Geo-matching with simultaneous altitude measurement for SAR-aided navigation systems

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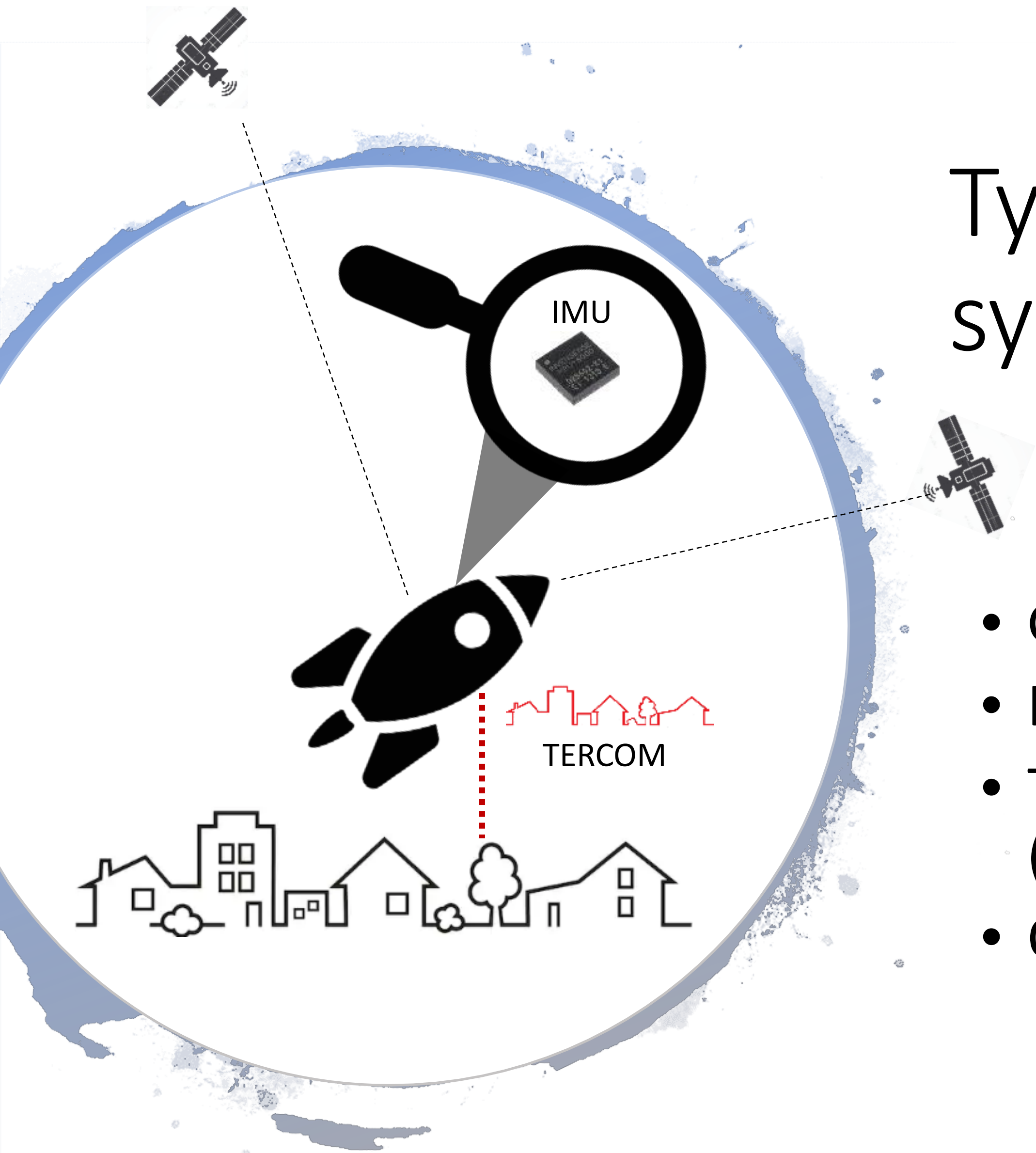
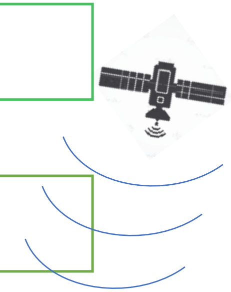
Typical navigation systems

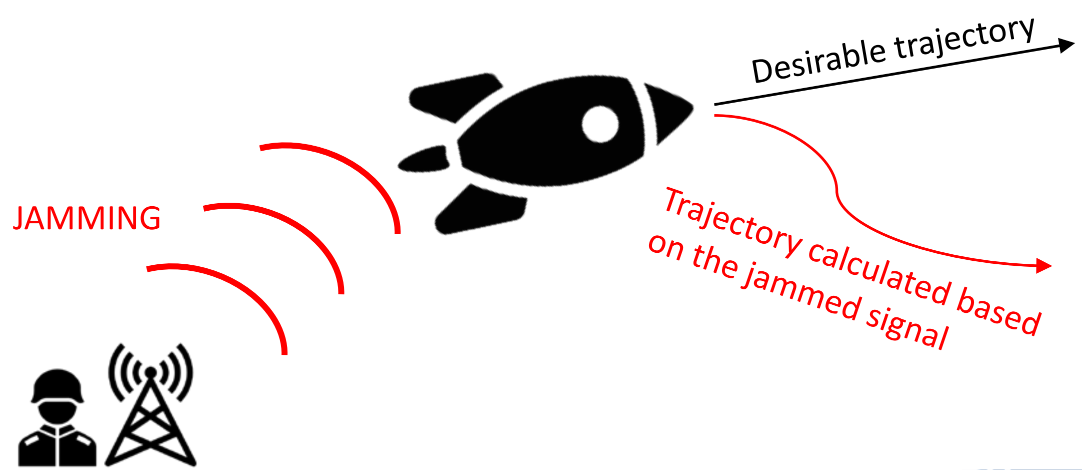


- Global Positioning System (GPS)
- Inertial navigation (IMU)
- Terrain Contour Matching (TERCOM)
- Others (e.g. astronavigation)

Problem with the GPS navigation

- Limitations for a civilian usage
- Relatively slow
- Susceptible to jamming
- Works only during peace





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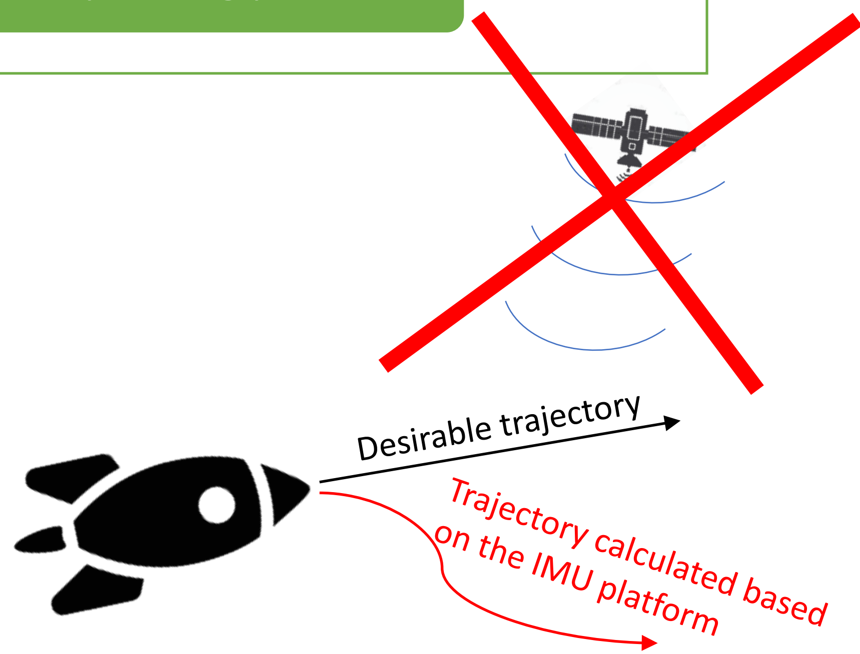
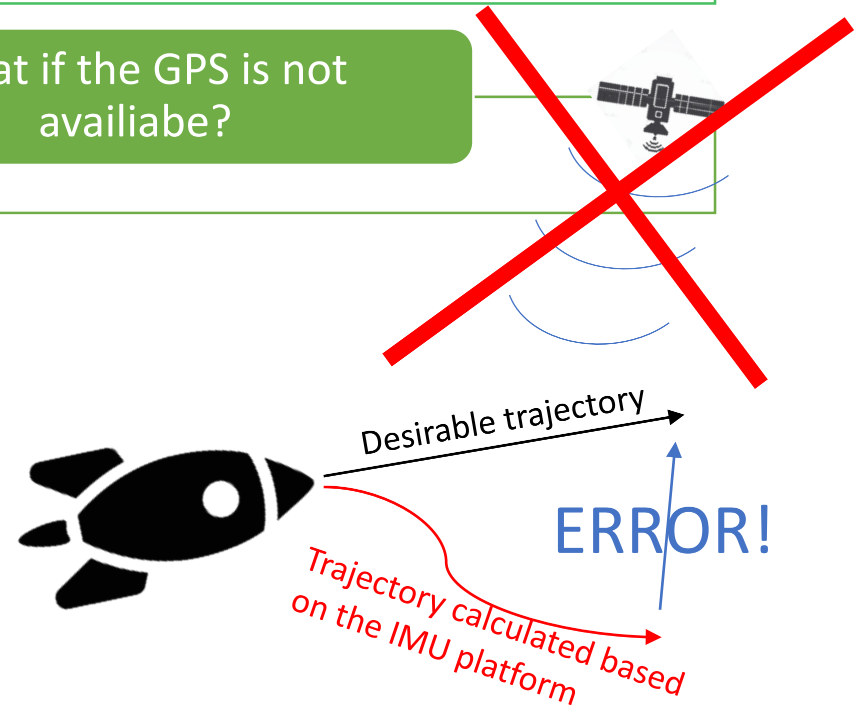


Problem with the IMU platform

- Typically suffers from an accumulated error
- Significant trajectory drift increasing in time
- Usually requires the GPS system to correct the error
- What if the GPS is not availiabe?



Synthetic Aperture Radars

- Relatively simple, low cost and small
- Can be mounted on UAV, drones, aeroplanes and cruise missiles
- High resolution images can be obtained
- Obtainable during rain, fog, night

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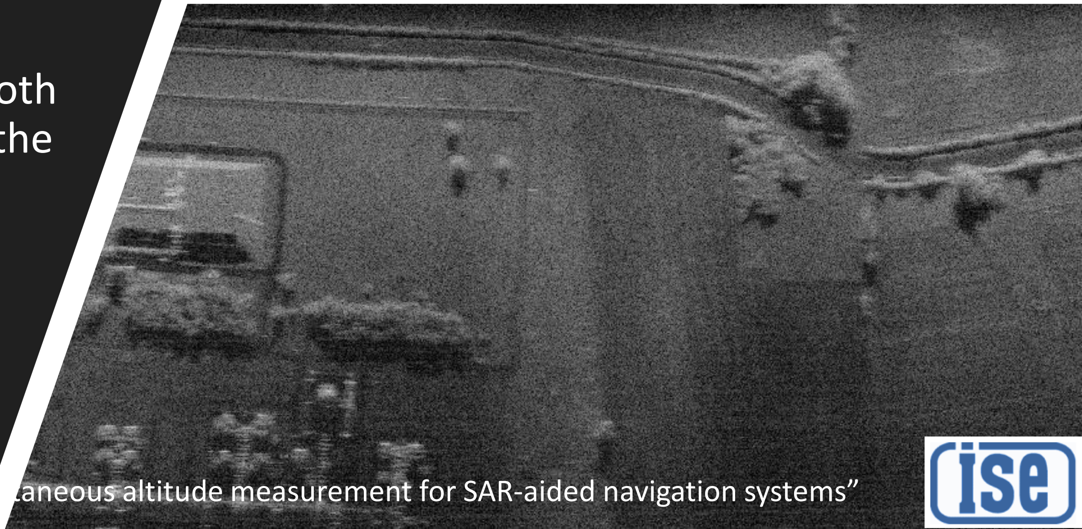
SAR and optical images

Both can be equipped with a georeference information assigning coordinates to the bounds.

SAR image – coordinates calculated during the fly based on the IMU trajectory

Optical image – given coordinates stored in the database

By matching characteristic points in both images and comparing their position the trajectory the error can be estimated.



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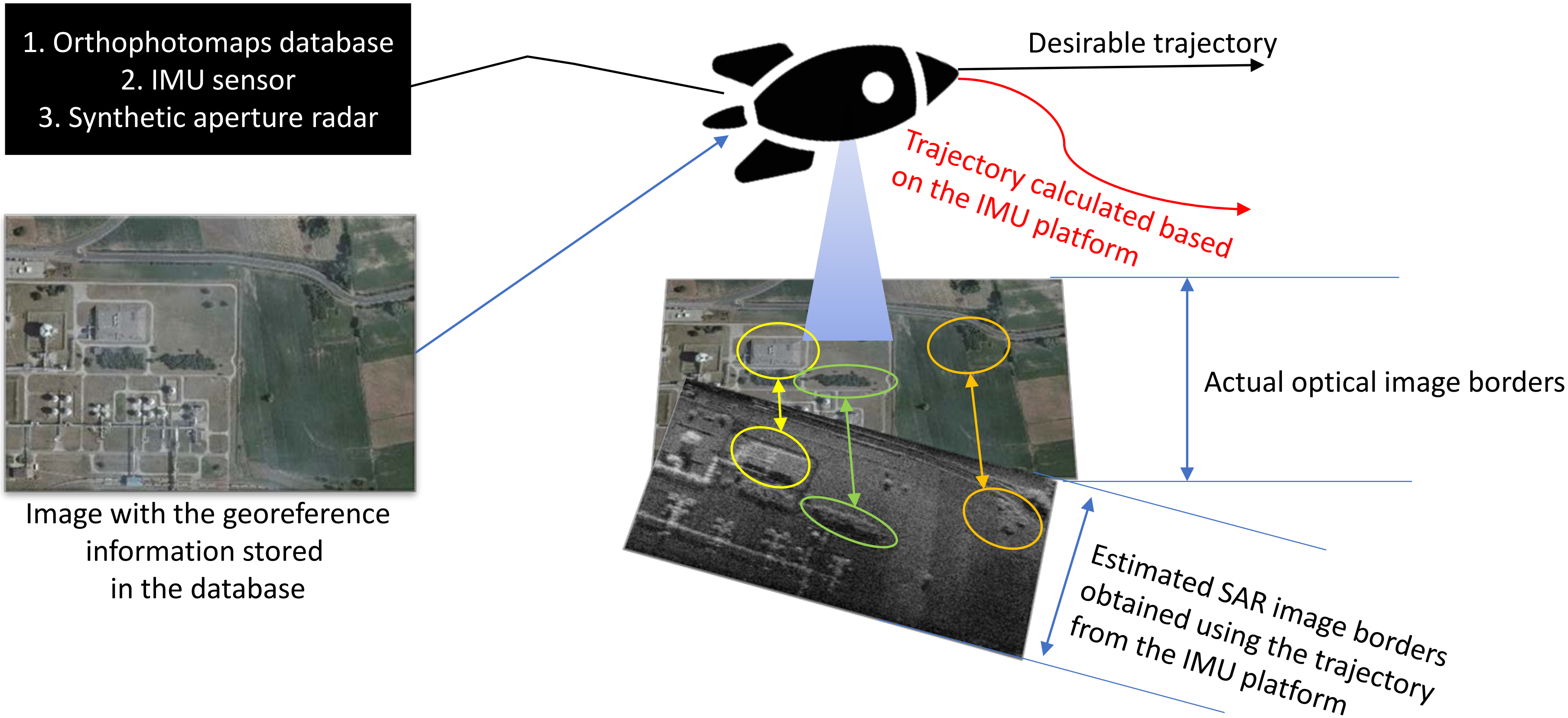
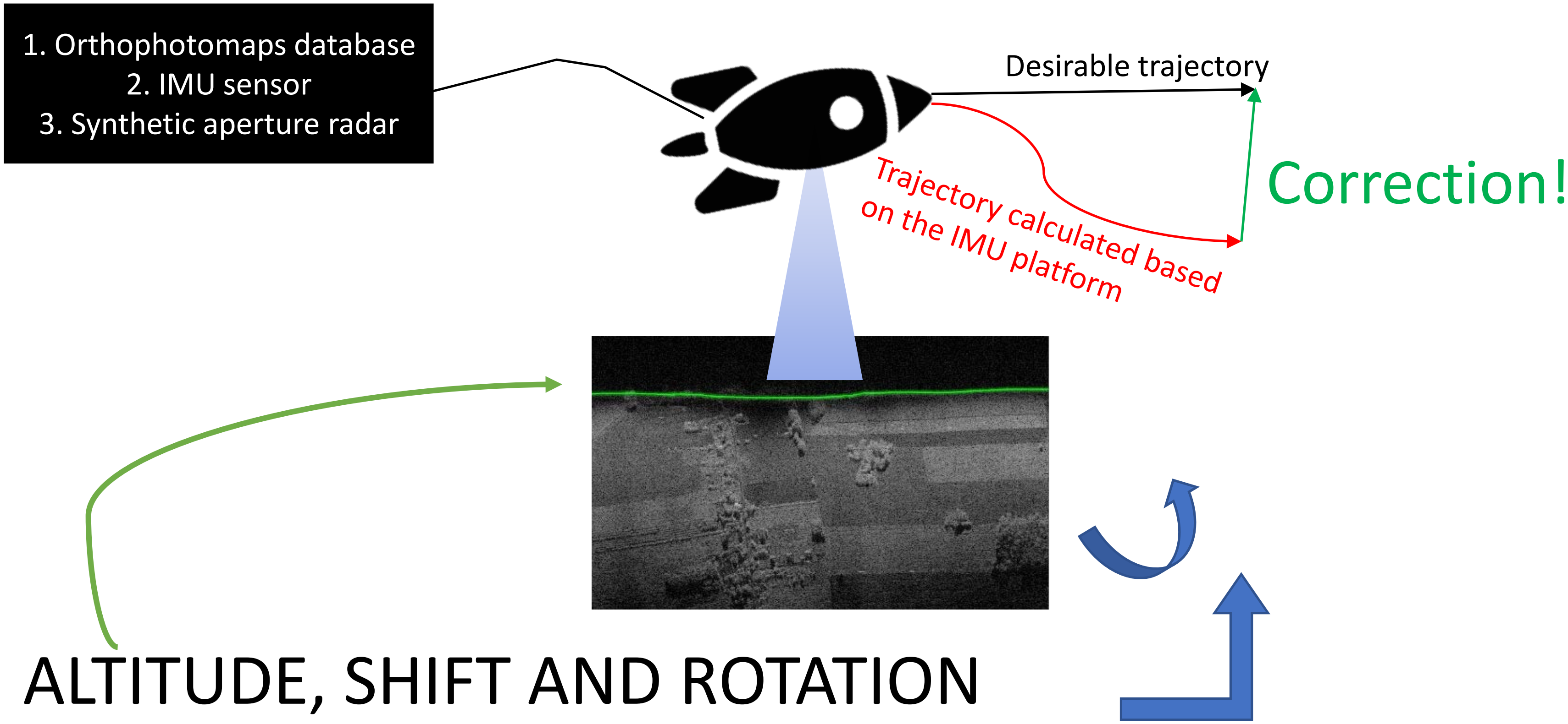
General idea

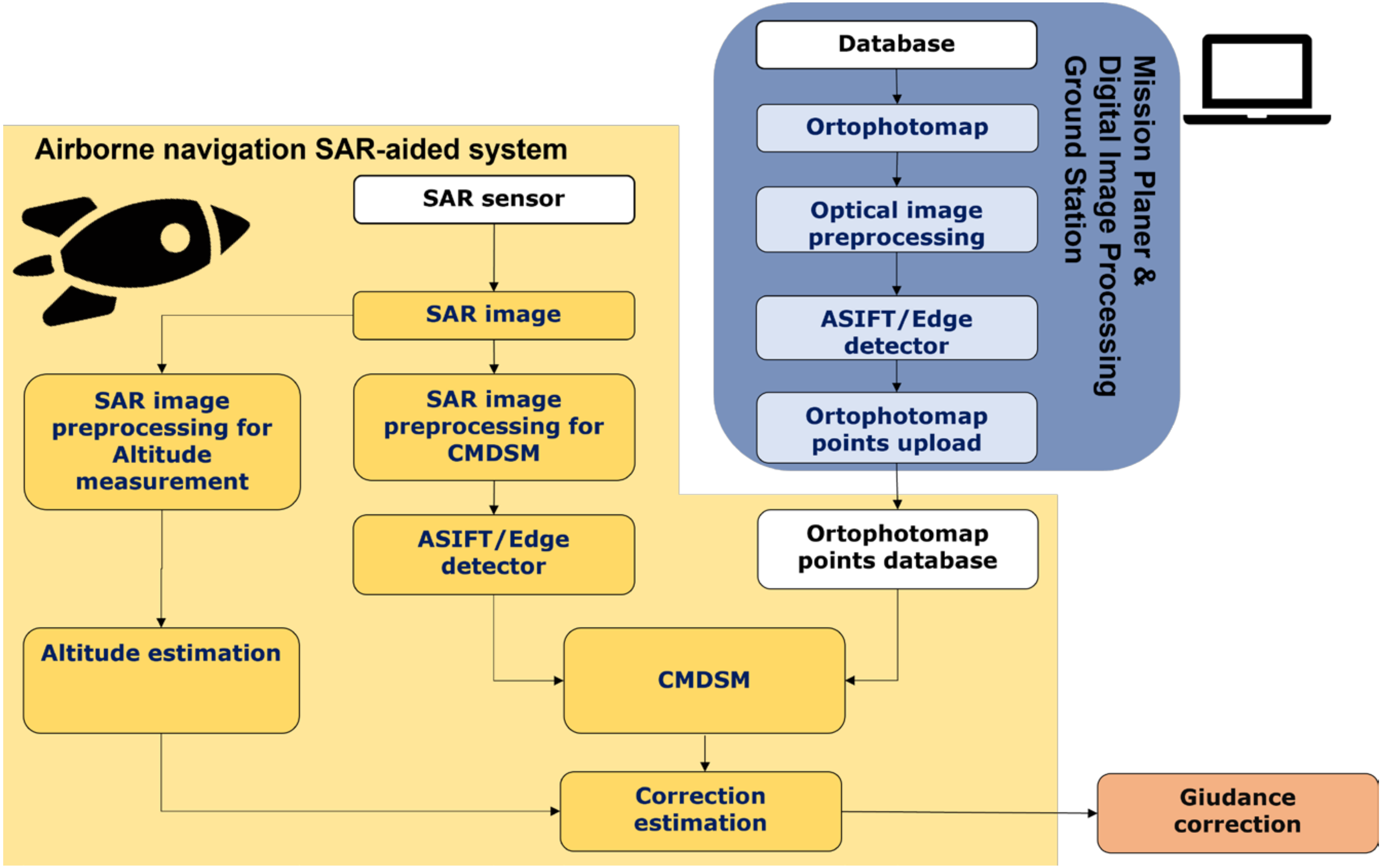


General idea



ALTITUDE, SHIFT AND ROTATION ESTIMATION!

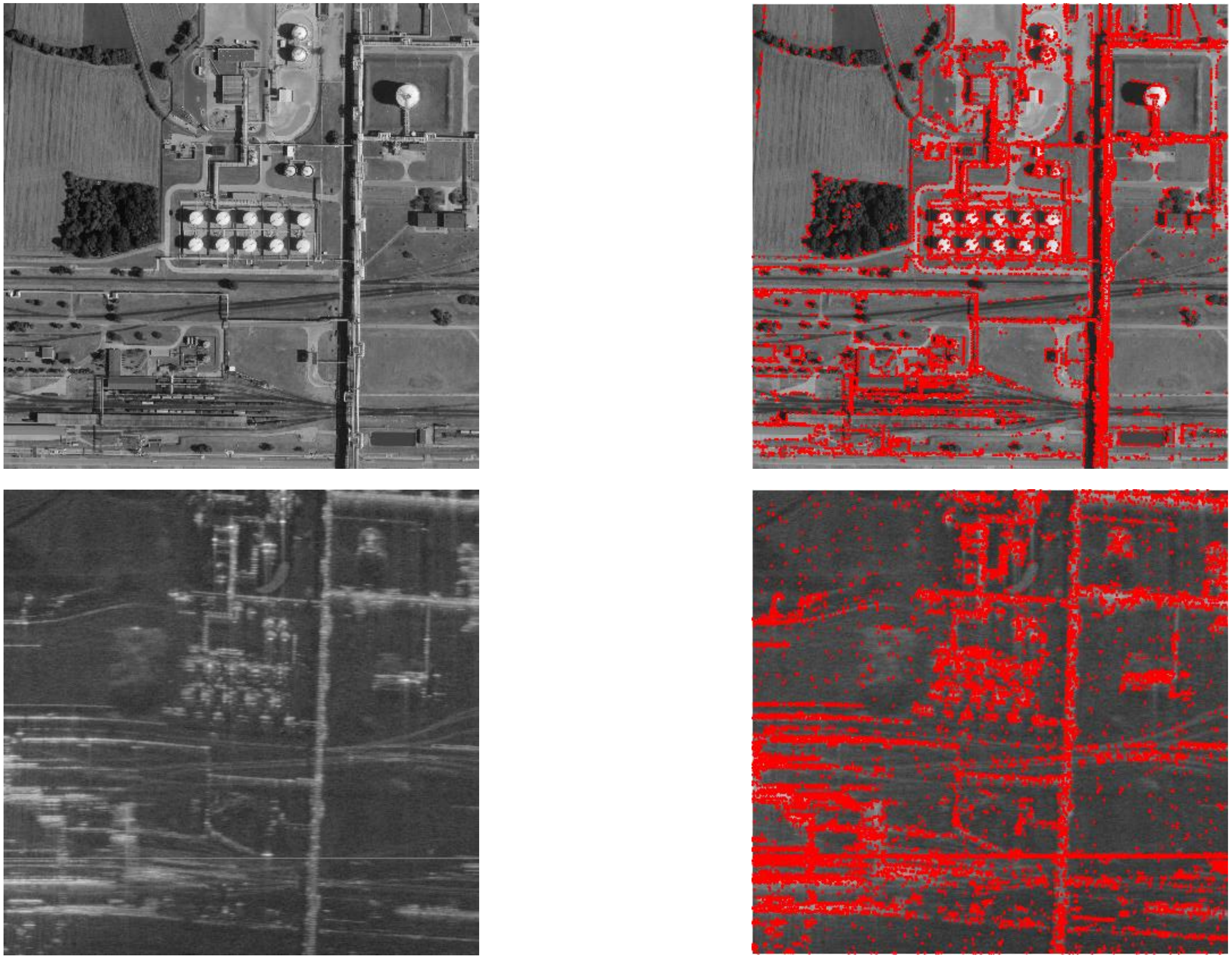
System architecture



Cumulative minimum square distance matching (CMSDM)

- CMSDM – the novel, proposed solution
- Works for both optical and SAR images
- Uses the classical brute force square distance integration
- Accelerated by the optimization algorithm
- Finds the error (shift, rotation) between the computed SAR image and the reference optical one

The CMSDM algorithm, step 1 – Sobel edge detection



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The CMSDM algorithm, step 2 – cubic calculation

$$\Omega(\Delta_{\mathrm{lat}}, \Delta_{\mathrm{lon}}, \alpha) = \sum_{n=0}^{N-1} \left\| \mathrm{R}_\alpha\left(\vec{\boldsymbol{s}}_{\boldsymbol{n}} + \begin{bmatrix}\Delta_{\mathrm{lat}} \\ \Delta_{\mathrm{lon}}\end{bmatrix}\right) - \Psi\left(\Theta_e, \mathrm{R}_\alpha\left(\vec{\boldsymbol{s}}_{\boldsymbol{n}} + \begin{bmatrix}\Delta_{\mathrm{lat}} \\ \Delta_{\mathrm{lon}}\end{bmatrix}\right)\right)\right\|_2,$$

where Δ_{lat} and Δ_{lon} are the latitude and longitude error, respectively, α stands for the rotation angle, $\vec{\boldsymbol{s}}_n$ is a vector in geographic coordinates representing the n-th point of total N points extracted from the SAR image, Θ_e is a corresponding set of vector representing points extracted from optical image. Ψ is a function which returns vector $\vec{\boldsymbol{v}}$ from a set V minimizing the distance to a given vector $\vec{\boldsymbol{x}}$. Function Ψ is defined as follows:

$$\Psi(V, \vec{\boldsymbol{x}}) \triangleq \underset{\vec{\boldsymbol{v}} \epsilon V}{\operatorname{argmin}} \|\vec{\boldsymbol{x}} - \vec{\boldsymbol{v}}\|_2.$$

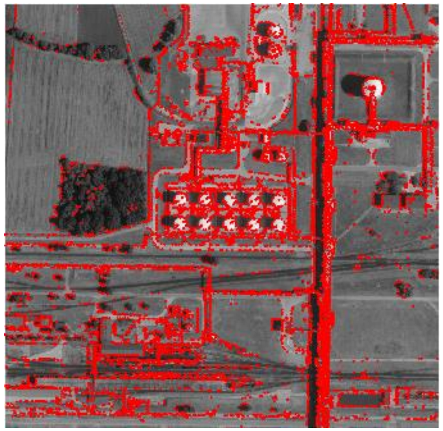
Function R_α is a rotation of two-dimensional vector $\vec{\boldsymbol{x}}$, around point $\bar{\boldsymbol{s}}$:

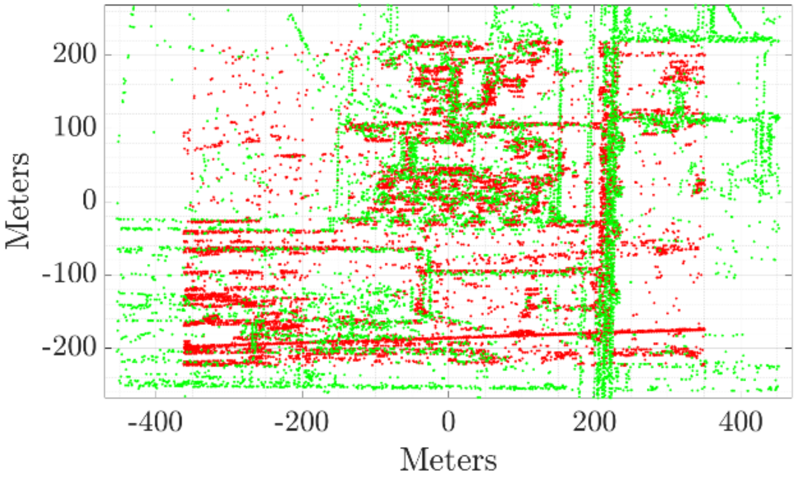
$$\mathrm{R}_\alpha(\vec{\boldsymbol{x}}) \triangleq (\vec{\boldsymbol{x}} - \bar{\boldsymbol{s}}) \cdot \begin{bmatrix}\cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha\end{bmatrix} + \bar{\boldsymbol{s}},$$

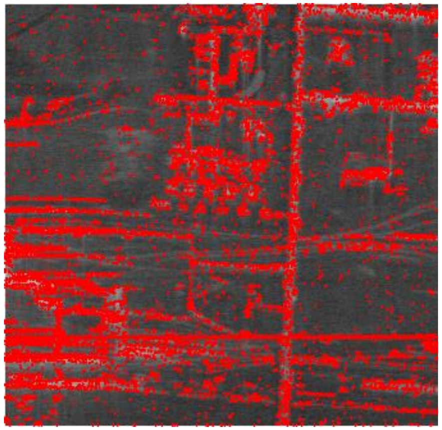
where $\bar{\boldsymbol{s}}$ stands for the mean value of all points extracted from the SAR image $\vec{\boldsymbol{s}}_{\boldsymbol{n}}$:

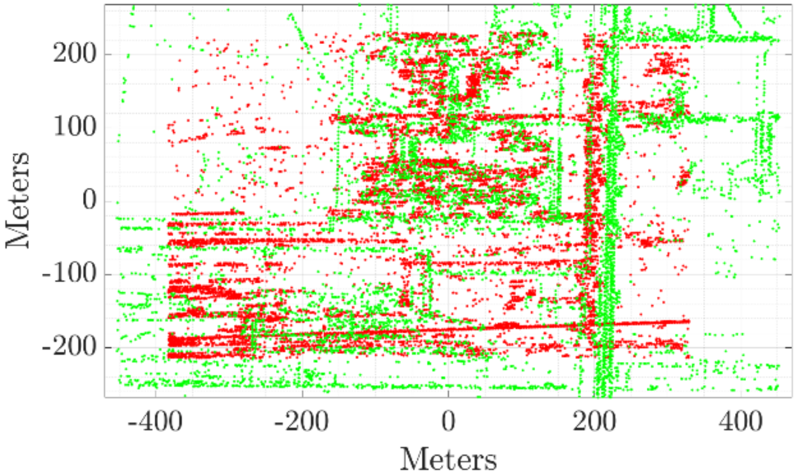
$$\bar{\boldsymbol{s}} = \frac{1}{N} \sum_{n=0}^{N-1} \vec{\boldsymbol{s}}_n .$$

The CMSDM algorithm, step 3 – minimum finding









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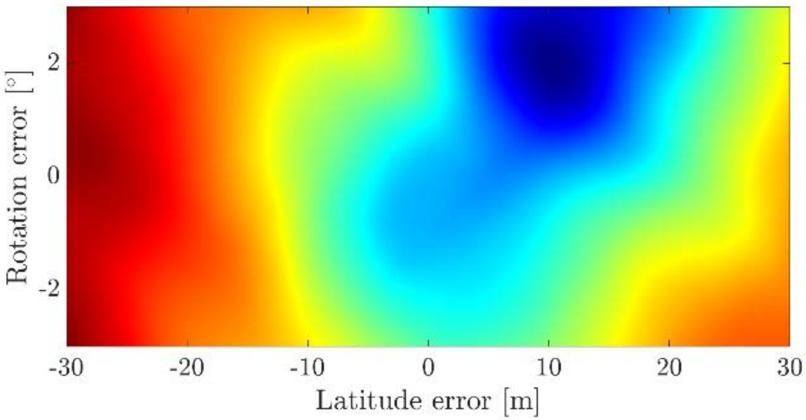
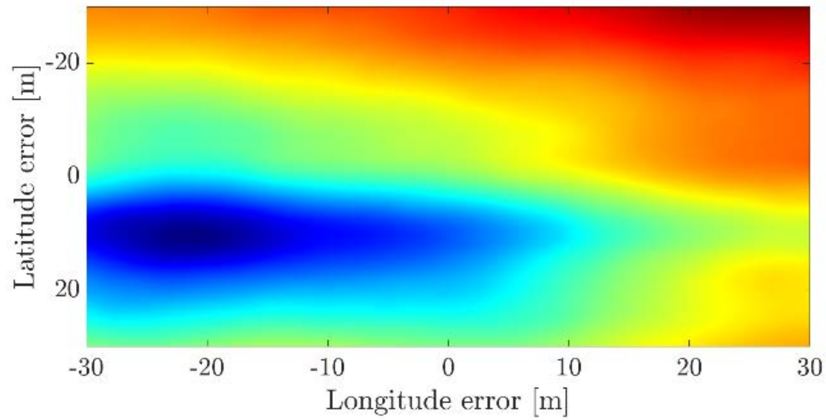
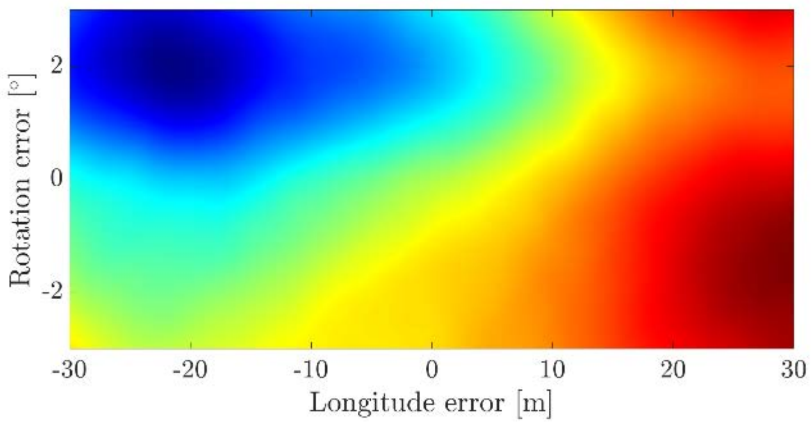


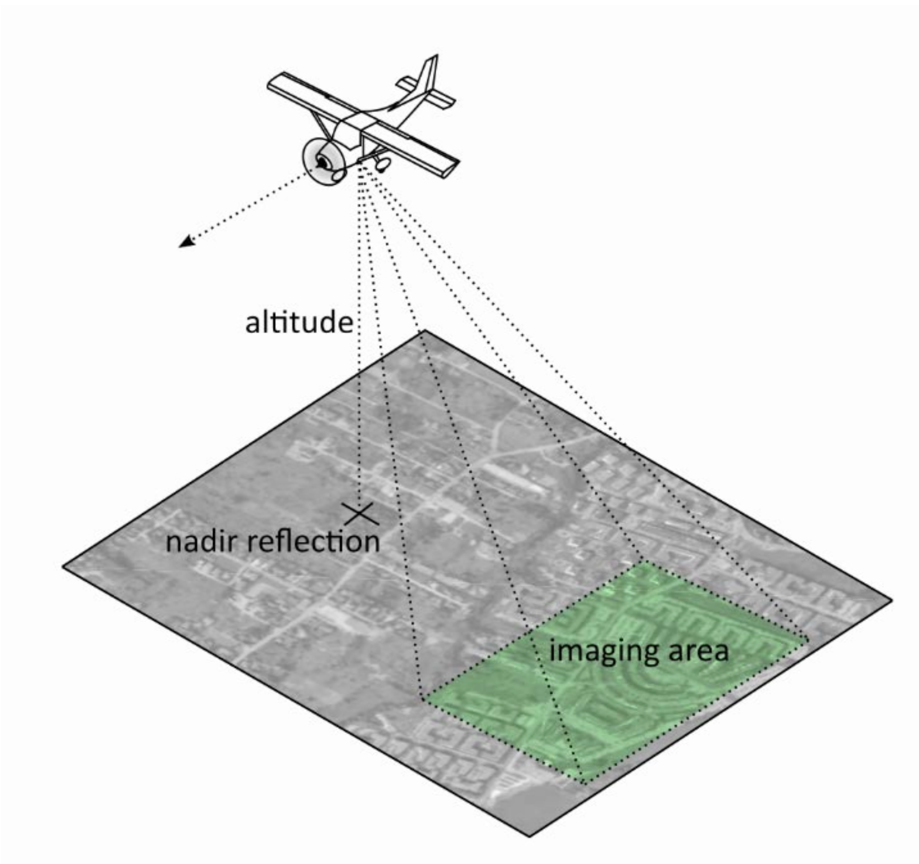


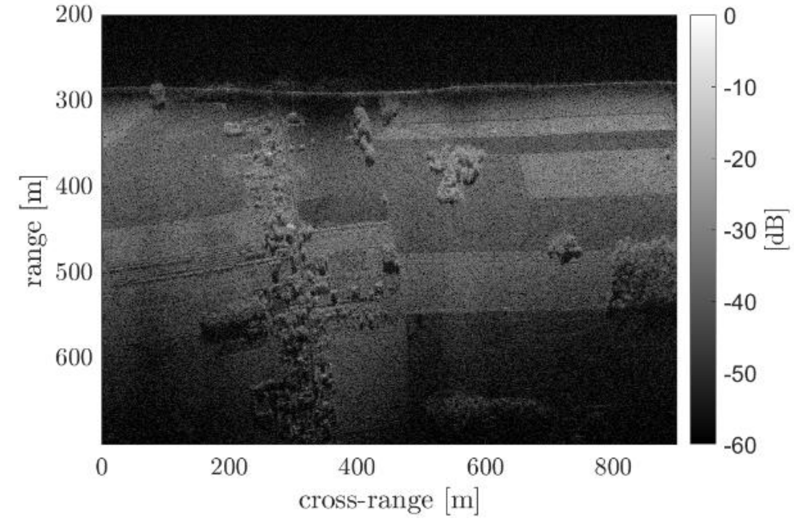


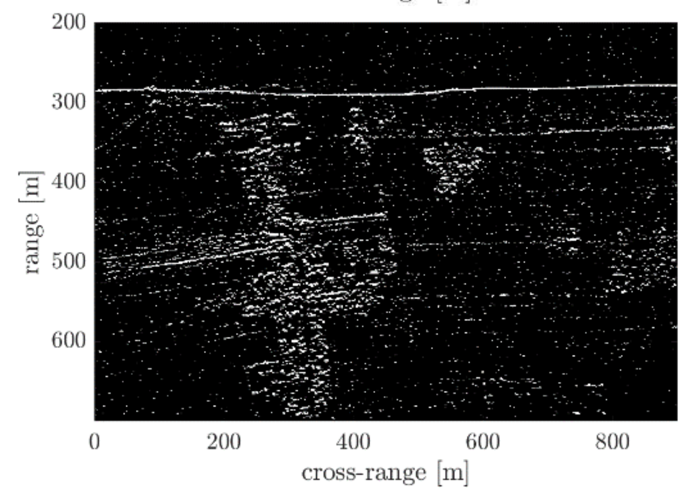
Altitude Measurement

- Altitude value is used as a reference when latitude and longitude errors are estimated,
- alititude is also used when transforming SAR image from slan-range to ground-range,
- altitude estimation error would result in biased trajectory estimation,
- instantaneous and precise platform altitude estimate is needed for valid system operation.

Altitude Measurement, cont.







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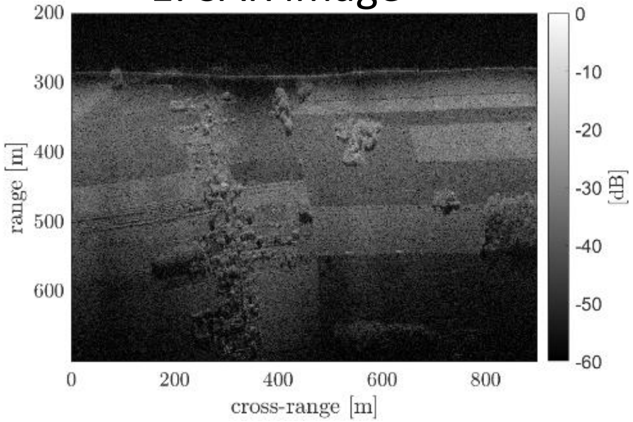
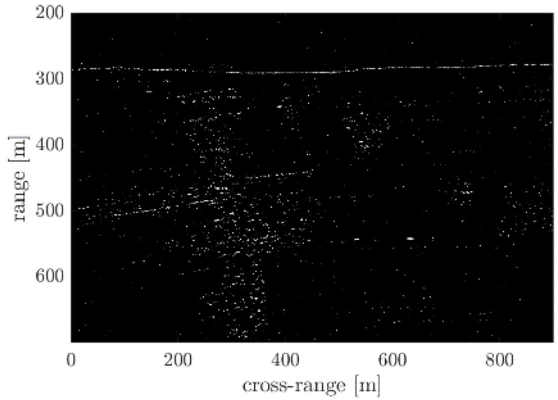
Altitude Measurement, cont.

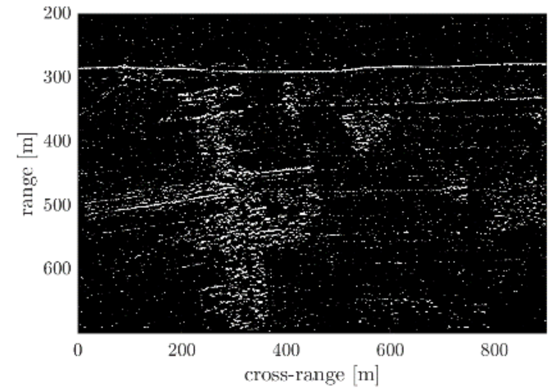
1. SAR image



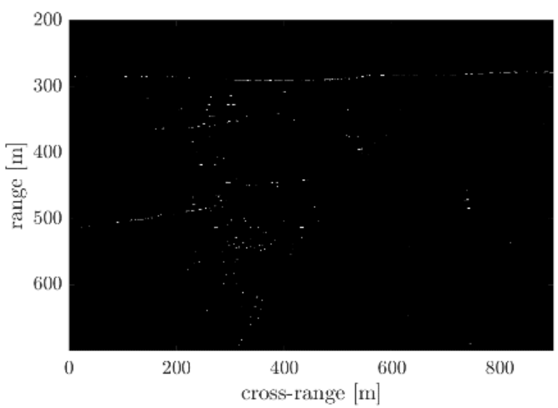
2. CA-CFAR detection



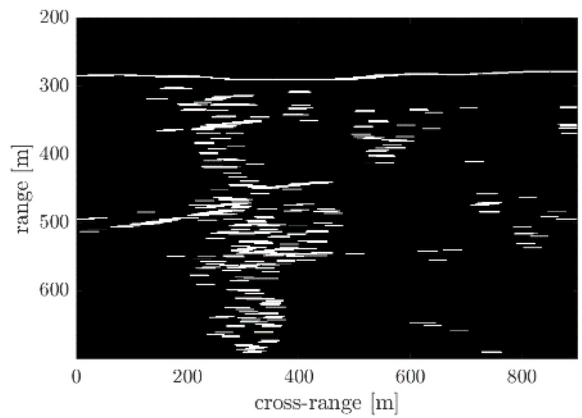
3. dilation



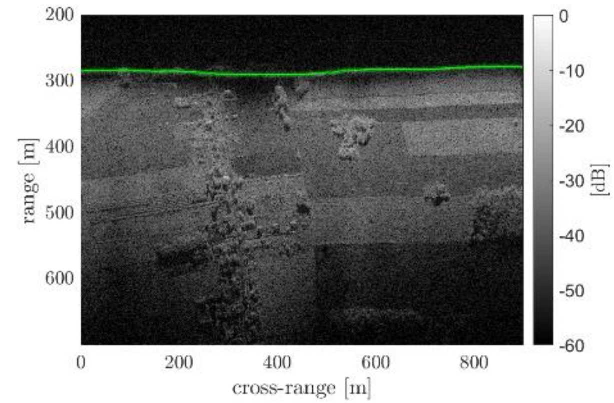
4. erosion



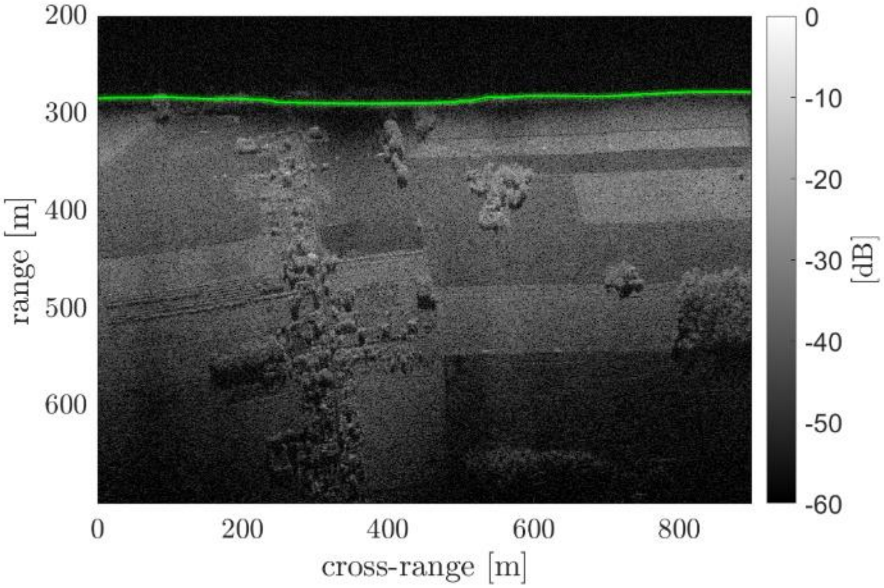
5. dilation

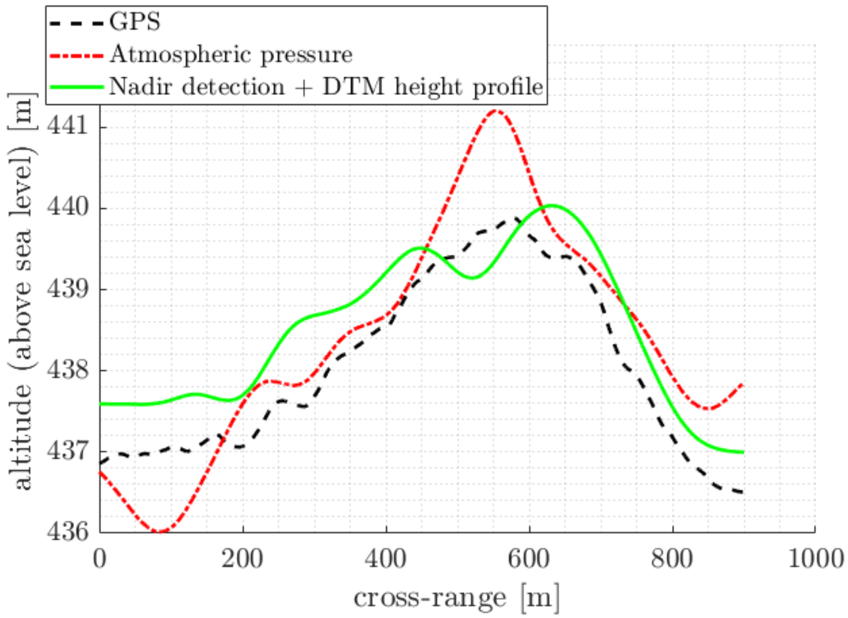


6. height detection



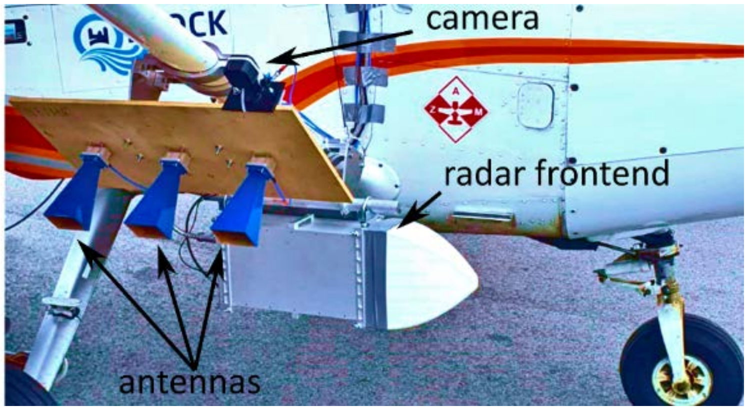
Altitude Measurement, cont.





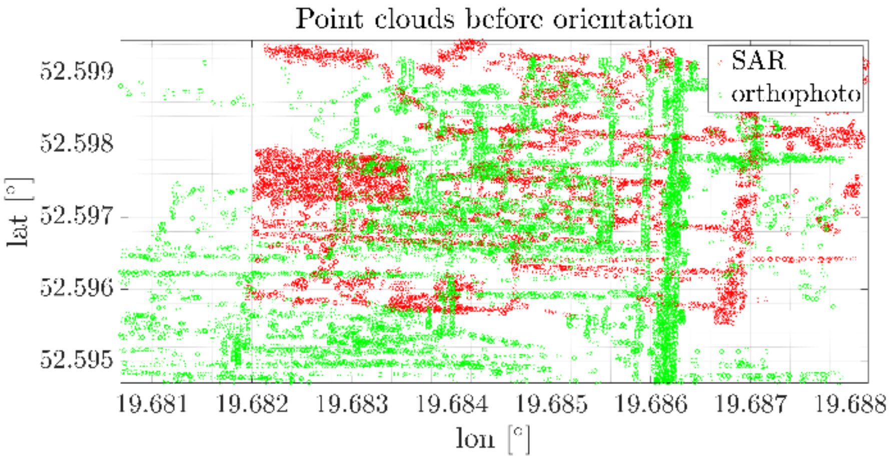
radar detecion is consistent with GPS measurement and barometric formula calculations based on atmospheric pressure measurements

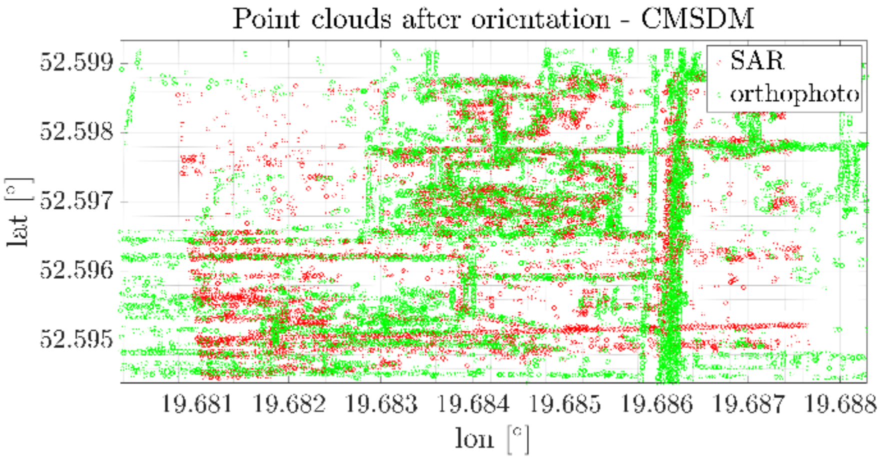
Results



No.	Longitude	Latitude	Rotation
1.	-8	5	1
2.	12	-8	1.5
3.	-25	-23	-2
4.	48	-31	2.5
5.	-59	40	-3
6.	80	50	4

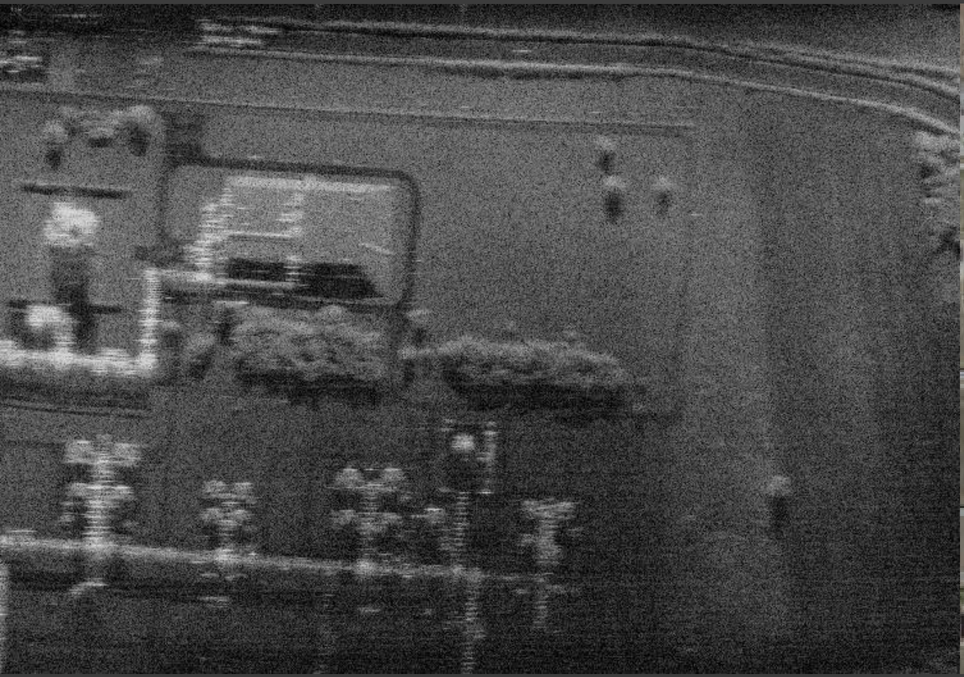
No.	Estimated	Estimated	Estimated
1.	-7.81	5.62	1.26
2.	11.82	-6.97	1.77
3.	-26.48	-24.21	-1.73
4.	49.31	-29.17	2.53
5.	-60.74	38.33	-2.93
6.	82.18	52.70	3.93





Conclusions

- A new approach to trajectory estimation has been proposed
- Proposed algorithm uses only one radar sensor
- Presented solution was succesfully validated in real-life trials
- A real-time implementation of the proposed CMSDM is planned in the future



Thank you for your attention