Using *Infrared-Based* Relative Navigation for Active Debris Removal

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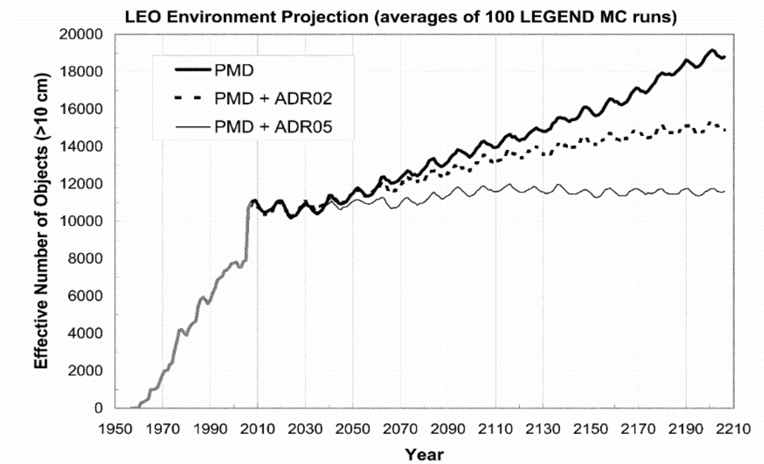
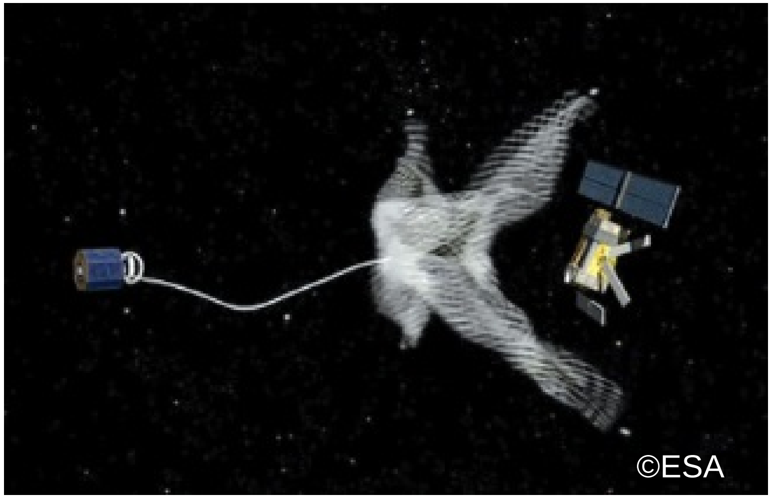
Outline

- Study Background
- Performed Studies
- Lessons Learned
- Conclusions
- Future Work

Active Debris Removal



[Kessler2010] The Kessler Syndrome: Implications to Future Space operations, Donald J. Kessler and Nicholas L. Johnson and J.-C. Liou and Mark Matney. 2010



looks very similar to
navigation problem of

Space Rendezvous and Docking Missions,

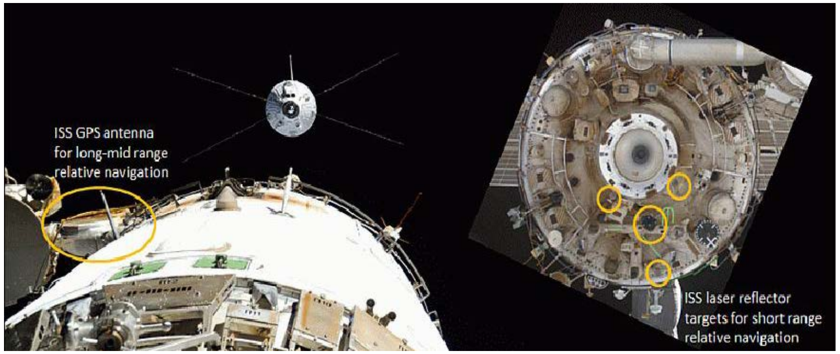
then why do we need new technologies

?

Navigation Challenges

ATV-ISS Rendezvous & Docking

- Cooperative Target



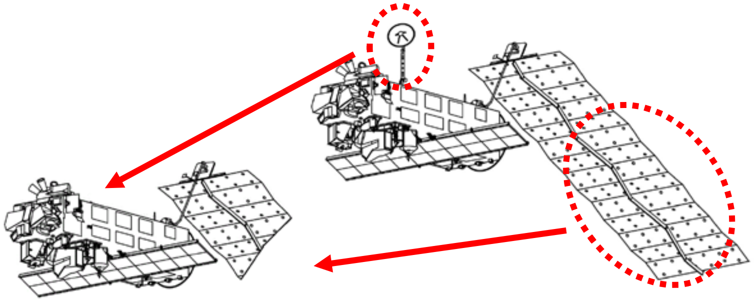
3-axis stabilised

Active Debris Removal (ADR)

- Uncooperative Target: *Space Debris*

NO fiducial marker
NO inter-satellite communication

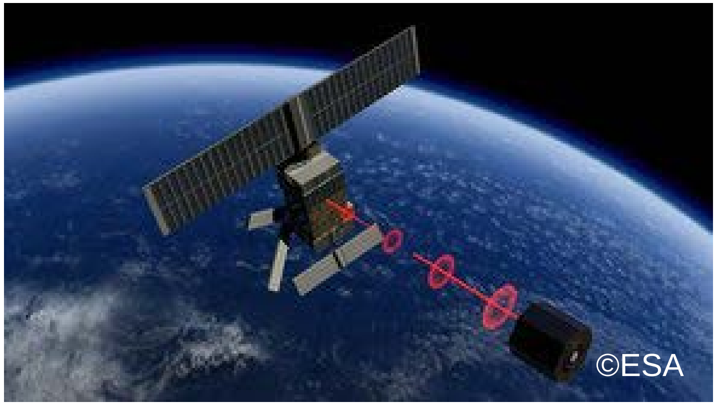
NO attitude control
Possibly <u>tumbling</u>
UNKNOWN relative orientation

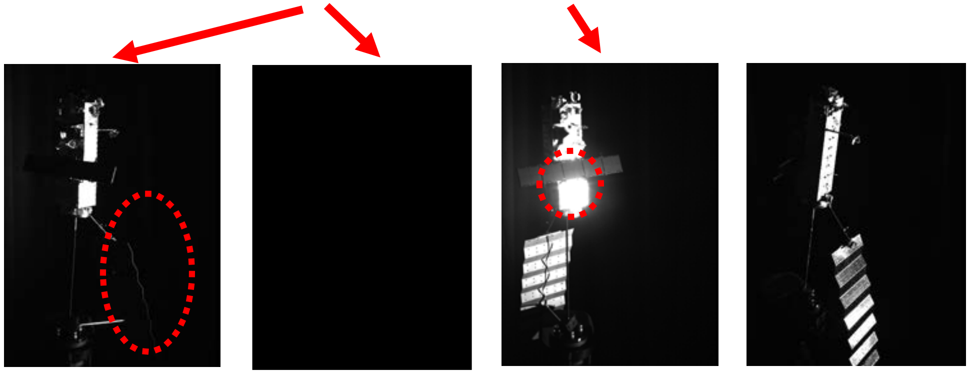


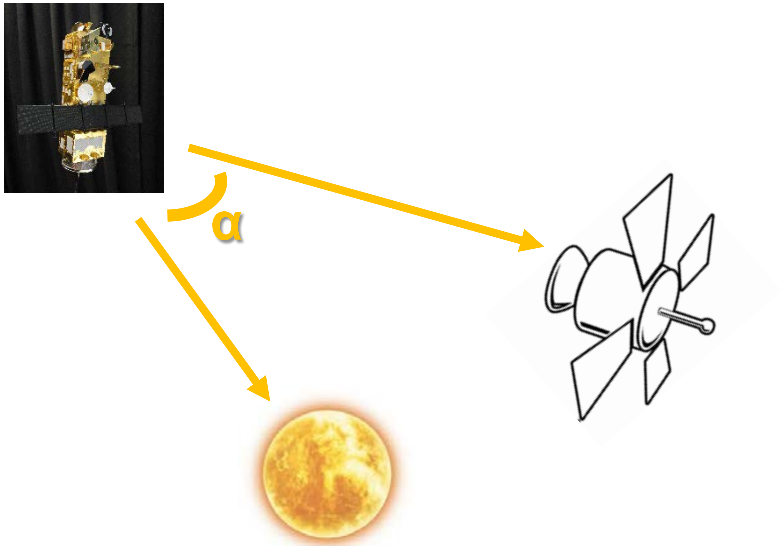
Options for Relative Navigation Sensing Technologies

- RADAR
  - Long and Medium Range
  - Active
- LIDAR
  - Active
  - Low accuracy @ short range
- Visual Camera
  - Passive
  - Affected by harsh Illumination Conditions

(Eclipse and Solar Glare)







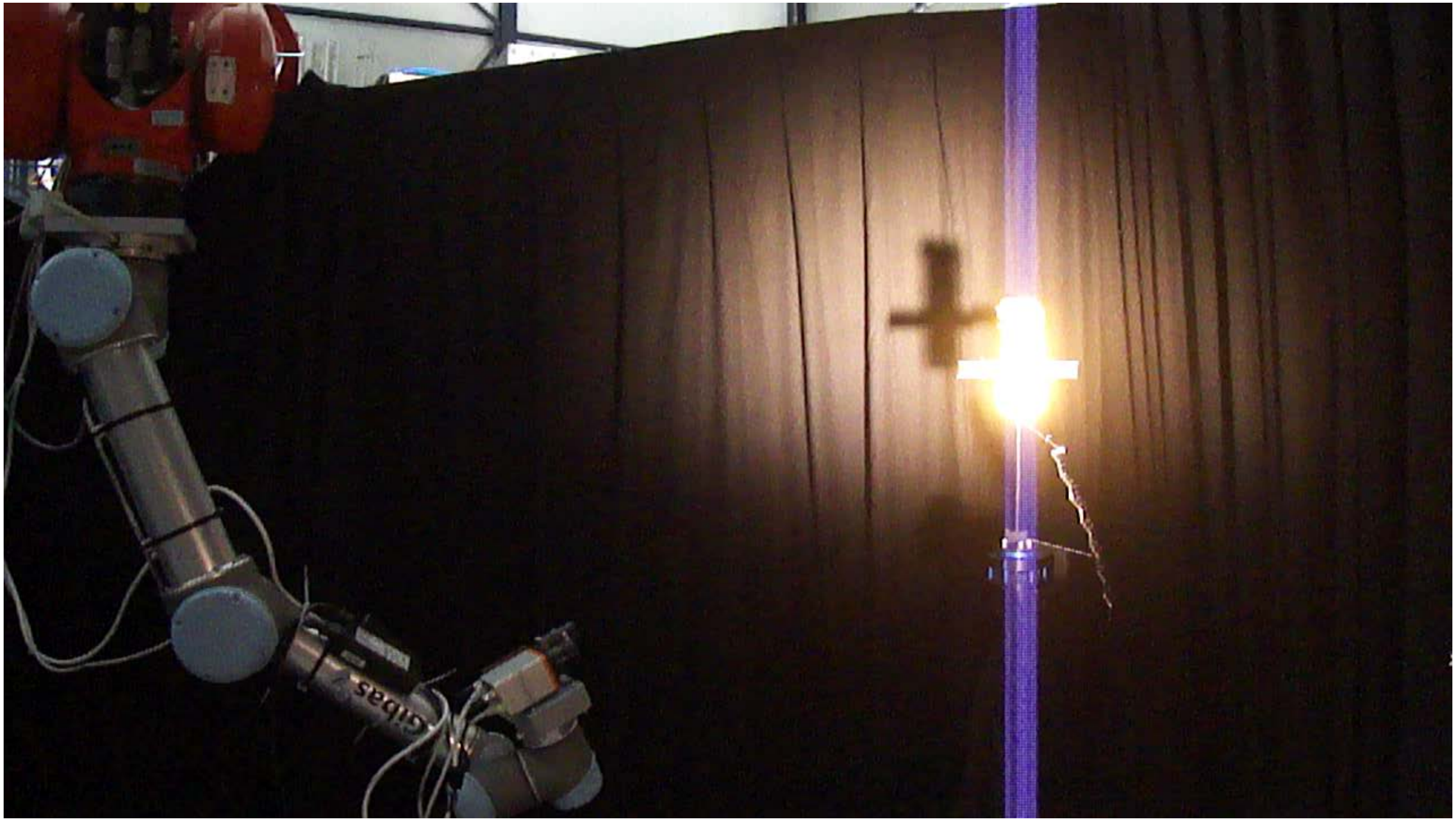
Relative Navigation Sensing Technologies

Could we propose alternative/ complementary solution

?

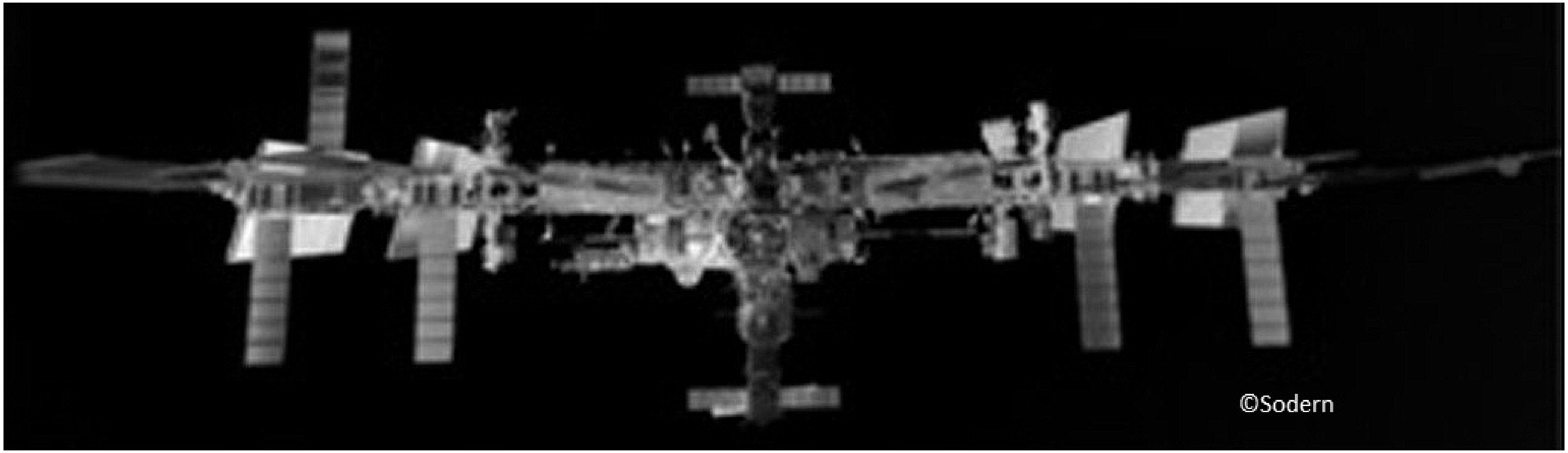
? INFRARED CAMERAS ?

Infrared Based Relative Navigation



Advantages of Infrared for ADR

- Independent from harsh illumination conditions of space
- Continuous measurements
- Do not get permanent damage when Sun is in the field of view (flexibility)
- In 2014, LIRIS experiment (ESA-Airbus-SODERN-JenaOptronik) from ATV flight to ISS showed promising results.
  - Setup: LIDAR, Visible and Infrared cameras



http://www.esa.int/spaceinimages/Images/2014/12/LIRIS_infrared [accessed 06/04/2017]

Why don't we use the approaches used for

Visual Systems

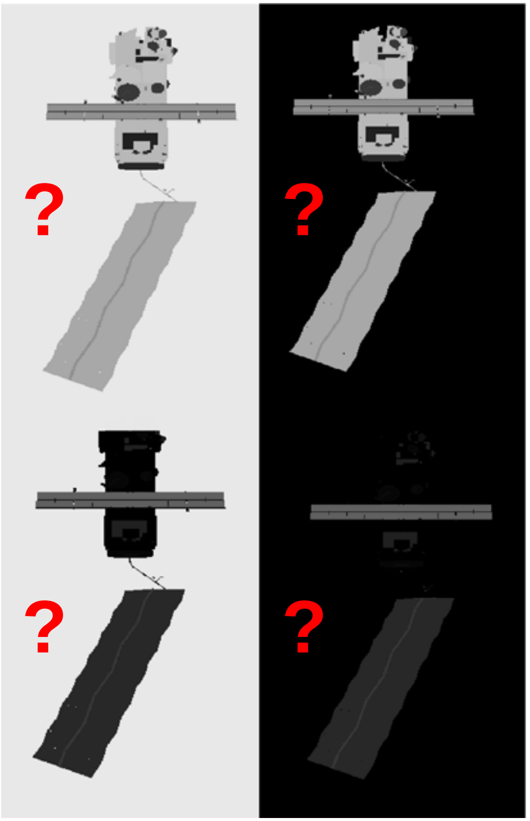
in relative navigation

?

Infrared Imaging Facts for ADR

- Man made space objects would have passive thermal control
  - But how after so many years?
- Fast variations in space thermal environment
  - e.g. Low Earth Orbit (~1/3 of orbit eclipse)
- Depending on the conditions thermal signature of the same object could be very different.

How would Space Debris would look like in infrared when chaser going to capture it?



What did we need to do verify Infrared based relative navigation for ADR

is feasible…

?

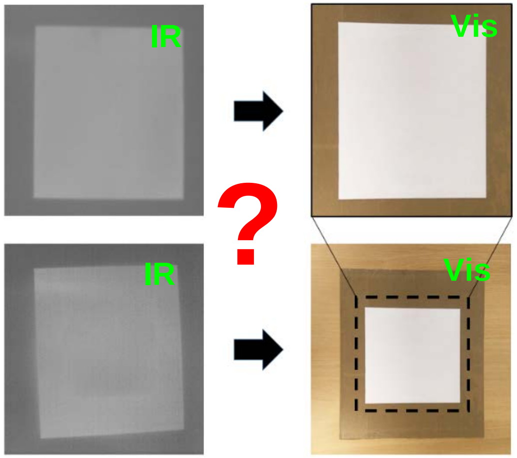
Justification Studies

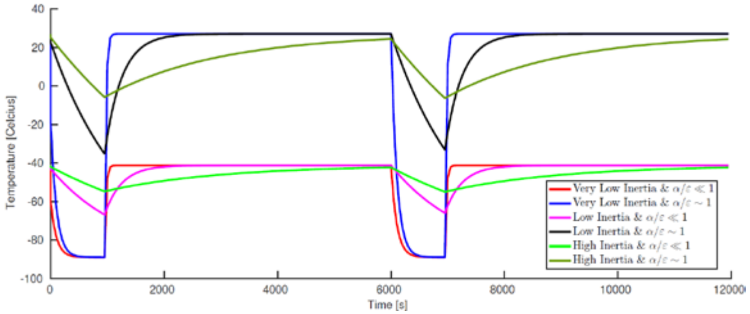
- Infrared modelling of space debris had been completed with the conclusion of precise modelling would not be possible due to the number of unknowns in ADR.

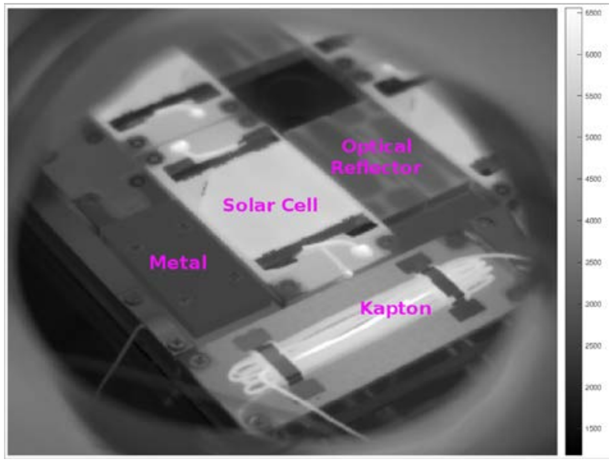
Yılmaz, Ö, Aouf, N., Checa E., Majewski, L., & Sanchez-Gestido, M. Thermal Analysis of Space Debris for Infrared Based Active Debris Removal, Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering (accepted)

- Performance analysis on feature detection algorithms for ADR targets under thermally varying conditions of space had been performed.

Yılmaz, Ö, Aouf, N., Majewski, L., & Sanchez-Gestido, M. (2017). Evaluation of Feature Detectors for Infrared Imaging in View of Active Debris Removal, 7th European Conference on Space Debris.





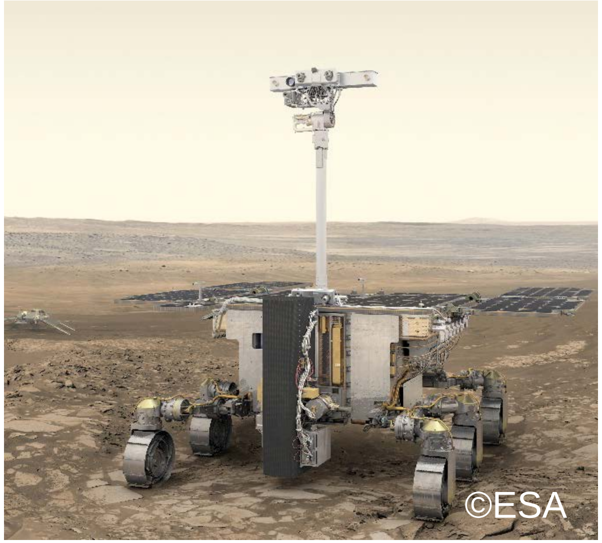


Relative Pose Estimation of Uncooperative Target under Pure Translational Motion

Bayesian Approach:
Simultaneous Localisation and Mapping (SLAM)

Use to reconstruct the map/environment that is unknown and localizing the robot in generated map.

Similar problem of Space Debris that we do not know its model very well, especially in infrared.



Time Update

$$x_k^- = A x_{k-1}$$

$$P_k = A P_{k-1} A^T + Q$$

Measurement Update

$$K_k = P_k^- H^T (H P_k^- H^T + R)^{-1}$$

$$x_k = x_k^- + K_k (z_k - H x_k^-)$$

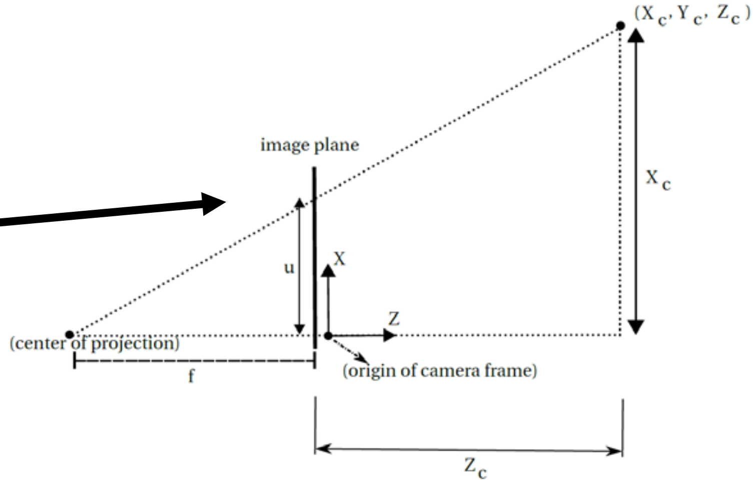
$$P_k = (\mathrm{I} - K_k H) P_k^-$$

Approach

Landmark map -> Space Debris structure

$$x_k = Ax_{k-1} + w_k$$ (Process Model)

$$z_k = Hx_k + v_k$$ (Measurement Model)



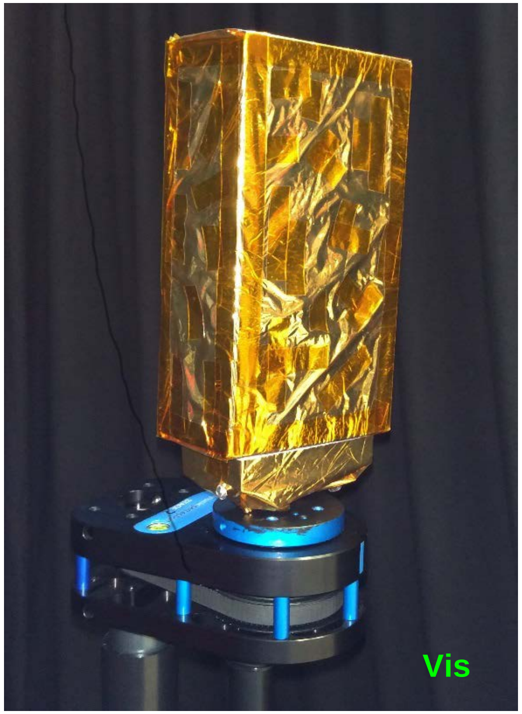
$$x = (T_x, T_Y, \beta T_Z, \omega_X, \omega_Y, \omega_Z, \alpha_1, \alpha_2, \ldots, , \alpha_n)$$

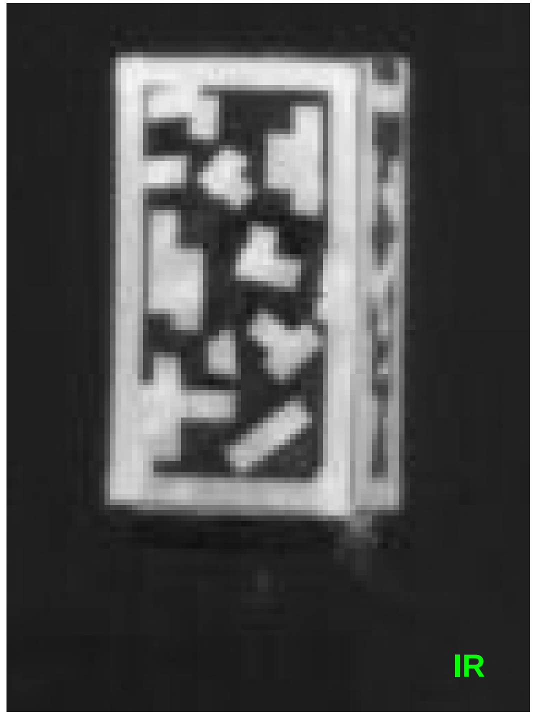
ADVANTAGE: *All available information (detected trackable features regardless of their physical interpretation) can be used.*

DISADVANTAGE: *Without 3D model, monocular camera can only provide solution UP-TO SCALE due to projective geometry <u>which can be solved</u> by limited ground intervention in the process or complementary sensors.*

Experimental Work – Real Infrared Imagery

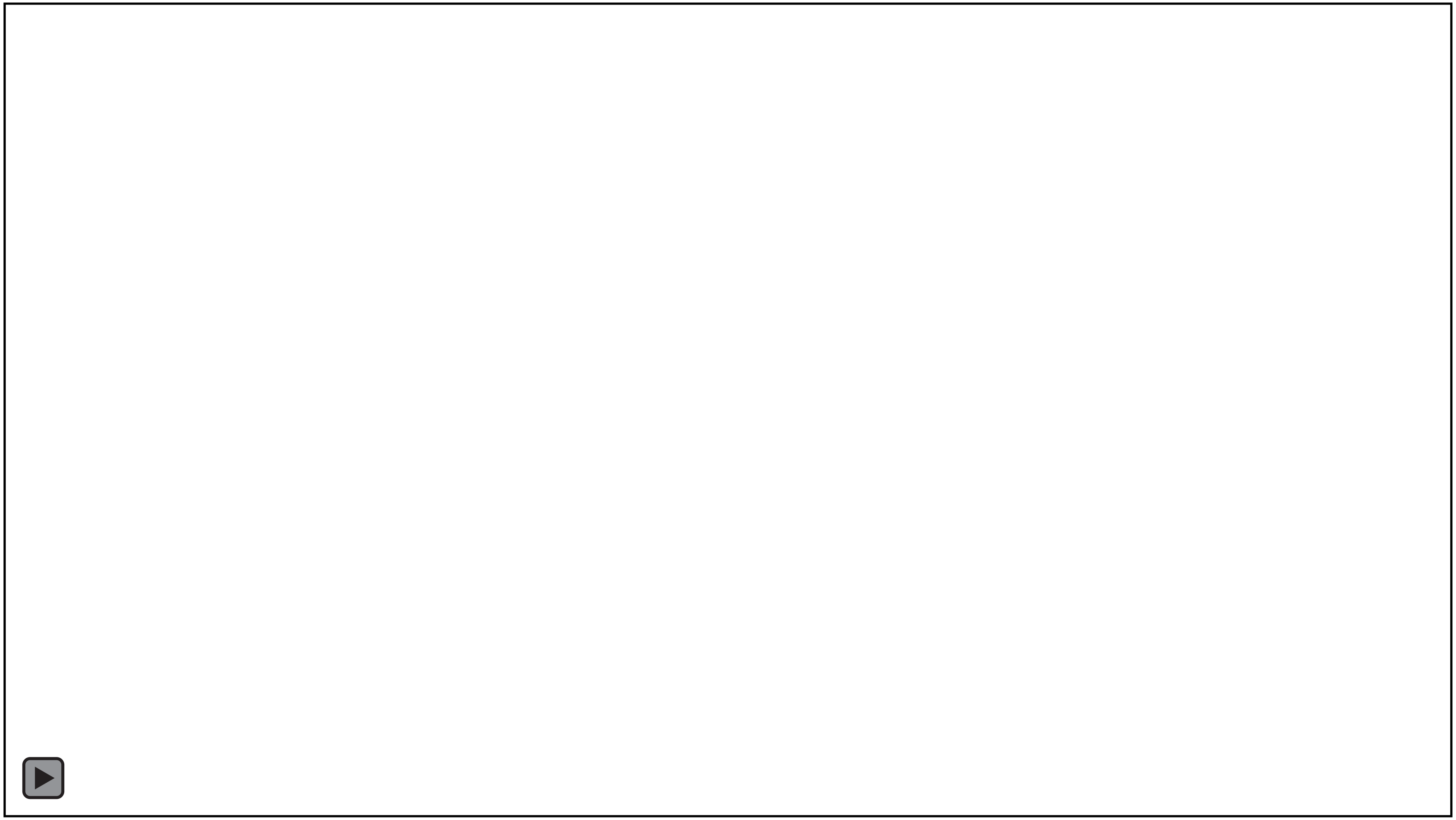
Experimental Work – Real Infrared Imagery





Property	Value
Detector	Uncooled Microbolometer
Spectral Range	8μm-14μm
Resolution	384x288
HFOV	29.9˚
Focal length	18mm
Pixel size	25μm
NETD	≈50mK @30˚C

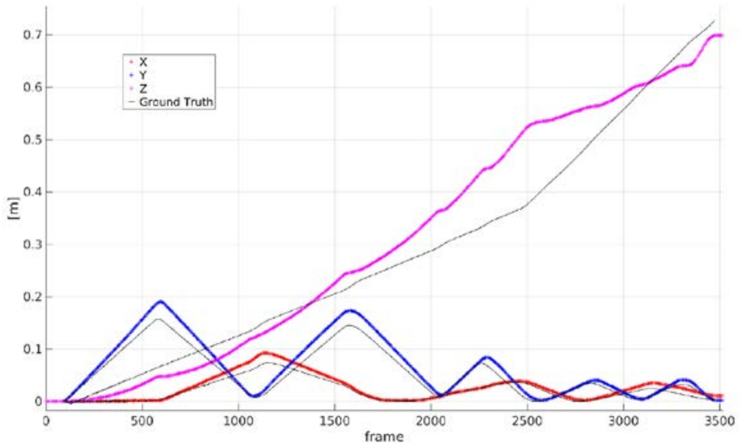
Experimental Work - Real Infrared Imagery

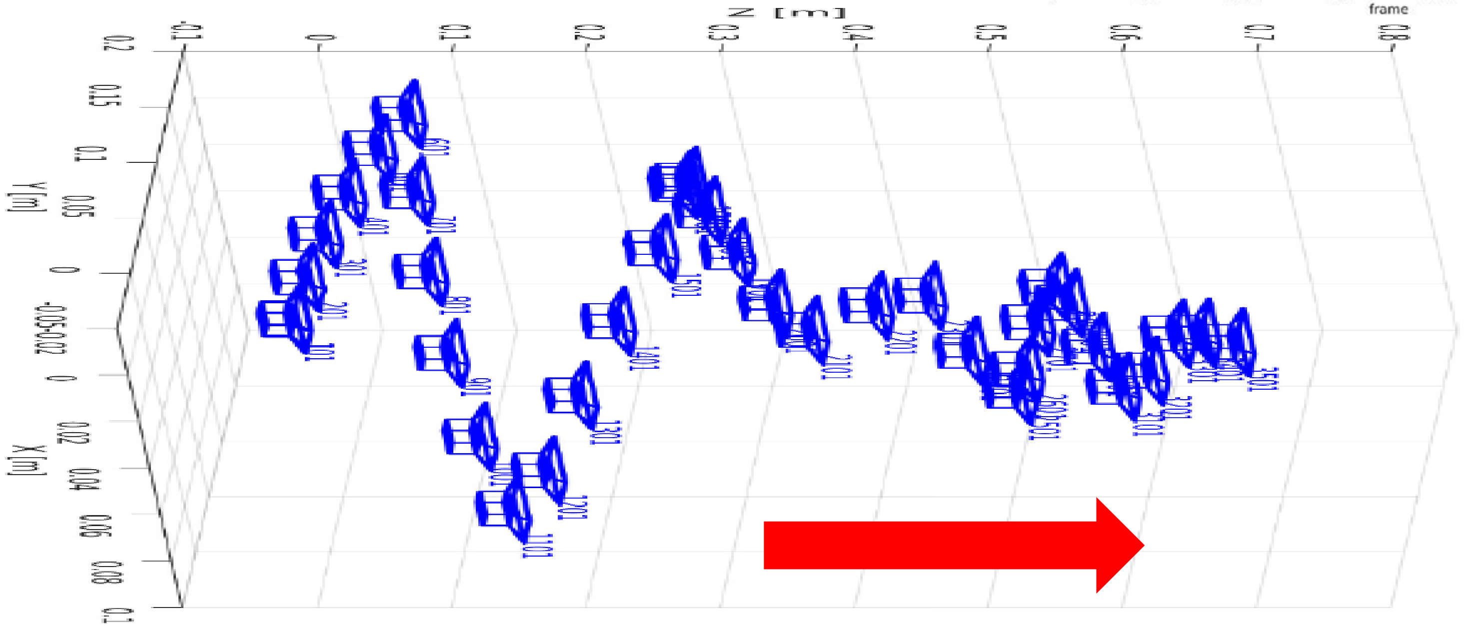


Experimental Work - Real Infrared Imagery

The work has been presented in **10th ESA GNC Conference.**

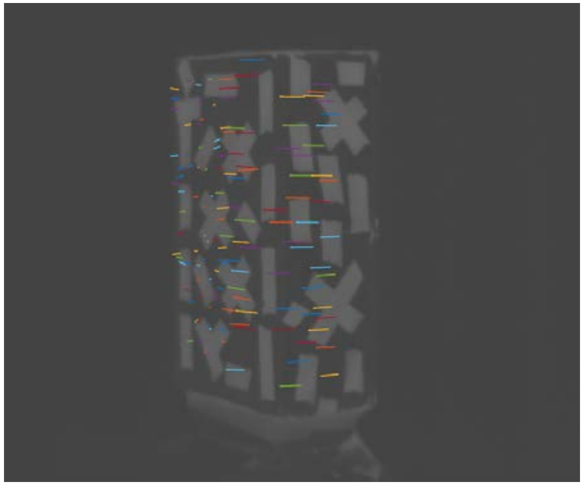
Yılmaz, Ö, Aouf, N., Majewski, L., Sanchez-Gestido, M. &, Ortega, G. (2017). Using Infrared Based Relative Navigation for Active Debris Removal, 10th International ESA Conference on Guidance, Navigation & Control Systems.

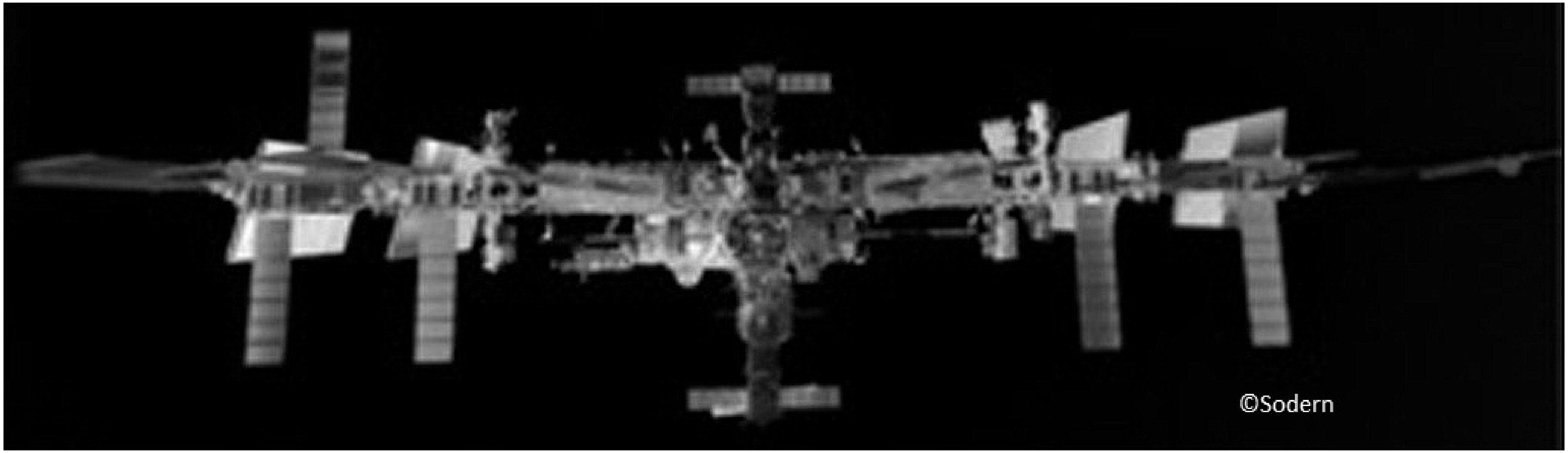




Lessons Learned for experimenting

- In air, required thermal environment can only be simulated up to certain extend and required contrast cannot be achieved due to safety reasons. However, these uncertainties ***do not much affect our proposed algorithm*** as we use all available information possible.





http://www.esa.int/spaceinimages/Images/2014/12/LIRIS_infrared [accessed 06/04/2017]

Lessons Learned for experimenting

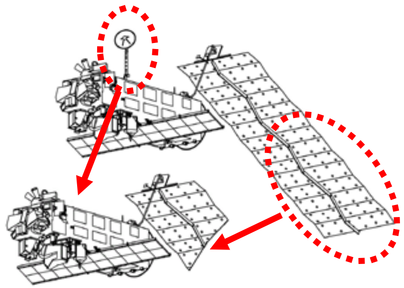
- **Scaling trajectory** is not straight forward from imaging point of view. Camera focusing and therefore depth of field are more sensitive at close range (<2m) which would not represent the real mission case of its relevant scale. Provided camera set up requires 5 re-focusing which is infeasible for tests. The algorithms tested only with 1 focusing procedure therefore we have seen their worst performance.
- Surface coating required for infrared imaging generate **ambiguities** in Motion Capture System (Vicon).

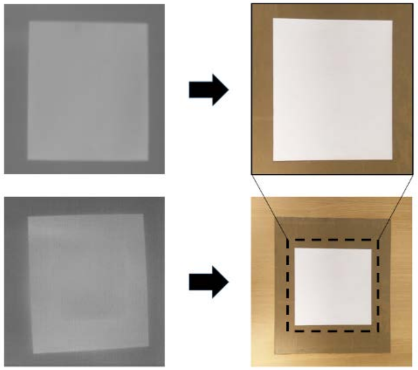
Conclusions

- Thermal imagery can be used for ADR under **any illumination condition**
- Infrared technology can provide **continuous information** while their visual counterparts cannot.
- Space environment has **fast thermal variations** on contrary to terrestrial applications of infrared
- The thermal variations in space environment and surface coating of the space debris can still **create enough contrast in infrared** during the mission
- Formation of infrared signature is **different** than visual. Experimental data collected from real space experiments like LIRIS shall be **handle and analyzed with care** for design of relative navigation applications.

Conclusions

- Our information about **conditions of space debris are limited**. We are not sure how space debris would be, more importantly how would they look like in infrared and visual (collision/configuration).
- Our SLAM based approach is **more tolerant to unknowns** of ADR application and infrared imaging in space.
- Our SLAM based approach provide **fast and computationally less heavy initialization** than model based approaches.





Future Work

- Completing the development and analysis on infrared based relative navigation algorithm for space debris with complex motion.
- Fusion of infrared based approach with other relative navigation sensors like depth measuring sensors for scale recovery

- Following e.Deorbit activities

We will be very happy to collaborate which will increase TRL level of our algorithm and to demonstrate its strength with real scenarios.

Questions??

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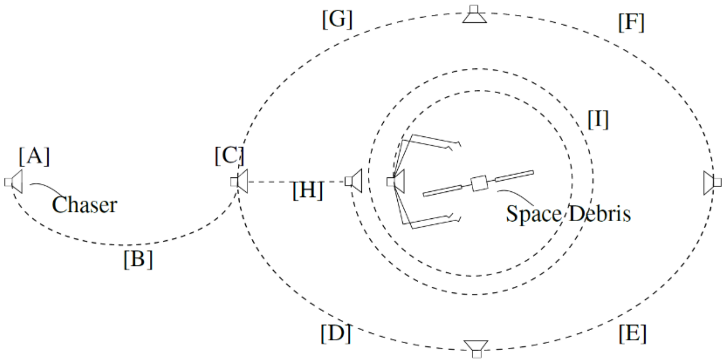
PhD scope

- Infrared Modelling of Space Debris
- Infrared Cues for Space Debris Detection and Tracking
- Relative Pose Estimation of Uncooperative Target under Pure Translational Motion



(Example)

- Relative Pose Estimation of Uncooperative Target under Pure Rotational Motion
- Relative Pose Estimation of Uncooperative Target under Complex Motion