A Far Range Image Processing Method for Autonomous Tracking of an Uncooperative Target

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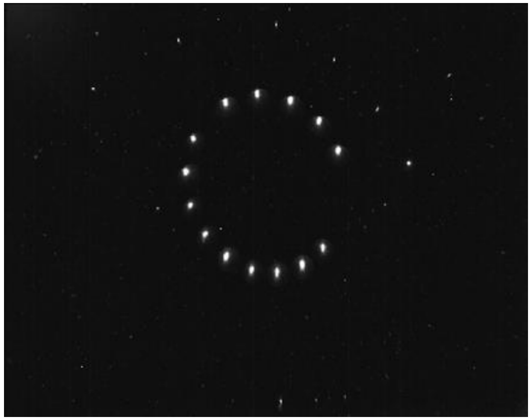
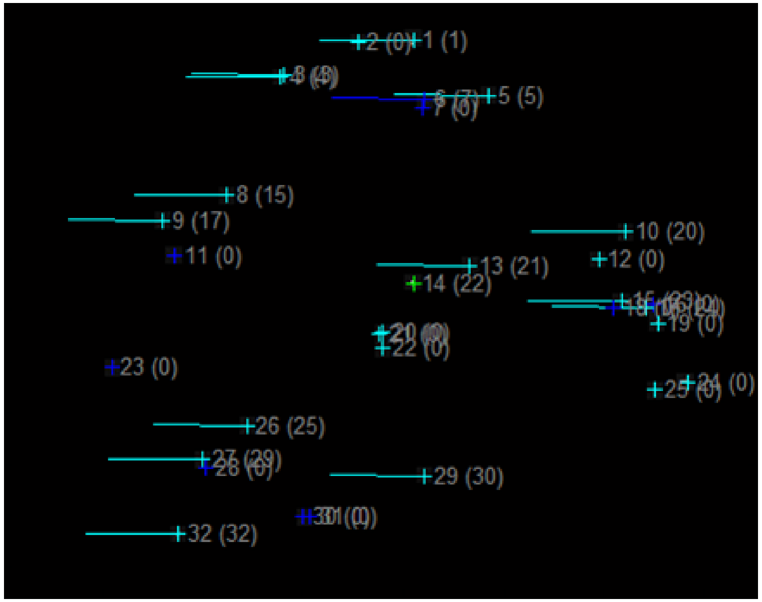


Introduction

- Preparation of future On-Orbit-Servicing (OOS) missions
- Approach (Rendezvous) phase is one of the most critical phases of an OOS mission
- Far Range: ~30km to ~ 500m
- Tasks:
    1. Detection and tracking of a target S/C in camera images
    2. Computation of the direction to the target (line-of-sight vector)
- Image Processing result is an important input for a relative navigation system based on angles-only measurements

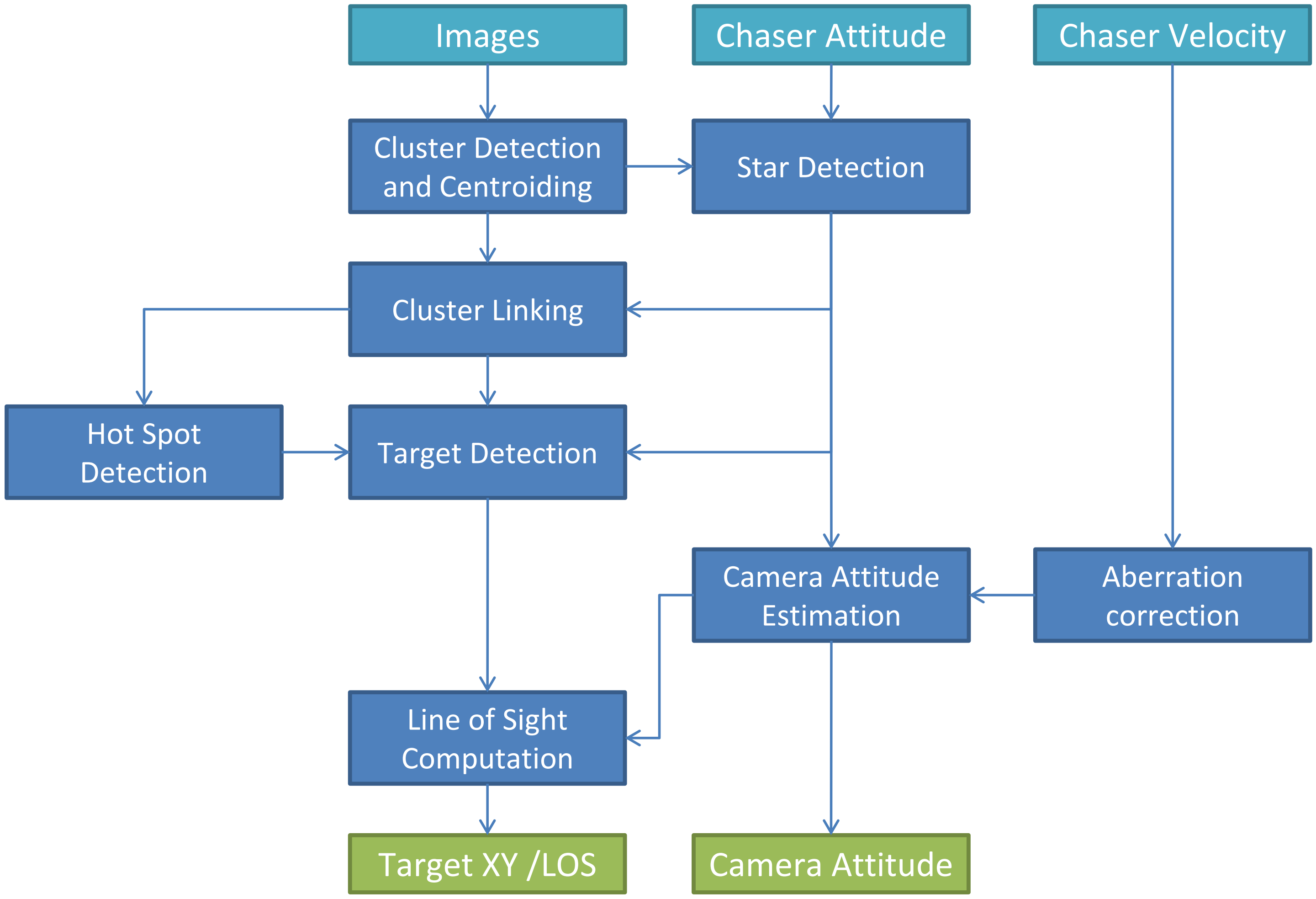
Far Range Image Processing – Objectives and Tasks

- Detection of objects of interests (clusters) in images
- Linking of clusters between two subsequent images
- Identification of stars (star catalog)
- Identification of camera hot-spots
- Detection of target S/C by motion segmentation
- On-board calibration of camera‘s attitude w.r.t. chaser S/C
- Computing Line-of-Sight Vector to target in J2000 reference system



Cyan: Stars
Green: Target
Blue: Non-identified objects

Functional concept



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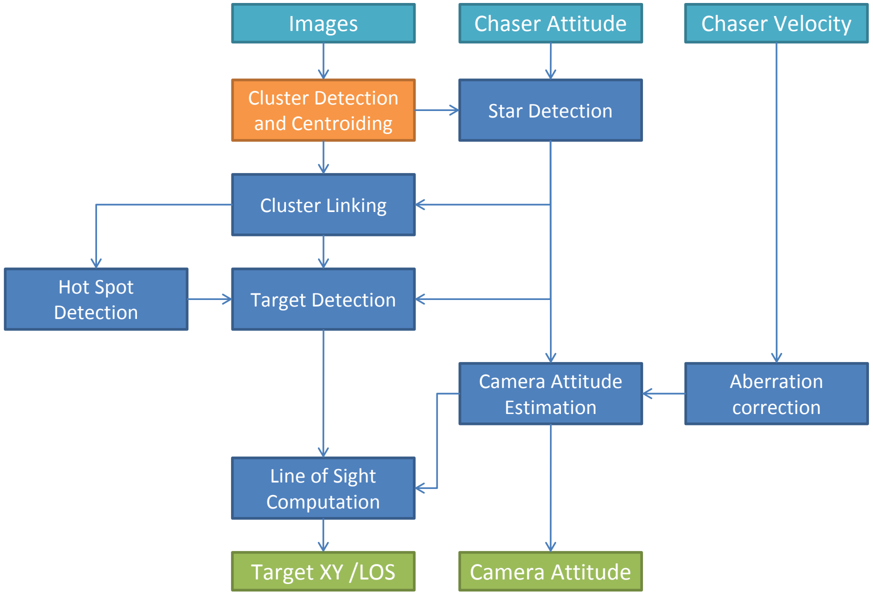
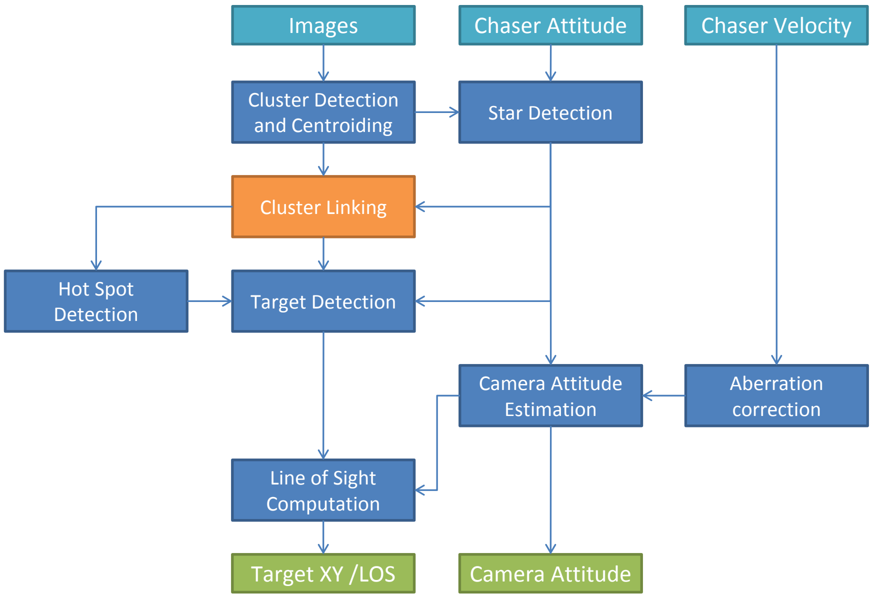
Cluster Detection and Centroiding



- Cluster is a set of connected pixels forming one object, e.g. stars, planets, moon, debris, target, hotspots, etc.
- Gray-scaled image $I(i,j)$ = Intensity/Brightness in pixel (i,j)
- Detect an object if $I(i,j) \geq I_0$
- Assign neighbor pixels to the cluster if $I(i,j) \geq I_1$
- Optional: Automatic setting of the thresholds
- Let S be the set of all pixels belonging to a cluster. The weighted size of the cluster is defined as $s_c = \sum_{p \in S} I(p)$.
- The weighted center of the target (center of brightness) is given by

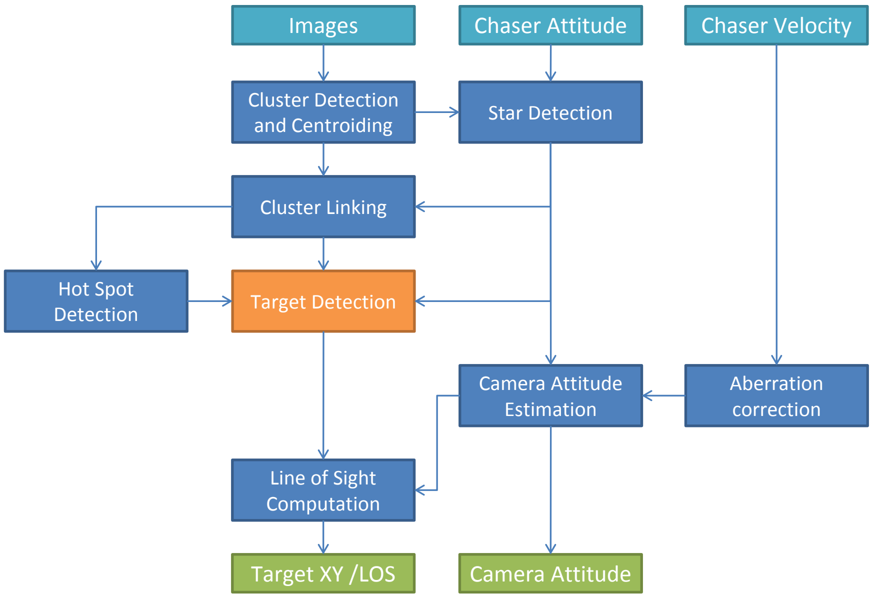
$$c_{cluster} = \frac{\sum_{p \in S} I(p)p}{s_c}.$$

Cluster Linking



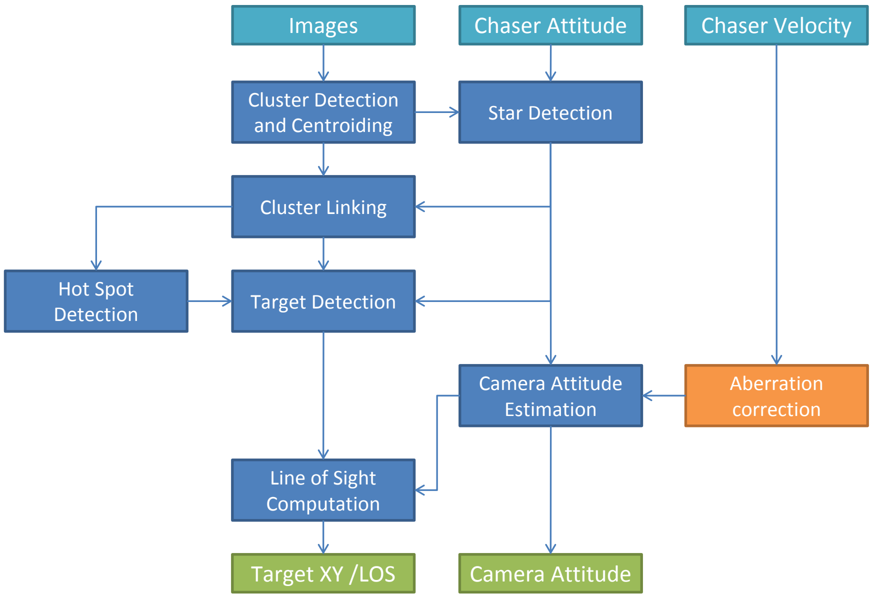
- Cluster Linking: Assigning each cluster of image $i+1$ to a cluster of image i :
  (1) Small difference in the size s_c
  (2a) The position of a star can be propagated. The difference between the position of the cluster of image $i+1$ and the propagated position should be as small as possible
  (2b) If a cluster is not marked as star, the position difference between the two linked clusters should be as small as possible.
- A weighted sum of size and position deviation is used as similarity measure.
- The assignment problem is solved with the Hungarian method.

Target Detection



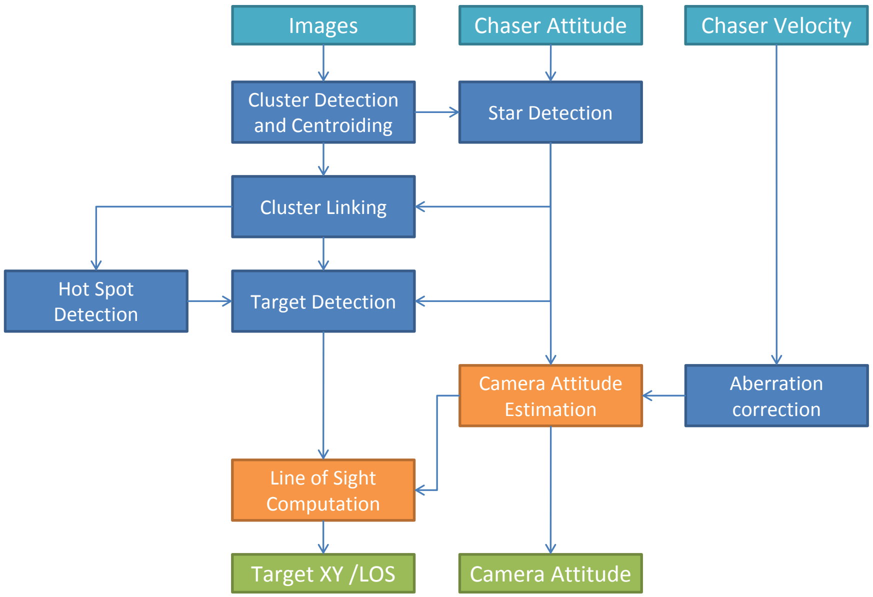
- Target Candidates: No stars, no hotspots
- Computation of a mean motion vector of all clusters in the 2D image domain
- Motion segmentation: Target = Cluster among the target candidates with the biggest deviation of the mean motion

Aberration Correction



- The apparent direction to the stars slightly differ from the real, geometric direction caused by the motion of the satellite (aberration)
  - *Annual aberration*: caused by motion of the Earth around the Sun
  - *Orbital aberration*: caused by motion of the spacecraft around the Earth
- Computation of an aberration correction quaternion
- Details: GFZ-Potsdam: CHAMP Attitude Aberration Correction, CH-GFZ-TN-2702, 2001

Camera Attitude & LOS Computation



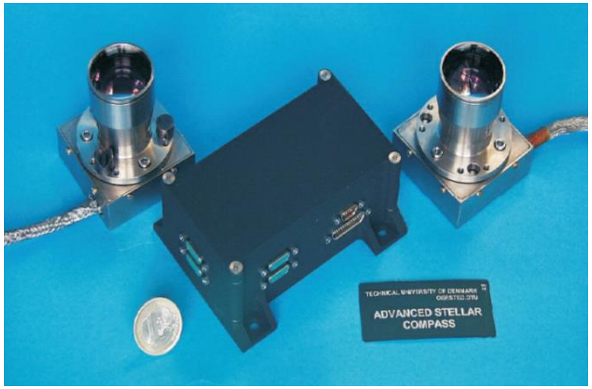
- On-board estimation of the camera attitude
  - ${u_j}^{J2000}$: Direction vector to a star j, $j = 1, \dots, N$ in J2000 system (Data from star catalogue)
  - u_j: Direction vector to star j in camera system, (Data previously extracted from the image)
  - Minimize $J(R) = \sum_{j=1}^{N} \omega_j \left\| u_j - R{u_j}^{J2000} \right\|^2$
  - The optimization problem can be rewritten to an eigenvalue problem for the associate quaternion (q-method)
- Attitude filter, update only if measurement is available (sufficiently large number of stars)
- The direction vector to the target (LOS-vector) can be determined from the computed attitude of the camera and the previously determined 2D pixel coordinates of the target.

Experiment „Advanced Rendezvous demonstration using GPS and Optical Navigation“

- Ground-in-the-loop experiment executed in the extended phase of the PRISMA mission (2012-04-23 – 2012-04-27)
- Demonstration of far range rendezvous to a non-cooperative target satellite
- Successful approach from 30km to 3km
- TANGO played the role of an uncooperative, passive target
- MANGO acted as chaser/servicer

Experiment „Advanced Rendezvous demonstration using GPS and Optical Navigation“

- VBS (Vision Based Sensor, DTU) used as rendezvous sensor
- Image pre-processing on-board, down-link during ground-contact
- On-ground actions
  1. Acquisition of camera images and telemetry data
  2. Determination of absolute orbit and attitude of MANGO
  3. Far range image processing
  4. Relative orbit determination
  5. Maneuver planning

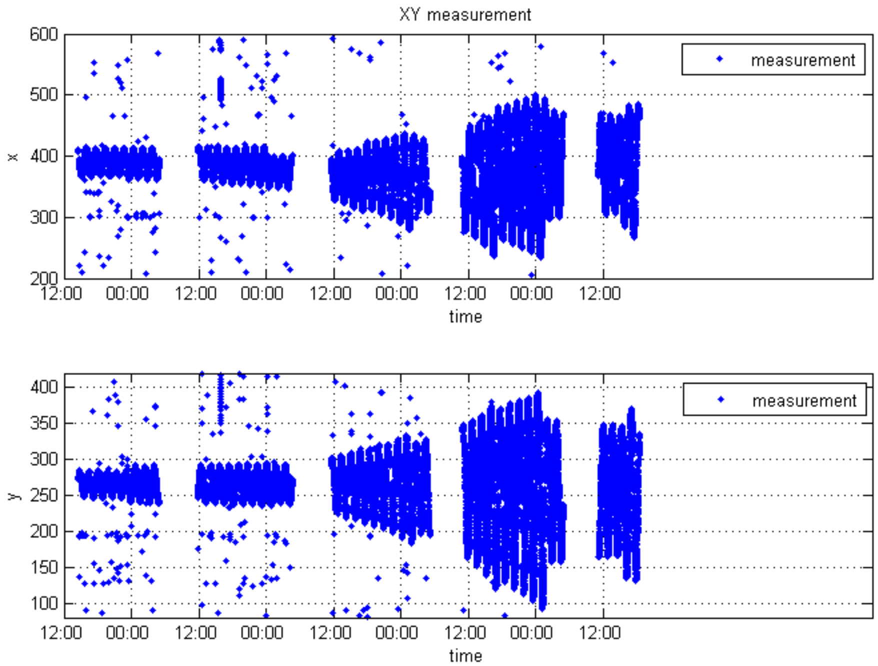


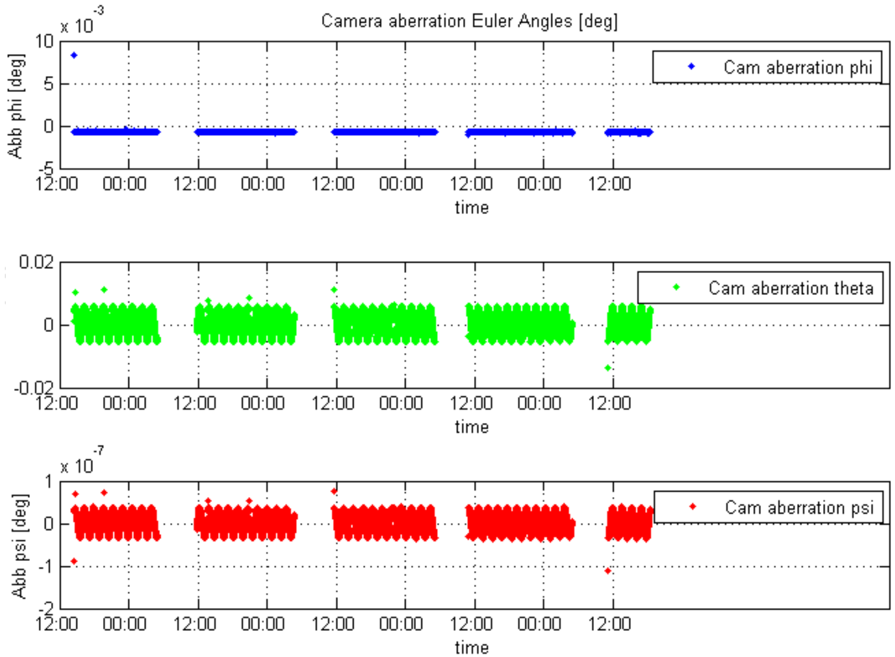
µASC (Advanced Stellar Compass)
High accurate star tracking platform

Far range camera

- Resolution: 752 x 580 pixels
- Field of view: 18.2° x 13.6°
- Focal Length: 20.187 mm
- Size of 1 pixel: 8.6µm x 8.3µm

Results – 2D measurement and camera aberration





Day	23.04.	24.04.	25.04.	26.04.	27.04.
Hit Rate	94.92%	94.99%	92.63%	96.41%	93.86%

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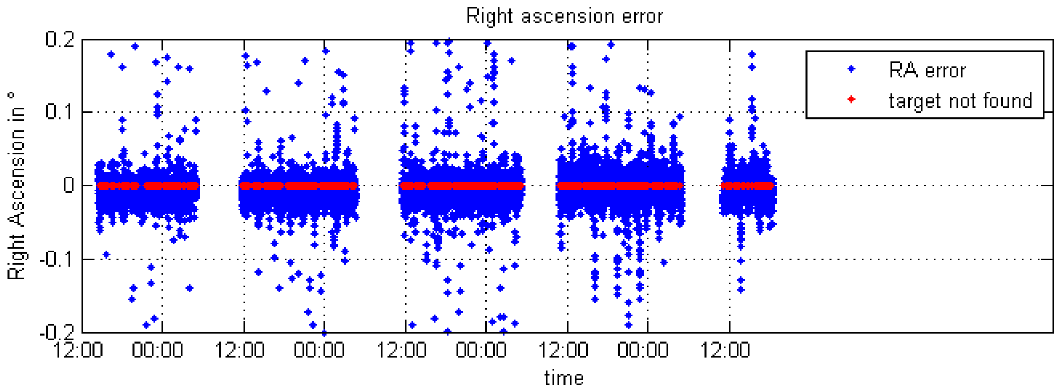
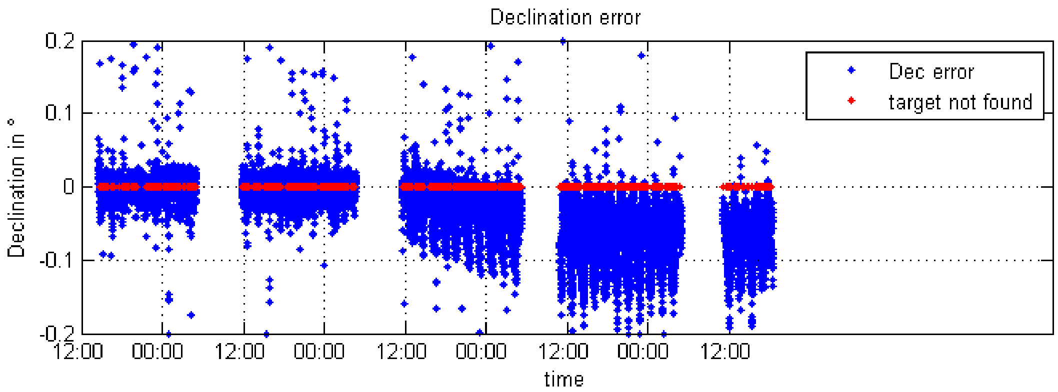
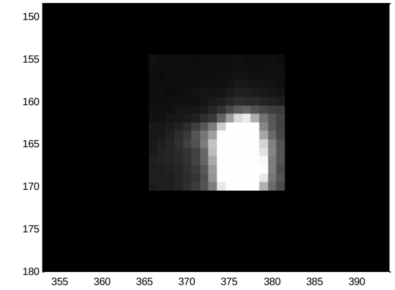
Results – Line-of-sight accuracy







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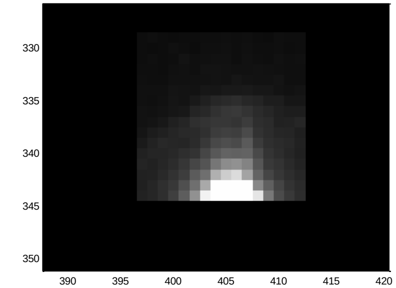

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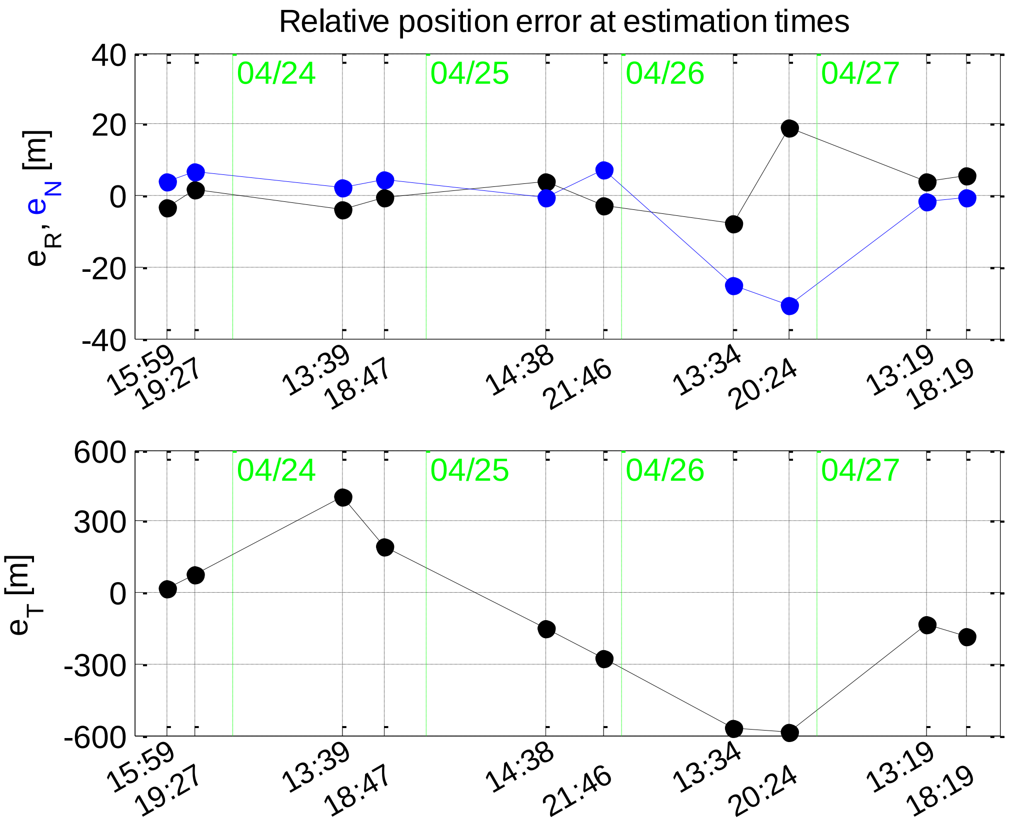
Results of relative navigation



e_T: error in tangential direction
e_R: error in radial direction
e_N: error in normal direction

Conclusion and Outlook

- Development of image processing algorithm for far range rendezvous
- ARGON has been one of the first documented demonstrations of ground-in-the-loop, man-in-the-loop far range rendezvous to an uncooperative target satellite
- The method can/will be reused for on-board image processing and navigation for future OOS demonstrations / missions
- As image processing accuracy is strongly dependent on the visibility of the target and the stars, analysis of camera sensitivity has been started.