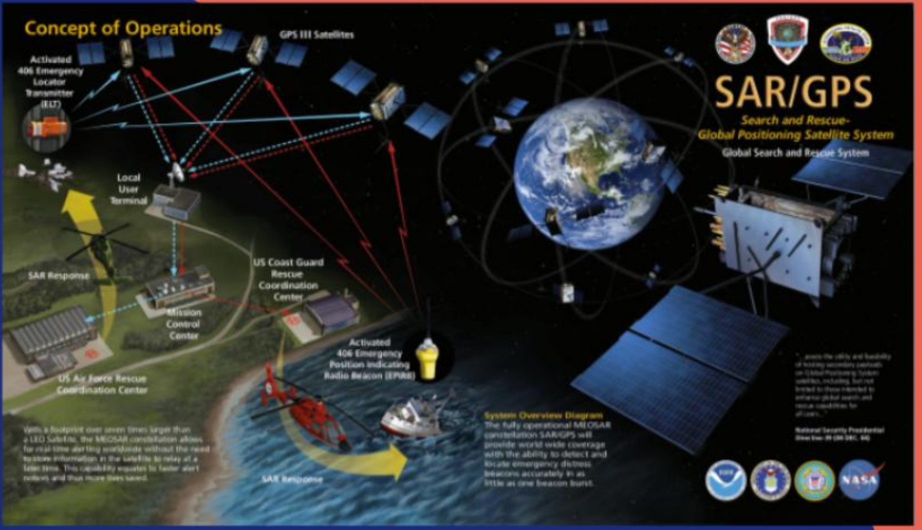
Introduction

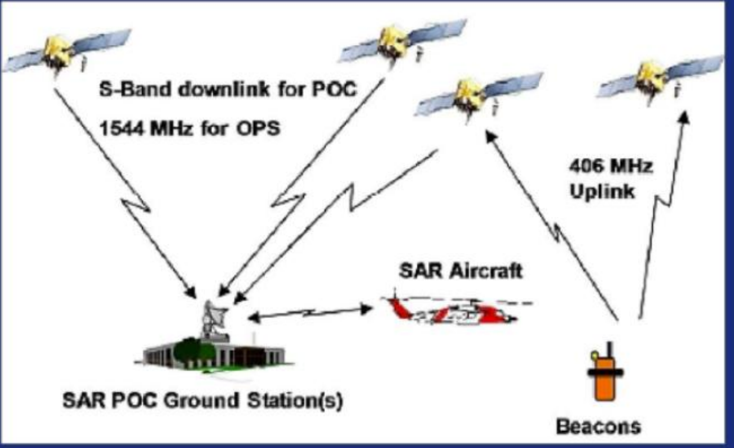
The project revolves around SAR, GPS and extended kalman filter and bring about an integrated approach.

Synthetic aperture radar is a remote sensing technique. It gathers information by creating power and then recording the power reflected back by the surface. It can detect different physical features of the surface, such as structure, temperature, and wetness

The Global Positioning System, or GPS, is a remote sensing system that serves as the backbone. This navigation system supplies GPS receivers with spatiotemporal data over a large geographical area.Some specific applications can also be utilized by GPS which can range from important situations like in emergency response, disaster management to entertainment activities such as in mobile games like Pokémon go

When the device is in an isolated place or travelling through places with a loss of connectivity, such as a tunnel, the situation becomes more challenging. Kalman filtering can be a good solution here because it delivers an accurate estimate of the device's location based on sensor data. When using a dynamic GPS-SAR integration technique, Kalman filtering should always be taken into account.





GPS

- GPS Mapping
- C/A Code
- Integration with SAR system
- Remote Sensing Applications

Extended Kalman

- Kalman Filter
- Extended Kalman
- Implementation w/ GPS correction and tracking

Tomography

- Spliced Interferometry

SAR

- Modified RDA with backprojection

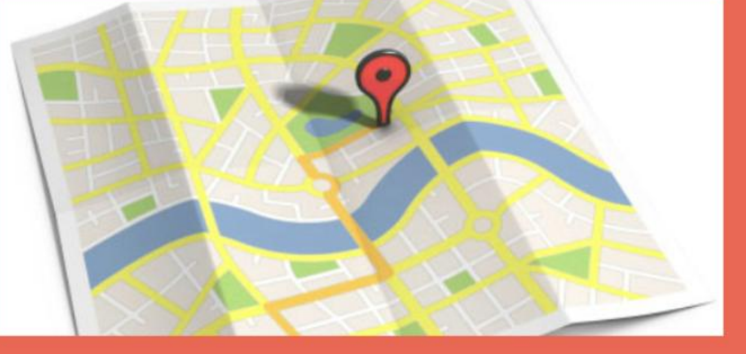
Made with VISME

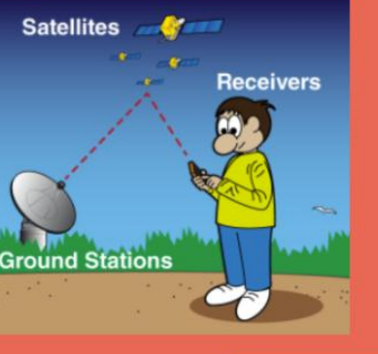
G

Global Positioning System

GPS was initially developed as a USA military specific technology but was later declassified for civilian usage. Current GPS systems employ a network of over 24 satellites that are hovering over Earth in a fixed satellite. The satellites are communicating 4 dimensional spatio temporal data: the three coordinates as well as their time instances.The GPS satellites usually operate in the L band with L1 and L2 bands being used for positioning data and CDMA codes.

A PNR code is communicated between the satellite and the receiver as a priori information. Using this PNR code, delays in the epochs of the code between the satellite and the receiver can be measured to get a final TOA. Other than the obvious satellite and receiver infrastructure, there is an important part of the system that needs to be deployed on Earth. This system is known as the control network or the control segment. The control segment basically ensures that the system is working as intended.





G

Global Positioning System

There is a need for explaining how the coarse acquisition code is generated for CDMA usage by the satellites. The C/A code is nothing but a long sequence of PRN which uniquely identifies the satellite among 24-32 others. These C/A codes are made from Gold codes due to their excellent correlation and cross correlation properties.

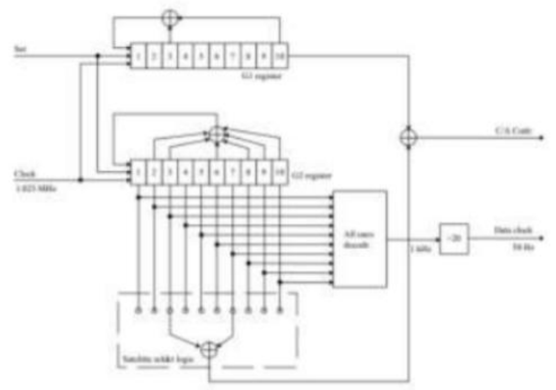


Figure 2.2: C/A code generator.

$$P(1) = x10 + x3 + 1$$

$$P(2) = x10 + x9 + x8 + x6 + x3 + x2 + 1$$

E

Extended Kalman

Extended kalman filter is extensively used in estimation theory. It is an extended version of normal kalman filter as the normal kalman filter is used only for linear models, but when we consider real world scenarios, most of the systems are nonlinear in nature. Therefore, an extended kalman filter becomes important. Extended kalman filter linearizes around the mean and covariance of the system considered. For nonlinear systems, it is considered the best option because of its low computational cost when we compare it to other non linear filters like particle filters. It is extensively used to solve real time problems such as in the navigation system in our case.

In target tracking, the approximation is done on a 3-dimensional space by calculating the position and velocity of the tracking object using different types of sensors.

$$\boldsymbol{x}_k = \boldsymbol{f}\left(\boldsymbol{x}_{k-1}, \boldsymbol{u}_{k-1}\right) + \boldsymbol{w}_{k-1}$$

$$z_k = \boldsymbol{h}\left(\boldsymbol{x}_k\right) + \boldsymbol{\nu}_k$$

Here
f= function of preceding stages
xk-1= preceding stage
uk-1= command input
Wk-1, vk= gaussian white noise for process model and measurement model
h= measurement function
zk= measurement

E

Extended Kalman

Then, standard deviations are calculated for the noise process in each of the directions namely x,y and z. The relationship is modelled between target state and sensor by setting the target state as variable. And by applying the concepts of extended Kalman filter in each direction, an estimation result is extracted from each axis and velocity of the object on that axis. Then, for each axis prior values are used for plotting the posterior of position and velocity for each axis. Standard error in both the cases are measured by taking into account the root mean squared error. Similar applications like terrain referenced navigation can also be performed using the same procedure as stated above.

Measurement residual	$\tilde{\boldsymbol{y}}_k = z_k - \boldsymbol{h}\left(\hat{\boldsymbol{x}}_k^-\right)$
Kalman gain	$K_k = P_k^- H_k^T (R + H_k P_k^- H_k^T)^{-1}$
Updated state estimate	$\hat{\boldsymbol{x}}_k^+ = \hat{\boldsymbol{x}}_k^- + K_k \tilde{\boldsymbol{y}}$
Updated error covariance	$P_k^+ = (I - K_k H_k) P_k^-$

Target State--

$$\boldsymbol{x} = \left[\boldsymbol{p}^T, \boldsymbol{v}^T\right]^T$$

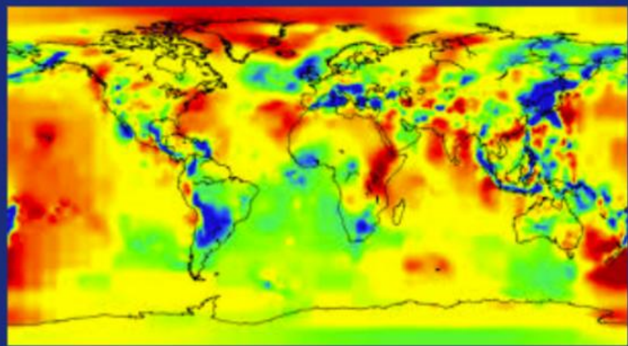
where,
p= position vector
v= velocity vector
Then, the system is modeled as a near constant velocity model in discrete time space.

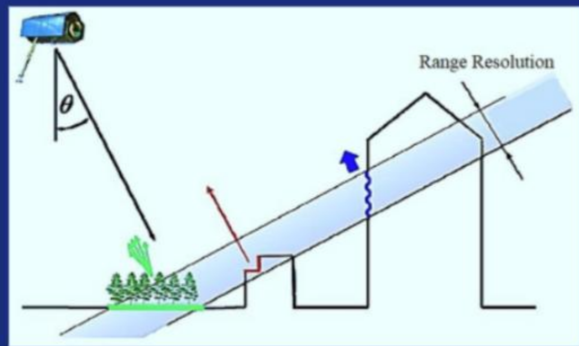
$$\boldsymbol{x}_k = \begin{bmatrix} \boldsymbol{p}_k \\ \boldsymbol{v}_k \end{bmatrix} = \boldsymbol{f}\left(\boldsymbol{x}_{k-1}, \boldsymbol{u}_{k-1}\right) = \begin{bmatrix} \boldsymbol{p}_{k-1} + \boldsymbol{v}_{k-1}\Delta t \\ \boldsymbol{v}_{k-1} \end{bmatrix} + \boldsymbol{w}_{k-1}$$

T

Tomography

Tomography is another concept that is especially relevant to SAR systems. SAR enjoys applications in diverse fields ranging from weather telemetry to oceanography. However, these landscapes are often very complex. To evaluate these terrains, a better technique must be devised. Over the past few years, the field of SAR tomography has taken a huge leap in popularity. SAR interferometry has been improved to a point that additional information can be extracted from the echoes of the SAR illumination. These techniques allow the 3d construction of a terrain rather than a traditional top down image supplied by the SAR system. Multidimensional SAR processing is a tough and innovative technique. It is currently used to map out urban areas, forests and even whole glaciers. By including the temporal domain as well, it is very possible that in the future we will see the concept of evolving 3D models come to life. This 3D SAR technique is able to consolidate height backscattering information as well as target and interference based separation in a single pixel which allows us to analyse the target of interest in much detail

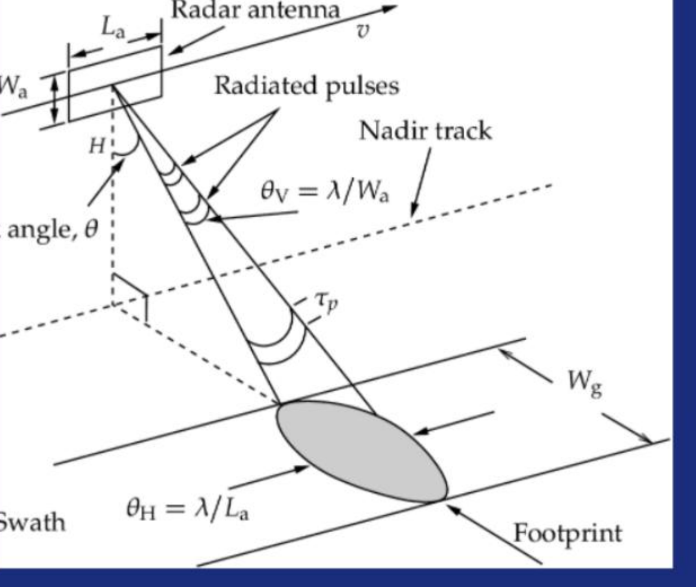




S

Synthetic Aperture Radar

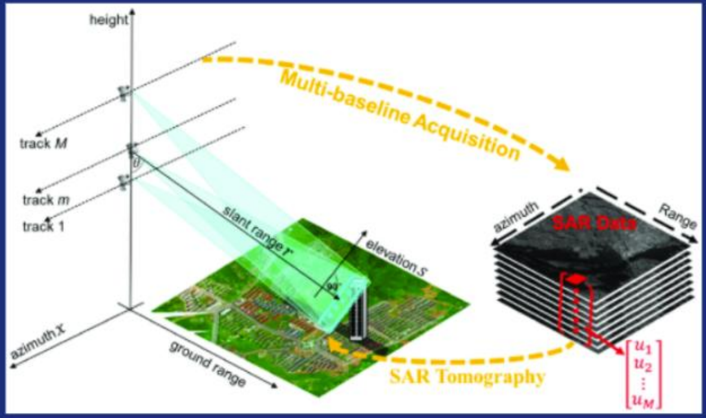
Synthetic aperture radar is an alternative methodology of generating high resolution images from a radar that is challenged in that aspect. Synthetic aperture radar or SAR is a novel remote sensing technique that has been exploited in recent times. SAR sensors produce their own stimuli and illuminate the ground while recording the amount of energy reflected and thus making important observations. Since the SAR illumination is heavily affected by the properties of the reflection media, the structure and general properties of terrain are easily representable.



S

Synthetic Aperture Radar

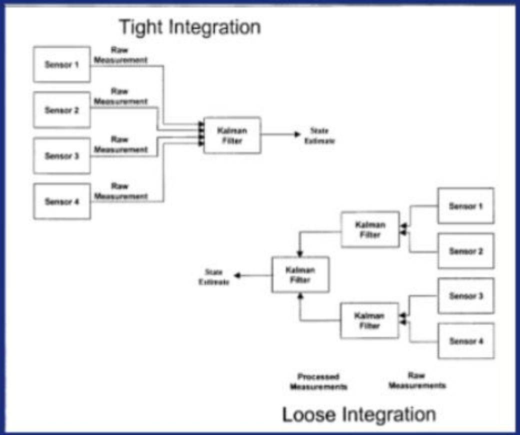
SAR radars are coherent in nature and use the straight lined path to create a fine resolution imagery of the whole landscape. SAR essentially exploits the motion of its source or carrier to create an effective antenna which has a much higher resolution than conventional antennas. By transmitting short pulses and reading its echos, the SAR system can thus simulate a better antenna while not being hardware fitted with one. Since the source is in motion, there is recombination of different echos received at different points in the spatio-temporal space. The system achieves this by using the concept of time multiplexing. The system, in effect, creates a parallel network of antennas due to the abovementioned platform motion. For a given time of operation, the system stores the unique identifiers, usually amplitudes and phase angles for future analysis. Using this mapped data, we can easily identify and recreate the signal at a later point of time when constructing the landscape.



I

System Integration

We have integrated the concepts of SAR, Kalman filtering and GPS acquisition so that targeting with SAR sensors can be achieved with good accuracy. Good accuracy earlier required high resolution SAR, but with this approach, it is possible to increase the accuracy without putting in more cost to the system. By modifying the extended Kalman filter on an airborne SAR system, higher accuracy can be achieved. The integration of SAR, GPS and the extended Kalman filter can be achieved by broadly two concepts. One is the loose integration and the other is the tight integration. In loose integration, the raw measurements taken from different sensors are given to the extended kalman filter by grouping the information from two sensors giving them to a single extended kalman filter. This approach is extended in case there are multiple sensors The second method is tight integration. In this method, all the raw measurements taken from multiple sensors are given to a single extended kalman filter. In this approach, the raw measurements are processed only one time.



I

System Integration

In RDA, a range-dependent azimuth filter is required to minimize aliasing and the impacts of the platform's rapid attitude variation. In the image's pixel values are scaled by r^3 to approximately correct for range roll-off in the images. In addition, the images are presented in decibels with a grayscale range that is randomly selected. The images are presented in decibels with a grayscale range that is randomly selected. When producing the RDA image using the low altitude data, we find that employing a hyperbolic azimuth chirp rather than the standard RDA parabolic azimuth chirp improves the focus.

Time domain back projection is done for reconstruction of the images from the SAR data. It is a simplistic method for creating visuals from raw synthetic aperture radar (SAR) data. SAR backprojection uses an azimuth matched filter for each pixel, accounting for range cell migration as well as aircraft motion. For producing images from SAR data, the time domain backprojection algorithm is an exact approach in which the radar cross-section is computed across a grid of pixels in ground range on the surface by the algorithm

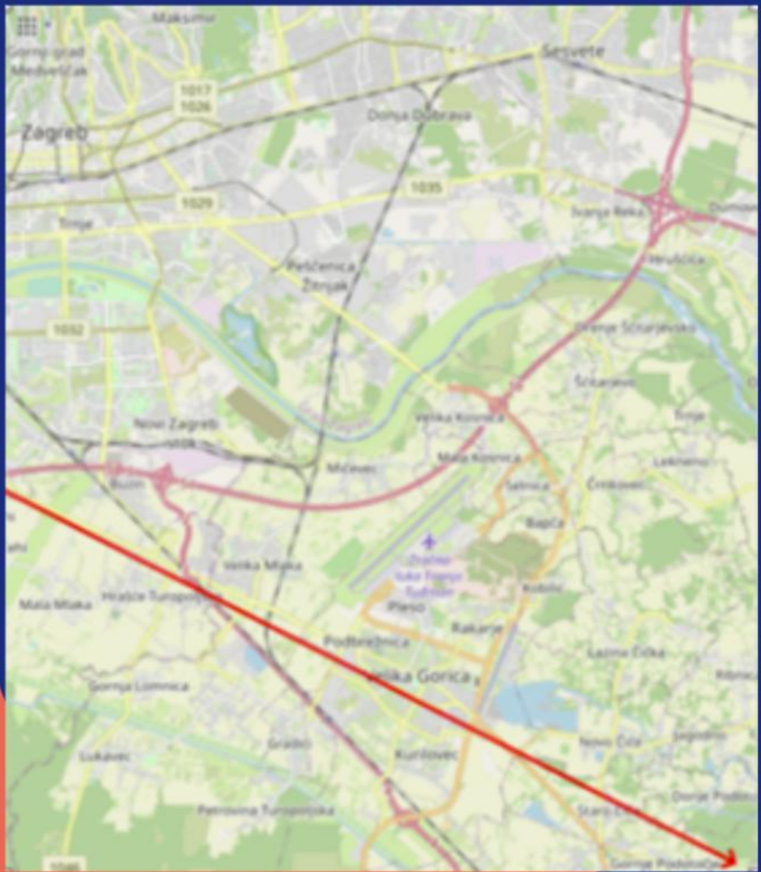
$$A(x_0, y_0) = \sum_n S(n, d[n]) P(d[n]) \exp\{-j4\pi(d[n]/\lambda - d^2[n]K_r/c^2)\}$$

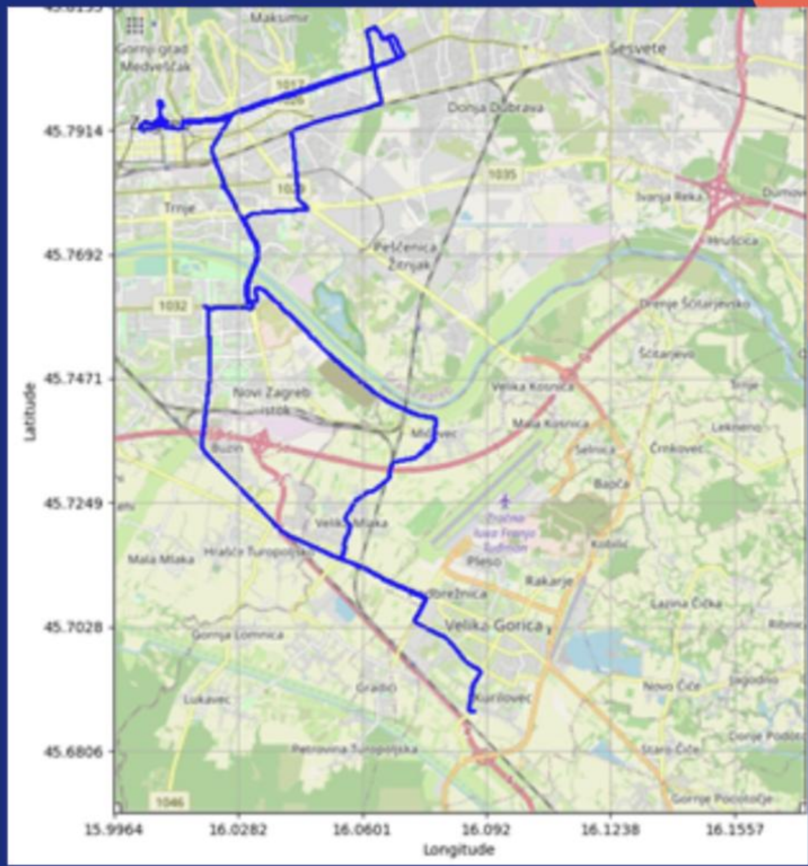
Where

A(xo,yo) is complex pixel value of the SAR image.
lambda= wavelength
d[n]= distance between the point and the antenna phase centre
n= pulse number

Results

Global Positioning System





C/A Code Generation for Satellite 6 When N= [1,32]

```
  Columns 1 through 31

    1     1     0     0     1     0     1     1     0     1     0     0     0     1
1     0     1     0     1     0     1     1     0     0     0     1     0     0     0
0     0

  Columns 32 through 62

    0     0     1     1     0     1     0     0     1     0     1     1     0     1
0     0     1     0     0     1     1     1     0     1     1     1     0     1     0
0     0

  Columns 63 through 93

    0     1     0     1     0     0     1     1     0     1     1     1     1     1
0     0     0     0     1     1     0     1     1     1     0     0     1     1     1
1     0

  Columns 94 through 124

    0     0     1     0     1     0     0     1     0     1     0     0     0     1
0     0     1     1     1     1     0     0     1     1     1     0     1     1     0
1     0

  Columns 125 through 155

    0     0     1     1     0     0     1     1     0     0     1     0     1     1
0     1     0     0     1     1     0     1     1     0     0     0     0     1     0
1     0

  Columns 156 through 186

    0     0     1     1     0     0     0     1     1     0     0     0     0     0
1     0     0     1     1     0     0     0     0     1     1     0     0     0     1
0     0

  Columns 187 through 217

    1     0     0     1     0     1     0     0     0     1     0     1     0     0
0     1     0     1     1     0     0     0     1     0     0     1     0     0     0
1     1

  Columns 218 through 248

    1     1     1     0     0     0     0     0     1     1     1     1     1     0
0     0     0     1     1     0     0     1     1     1     0     1     0     1     0
0     1

  Columns 249 through 279

    1     0     0     0     1     0     0     0     1     1     0     0     0     0
1     1     0     1     0     1     0     1     1     1     0     0     1     0     1
0     0

  Columns 280 through 310

    1     0     0     0     1     1     1     1     0     0     0     1     1     0
1     0     1     1     1     0     0     0     1     1     1     0     0     0     1
1     1

  Columns 311 through 341

    0     1     0     0     0     0     0     1     0     1     1     0     1     0
1     0     1     0     1     1     0     0     1     1     1     0     0     1     0
1     1

  Columns 342 through 372

    1     0     1     1     0     0     1     0     1     1     1     1     0     0
1     1     0     1     1     1     1     0     1     1     0     0     1     1     1
1     0

  Columns 373 through 403

    0     0     1     0     1     0     0     0     0     0     1     1     0     0
1     1     1     1     0     1     1     0     0     0     1     1     1     0     0
1     1

  Columns 404 through 434

    1     0     1     1     1     0     1     0     1     0     0     1     1     0
0     1     0     1     0     0     1     0     1     0     0     1     1     0     1
1     1

  Columns 435 through 465

    0     0     1     1     0     1     1     1     0     0     1     0     1     1
0     0     1     1     1     1     1     1     1     0     0     1     1     1     1
1     0

  Columns 466 through 496

    1     1     0     1     0     0     1     1     1     0     0     1     0     1
0     1     0     1     0     0     1     1     1     0     0     0     1     0     0
```

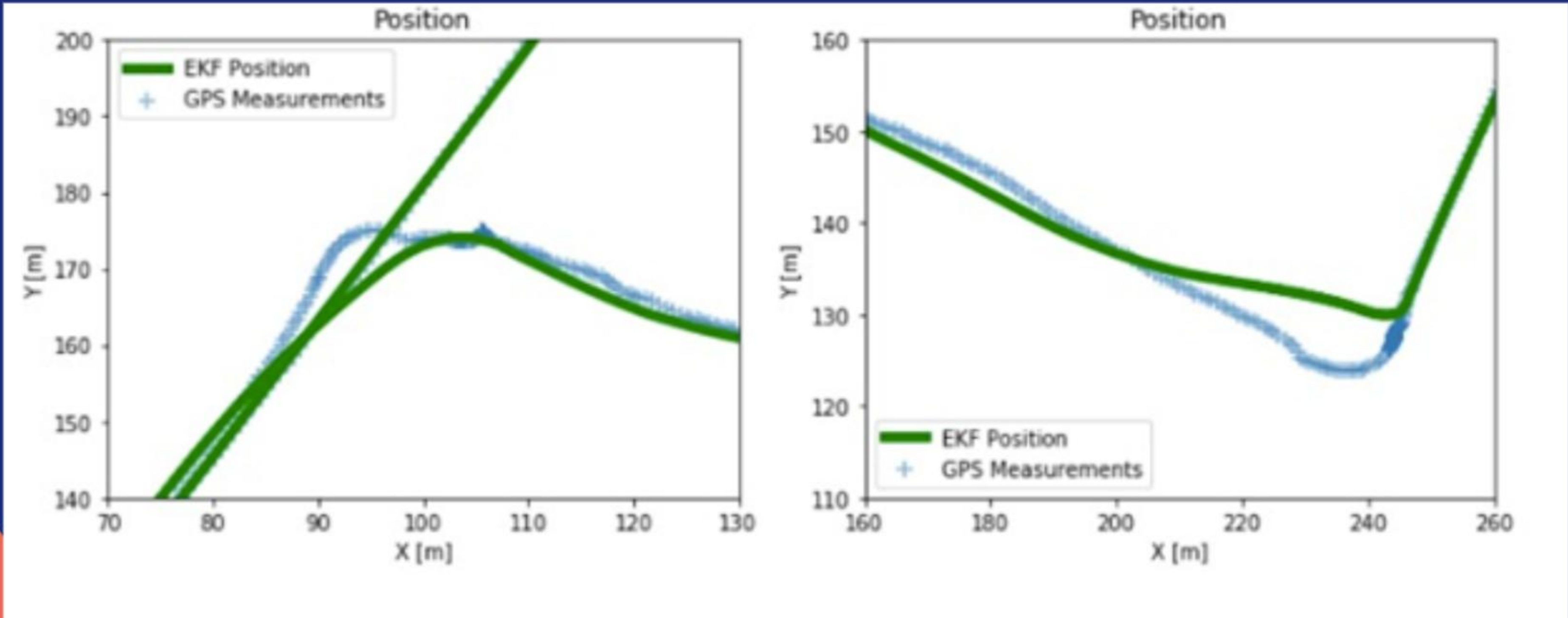
```
1     0

  Columns 497 through 527

    0     0     0     1     0     1     0     1     1     1     0     0     1     1
1     1     0     0     1     1     0     0     0     0     0     0     0     0     1
1     0

  Columns 528 through 558

    0     1     0     1     0     1     0     1     1     1     0     0     0     1
1     1     1     1     0     1     1     0     0     0     1     0     0     1     0
0     0

  Columns 559 through 589

    1     1     1     0     1     0     0     0     1     0     0     0     0     1
1     1     0     0     1     0     0     1     1     0     0     1     0     1     1
0     0

  Columns 590 through 620

    0     0     0     1     0     0     0     1     1     1     0     1     1     0
1     1     1     0     0     0     1     0     0     0     0     0     1     1     1
1     0

  Columns 621 through 651

    0     0     1     1     0     0     0     1     1     1     0     1     0     1
1     1     0     0     0     0     1     1     1     0     1     0     1     1     0
0     1

  Columns 652 through 682

    1     0     1     1     1     1     1     0     1     1     0     1     1     0
0     0     1     0     0     1     1     1     0     1     0     1     1     0     0
1     0

  Columns 683 through 713

    0     1     1     1     1     0     0     1     1     0     1     1     0     1
0     1     1     1     0     1     0     1     1     1     0     1     1     1     1
1     0

  Columns 714 through 744

    0     0     0     1     1     1     0     0     1     0     0     0     0     1
1     1     0     1     0     0     0     1     0     1     0     0     1     1     0
1     1
```

```
  Columns 745 through 775

    1     1     1     0     1     0     0     1     1     1     1     0     0     1
0     1     0     1     1     1     1     1     0     1     0     1     0     1     0
0     1

  Columns 776 through 806

    0     0     0     1     1     1     1     0     0     1     1     0     1     0
0     0     0     0     0     0     1     1     0     1     1     1     0     0     1
0     0

  Columns 807 through 837

    1     1     1     0     0     0     0     0     1     0     1     1     1     0
0     0     0     1     1     1     1     0     0     0     0     0     1     1     0
0     0

  Columns 838 through 868

    0     0     1     0     0     1     0     0     0     1     0     0     1     1
0     1     0     1     0     1     0     0     0     1     1     0     0     0     0
1     0

  Columns 869 through 899

    1     1     0     0     0     0     0     1     1     0     0     1     0     1
1     0     1     0     1     1     1     0     1     0     1     1     0     1     0
1     1

  Columns 900 through 930

    0     0     0     0     1     0     0     0     0     1     1     1     1     1
1     1     0     1     0     0     0     0     0     1     0     0     0     0     1
0     1

  Columns 931 through 961

    1     0     0     1     1     0     0     1     0     0     0     1     1     0
0     0     1     1     0     1     1     1     1     1     0     0     0     1     0
1     0

  Columns 962 through 992

    1     0     1     1     1     1     1     0     1     1     0     0     1     1
0     1     1     1     1     0     1     1     0     1     0     0     1     1     1
1     0
```

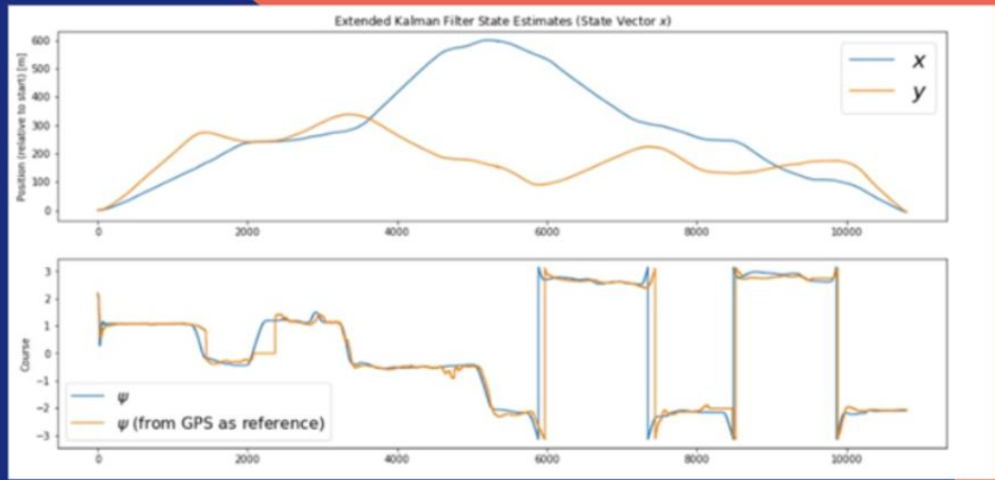
```
  Columns 993 through 1,023

    1     1     1     1     1     1     1     1     1     0     1     1     0     0
1     0     0     0     1     0     1     1     1     0     1     1     1     1     0
0     1

>>
```

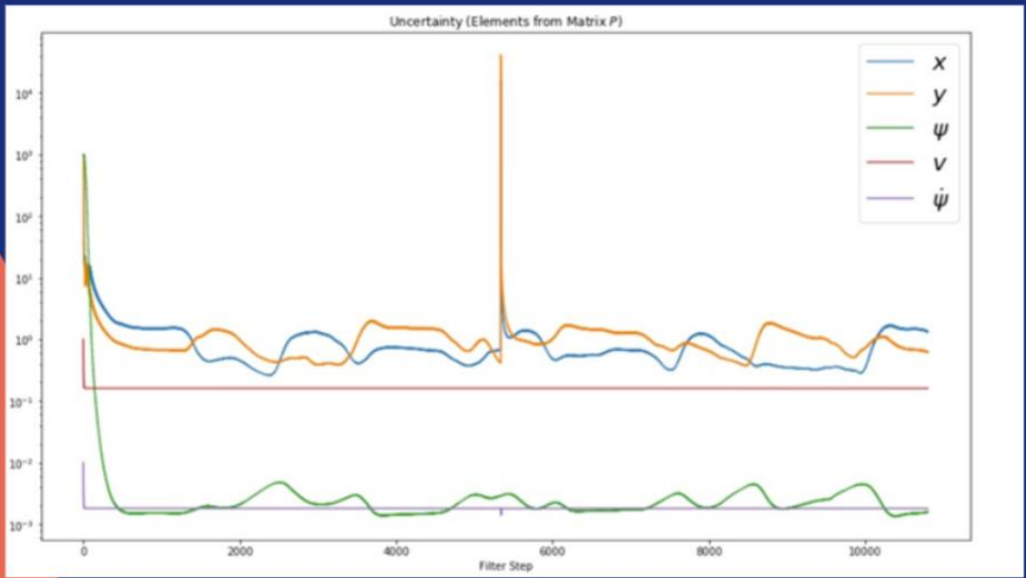
Results

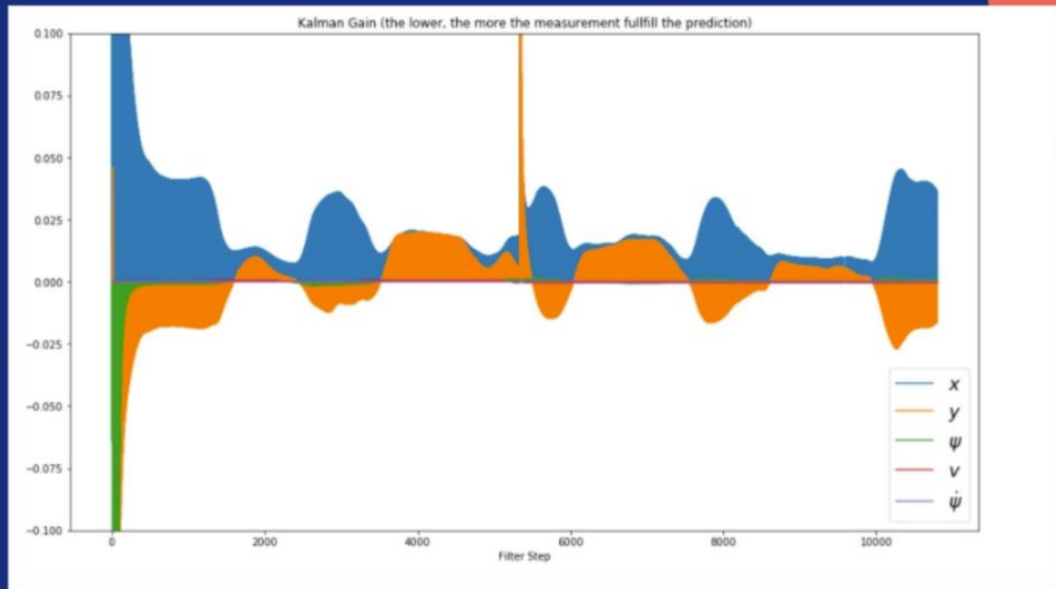
Extended Kalman Tracking



Results

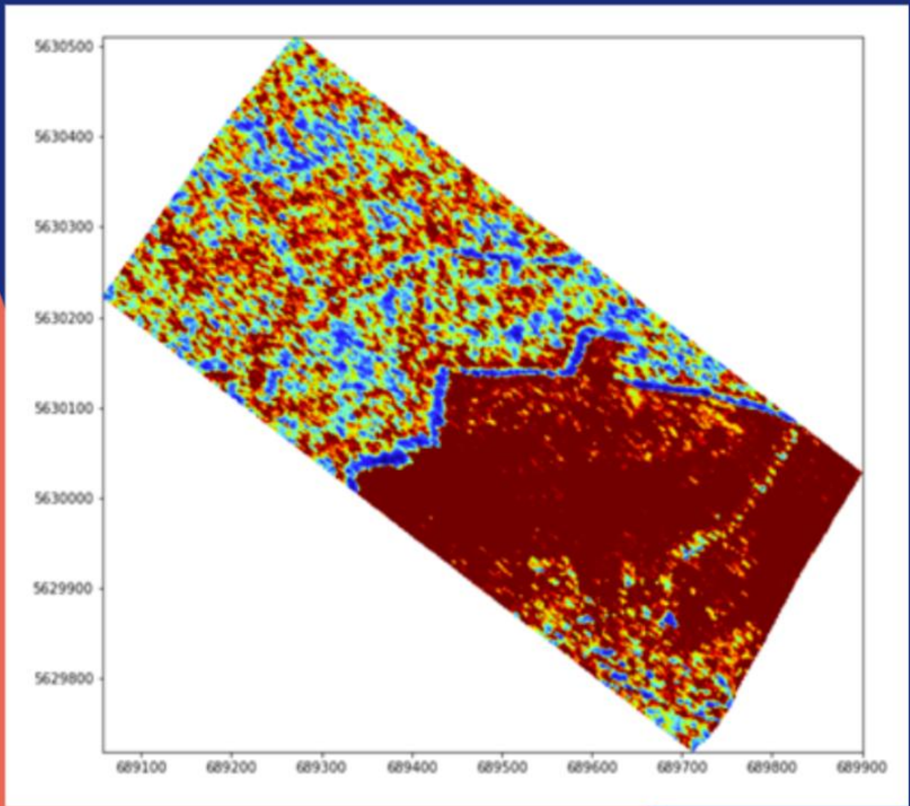

Extended Kalman Filter State Estimates (State Vector x)
Position (relative to start) [m]
Course
x
y
ψ
ψ (from GPS as reference)

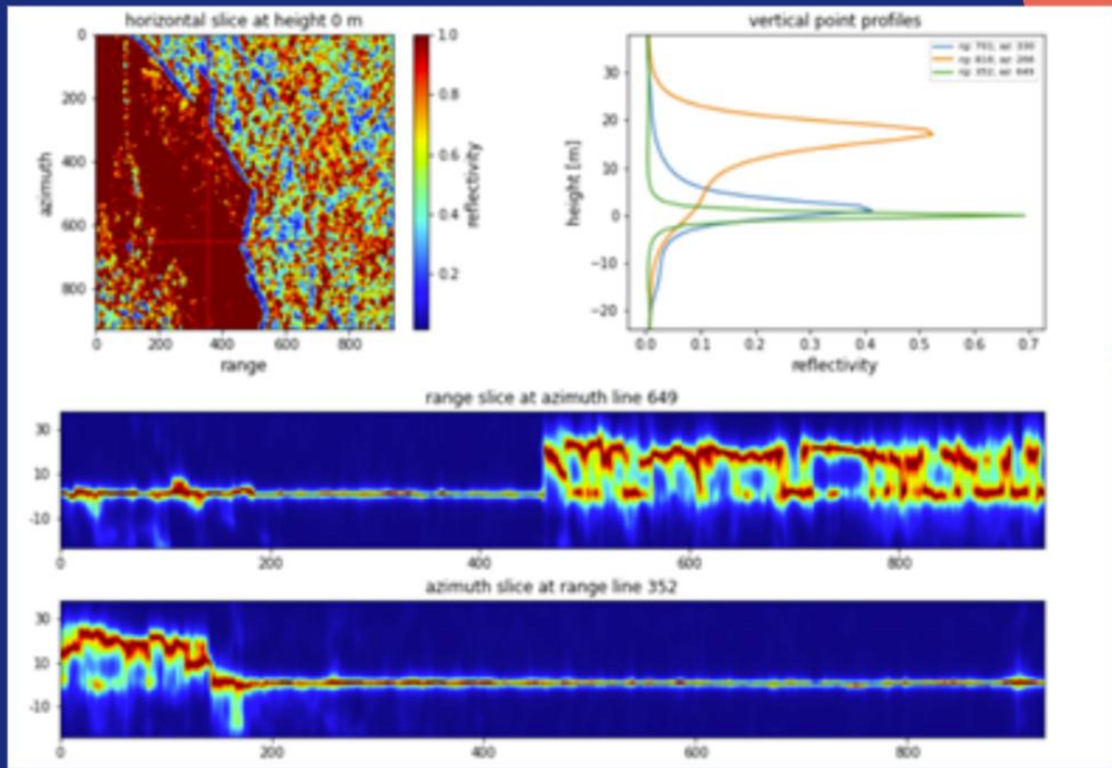

Uncertainty (Elements from Matrix P)
Filter Step
x
y
ψ
v
ψ̇


Kalman Gain (the lower, the more the measurement fullfill the prediction)
Filter Step
x
y
ψ
v
ψ̇

Results

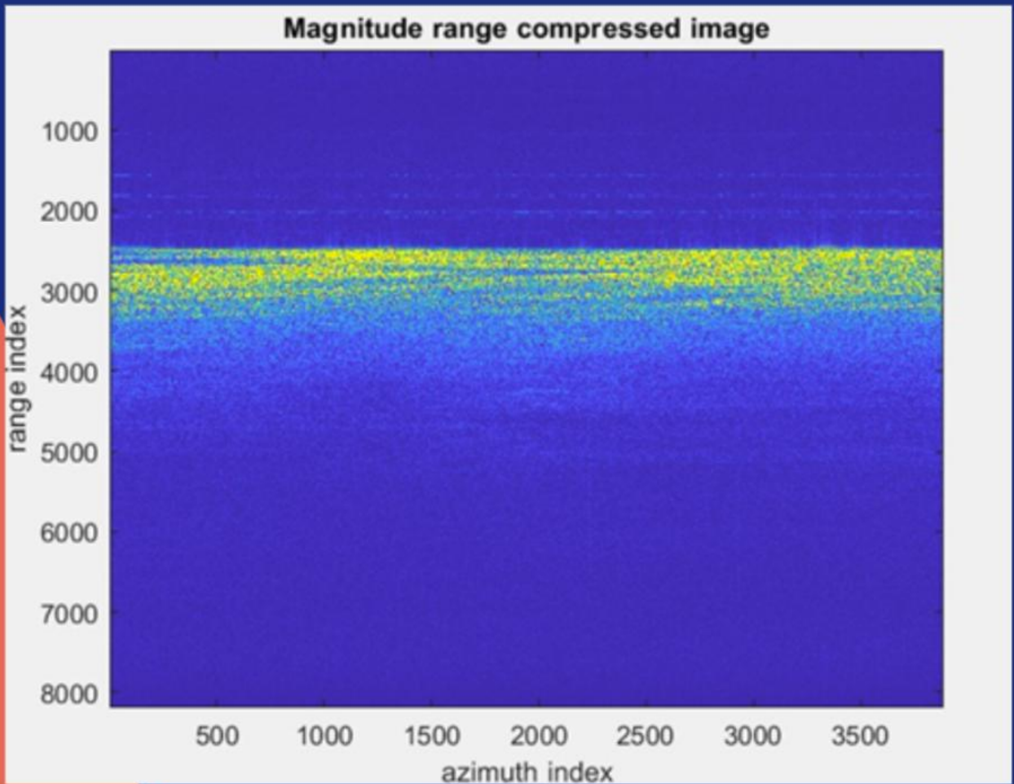
SAR Processing

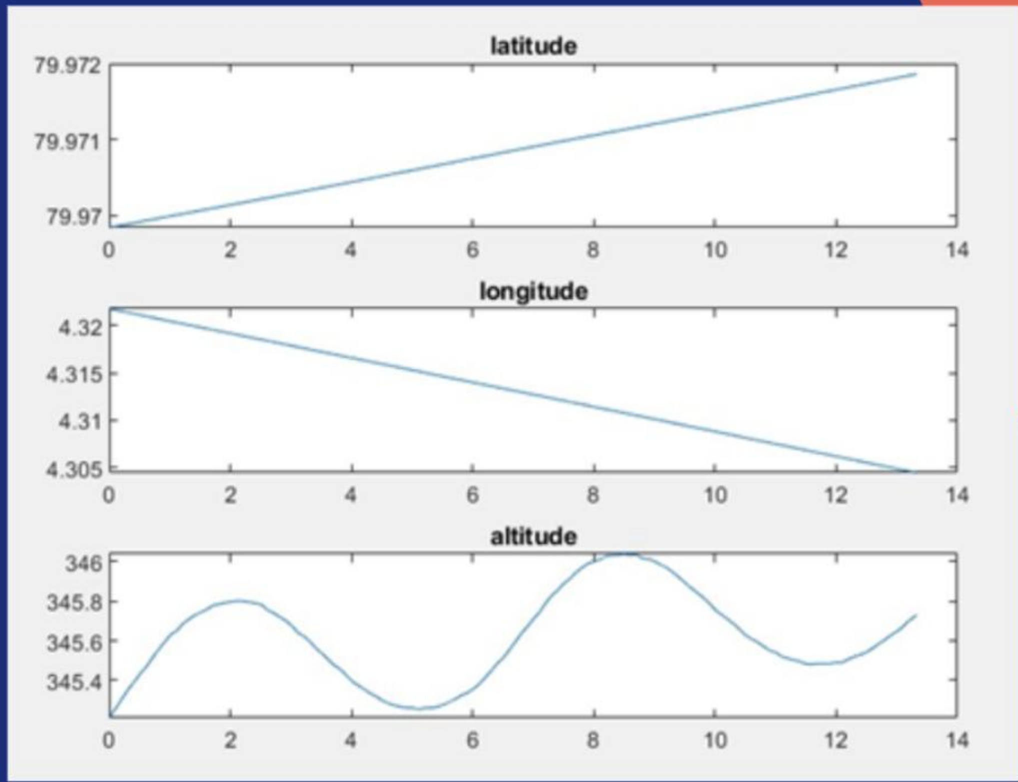




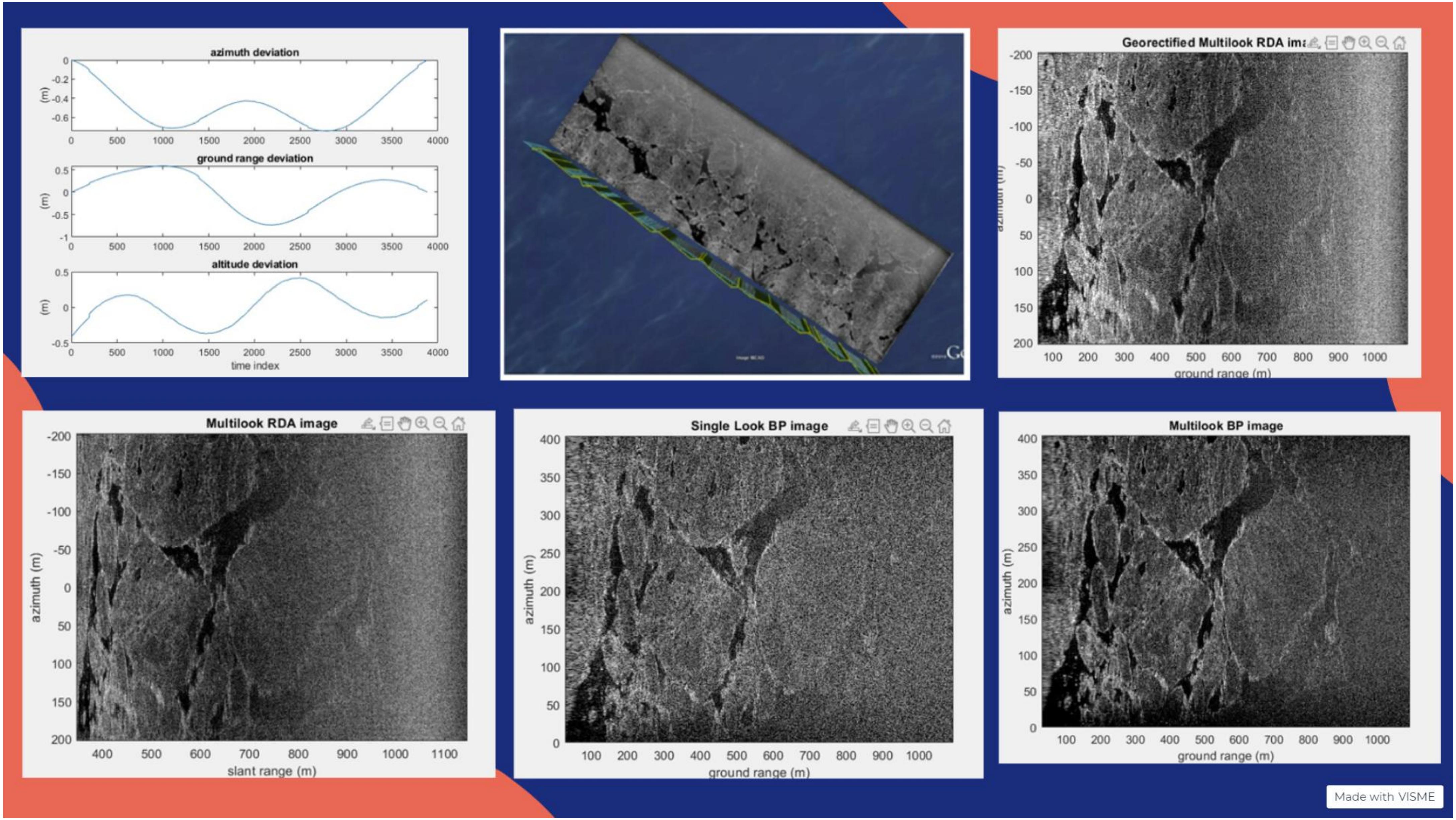
Results

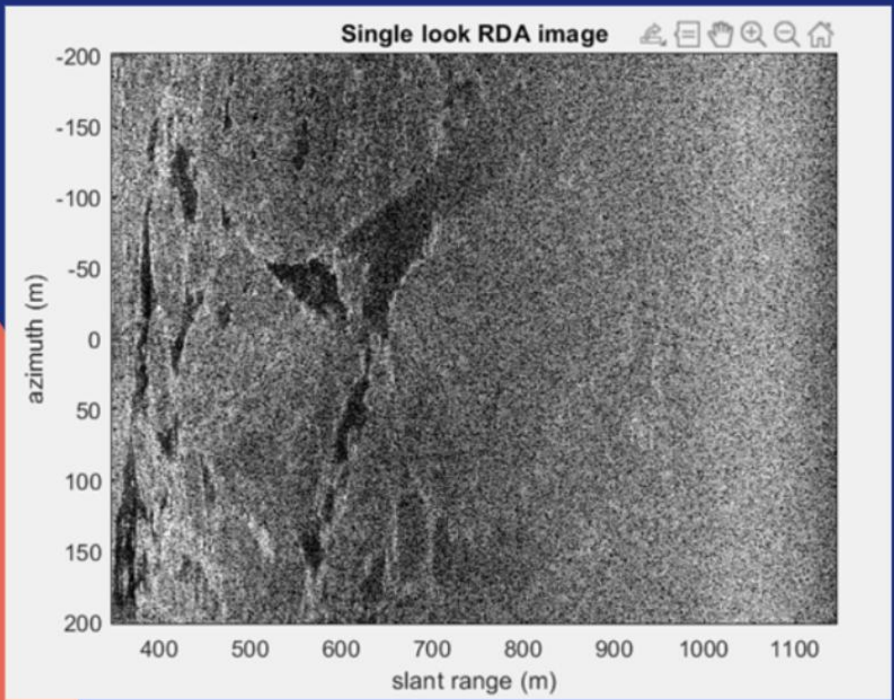
Modified RDA

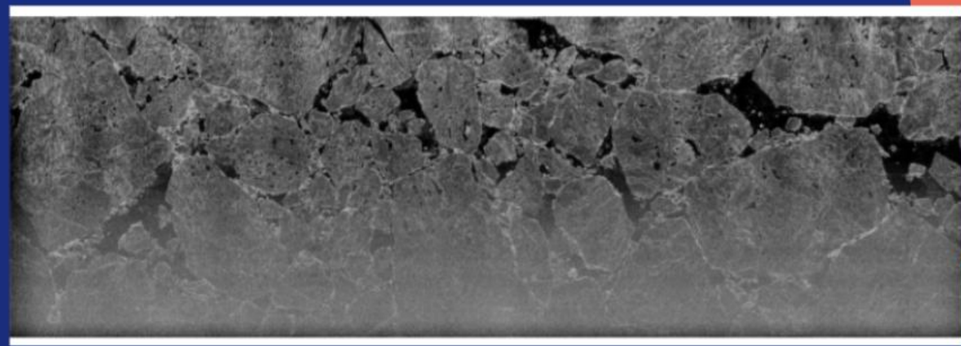




Made with VISME


azimuth deviation
ground range deviation
altitude deviation
(m)
time index
Georectified Multilook RDA ima
ground range (m)
Multilook RDA image
azimuth (m)
slant range (m)
Single Look BP image
azimuth (m)
ground range (m)
Multilook BP image
azimuth (m)
ground range (m)
Made with VISME


Single look RDA image
azimuth (m)
-200
-150
-100
-50
0
50
100
150
200
400
500
600
700
800
900
1000
1100
slant range (m)



Conclusion

We have successfully implemented the integration of SAR, GPS and extended Kalman filter in theory and by the results shown and minimized the error in location of target using this integrated approach. With aircraft position accuracy, the SGPS performed slightly better. With location accuracies of 5ft and 3ft, respectively, the DGPS and CPGPS models functioned admirably. The filter has numerous bias states the integrated filter model has problems in this regard. We focused majorly on errors calculation of targets, but in future, the SAR, such models can be made that can further reduce states.

Thank You !