Active alignment system for quantum communications

GSTP 4000135420 /21/NL/GLC/zk

Final Presentation

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UKRI Science and Technology Facilities Council
RAL Space

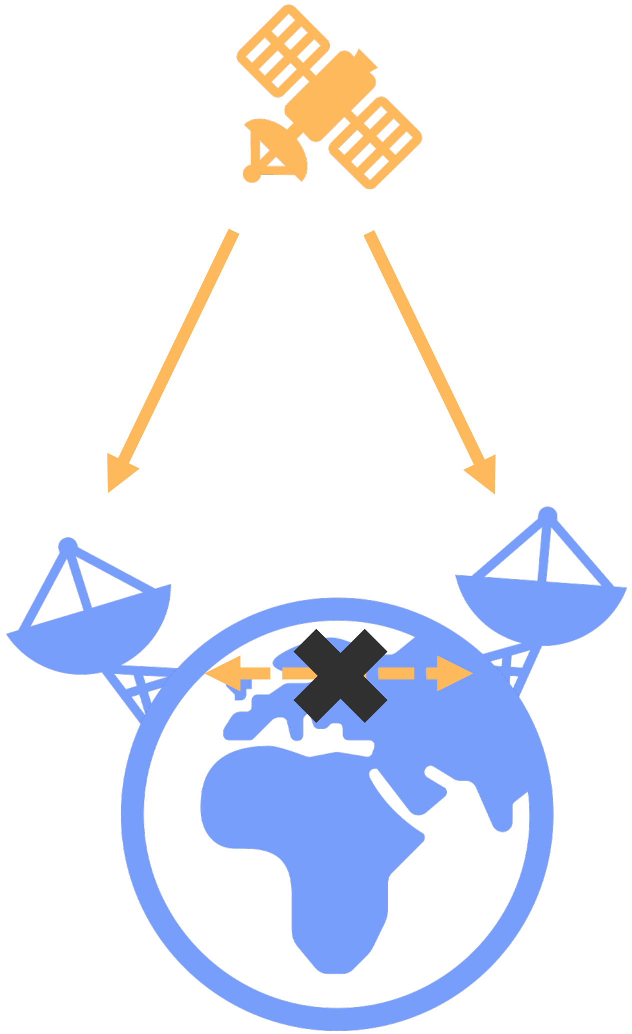
Presentation overview

- Project background
- Active alignment system
  - Design and assembly
  - Performance testing
- Project achievements
- Next steps
- Summary of deliverables
- Contract closure

Project background

- Optical links from satellites are a promising candidate for enabling quantum communication
  - Encryption key is encoded in the quantum properties of a string of photons
  - If the key is intercepted, the quantum state is changed and discarded so communication is secure
  - Encryption key must be propagated through free space

- Demonstration on small satellites is desirable
  - To enable quick demonstrate of new quantum technology
  - Potential for constellations of quantum satellites in future



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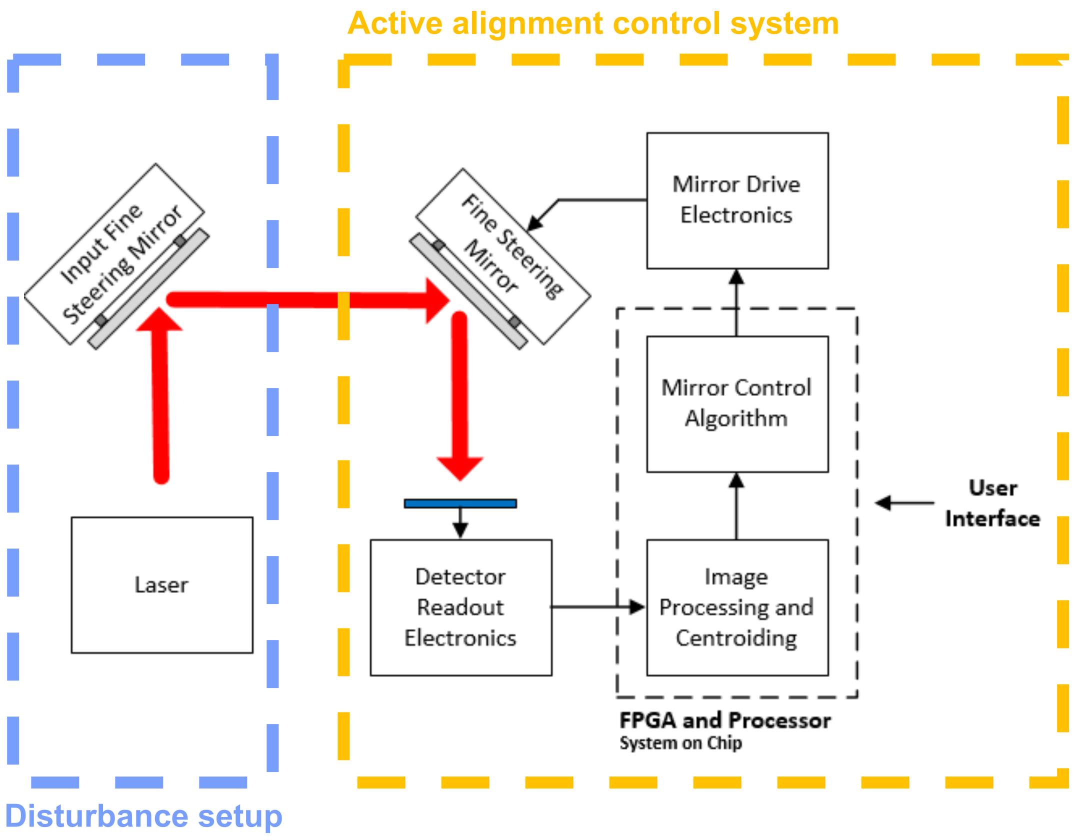
Active alignment system proposal

- Optical signals used to generate quantum keys are power limited
  - Need to maximise transmission from satellite
  - Requires narrow beam and precise pointing

- Active alignment system
  - Fine steering mirror (FSM) in closed loop control with a detector to track an uplink beacon sent from the ground station
  - Quantum beam reflected from same FSM is precisely pointed at the ground station

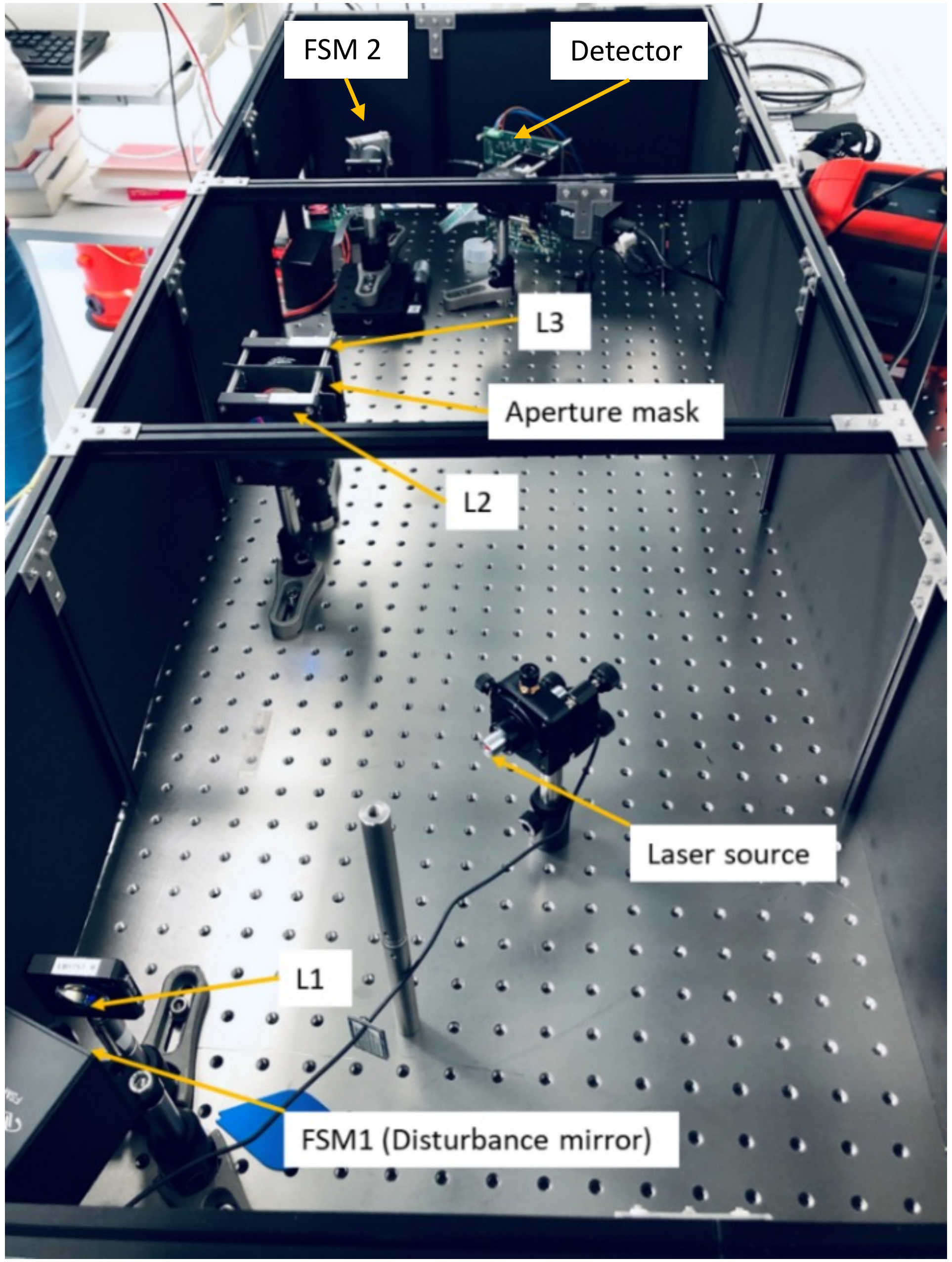


System assembly

- COTS and in-house-designed components

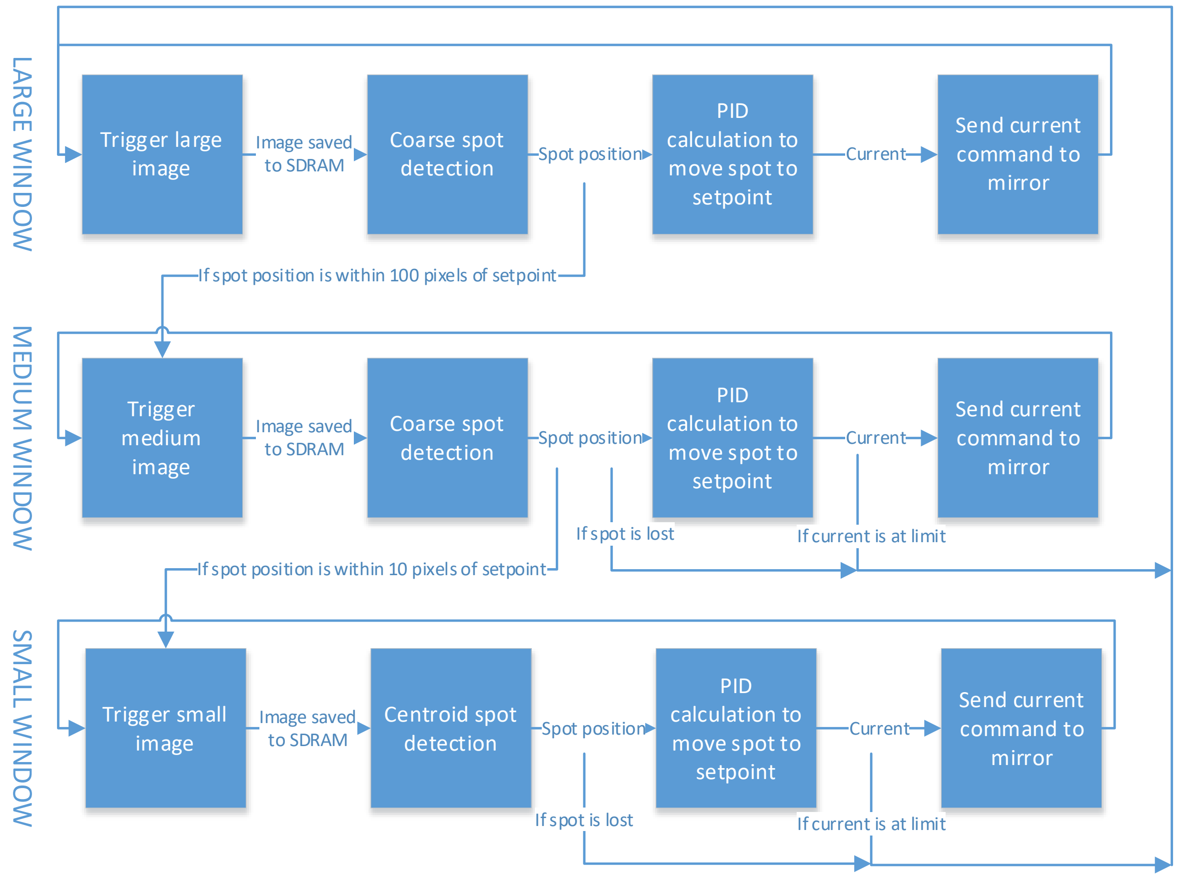
Component	Part
Detector	CMOSIS CMV4000
Detector readout electronics	Custom in-house electronics
FPGA and processor	SmartFusion2 system on a chip and Microchip ARM Cortex M3 microprocessor
Mirror drive electronics	Custom in-house electronics
Control FSM	Demcon FSM 20mm

- Designed an optical setup for testing
- Chose and optimised alignment and control algorithms



Active alignment algorithms

- Spot detection algorithms
  - Identified need for progressively smaller detector windowing
  - Coarse: brightest group
  - Fine: centroid
  - Perform on microprocessor rather than FPGA
- Control algorithm
  - PID



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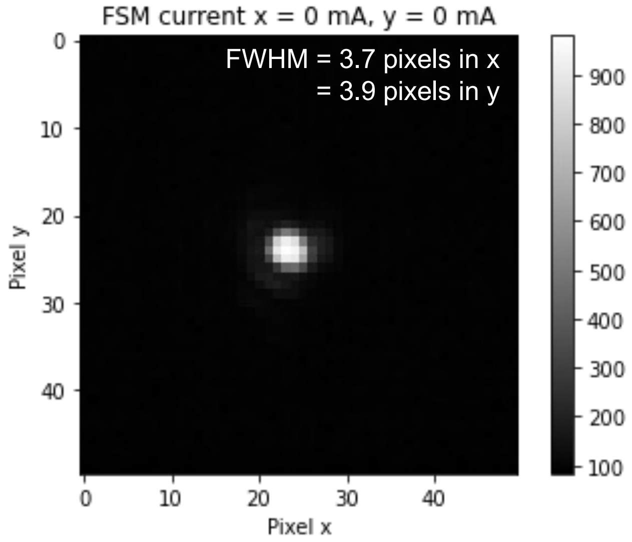
Performance testing

	Requirement	Verification method	Status
1	The detector shall capture a spot of diameter between 3 and 5 pixels measured at the full-width half-maximum.	Test	Compliant



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	Requirement	Verification method	Status
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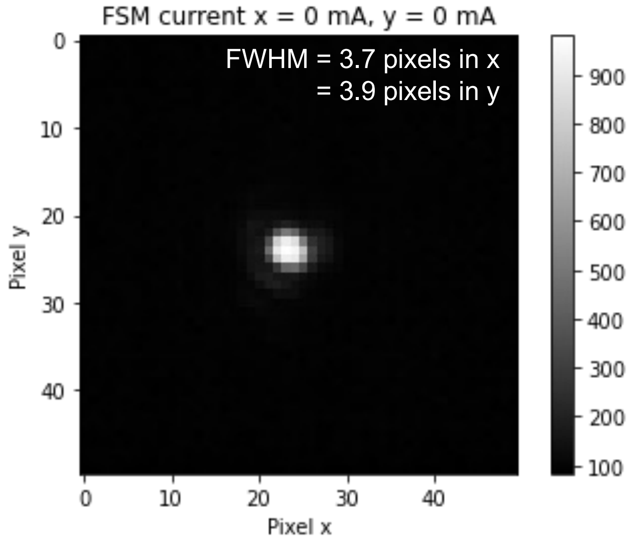

Window size	Max. loop speed
50x50 pixels	15 ms (66 Hz)
15x15 pixels	6 ms (166 Hz)

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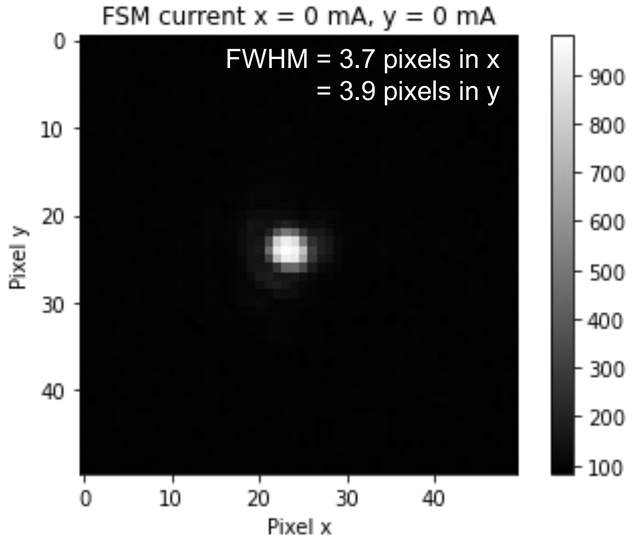
3	The control system shall stabilise optical perturbations of 3 arc seconds at frequencies of up to 5 Hz to within 0.5 pixels rms.	Test	Compliant



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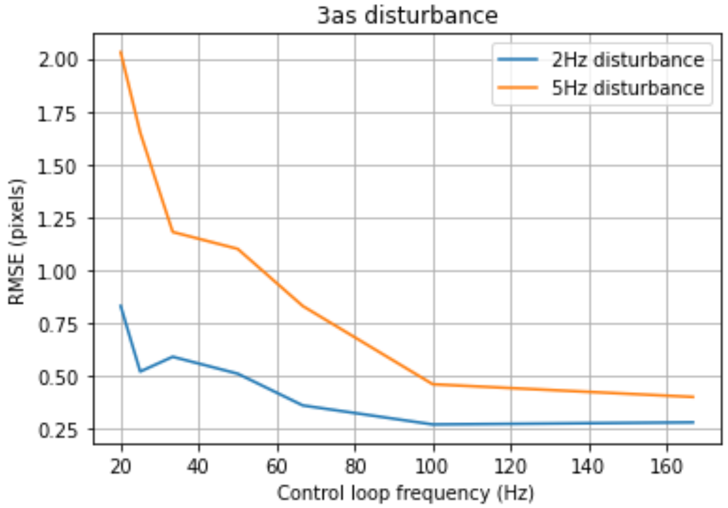

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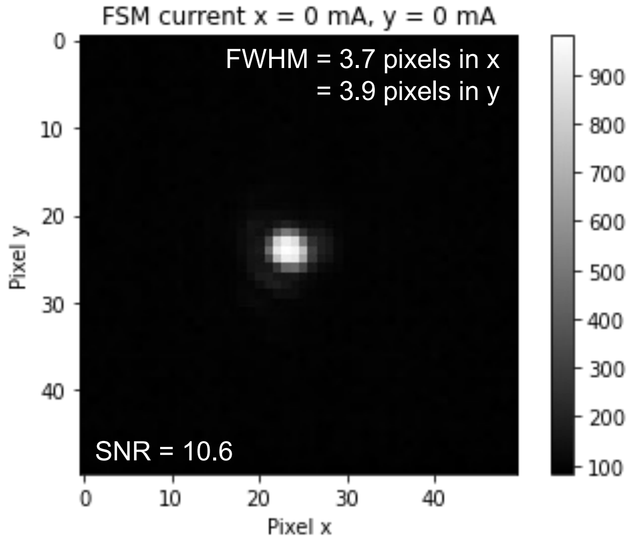
3	The control system shall stabilise optical perturbations of 3 arc seconds at frequencies of up to 5 Hz to within 0.5 pixels rms.	Test	Compliant
4	The control system shall operate at a spot signal-to-noise ratio of 10 or higher.	Test	Compliant



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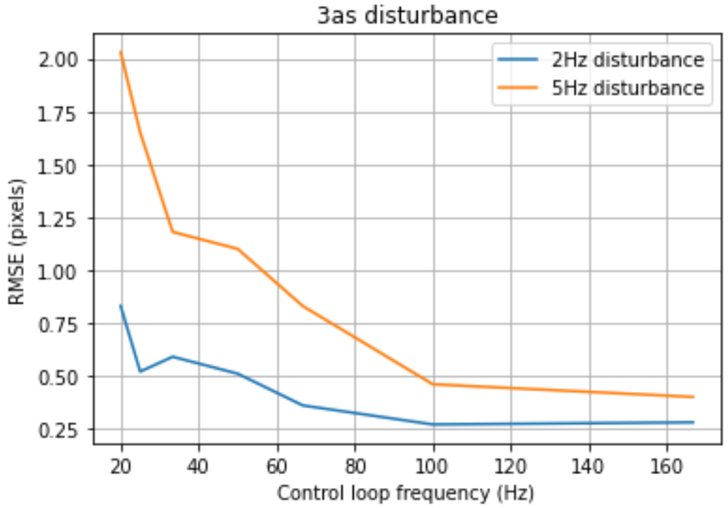

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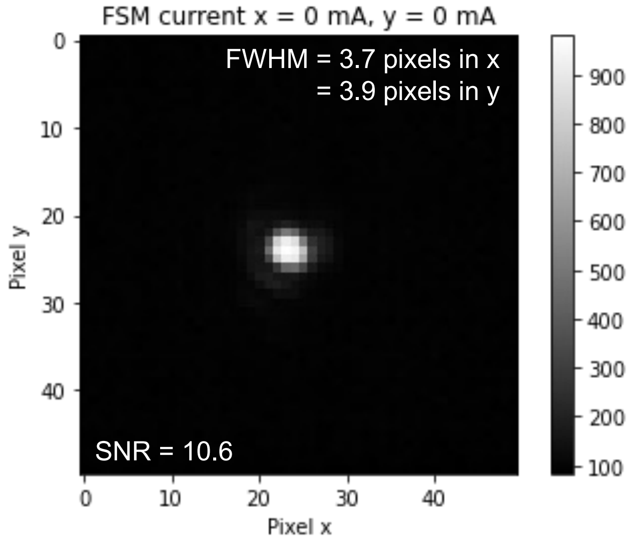
4	The control system shall operate at a spot signal-to-noise ratio of 10 or higher.	Test	Compliant
5	The active alignment system shall meet the dynamic performance requirements (3 & 4) within a vacuum environment.	Test	Compliant



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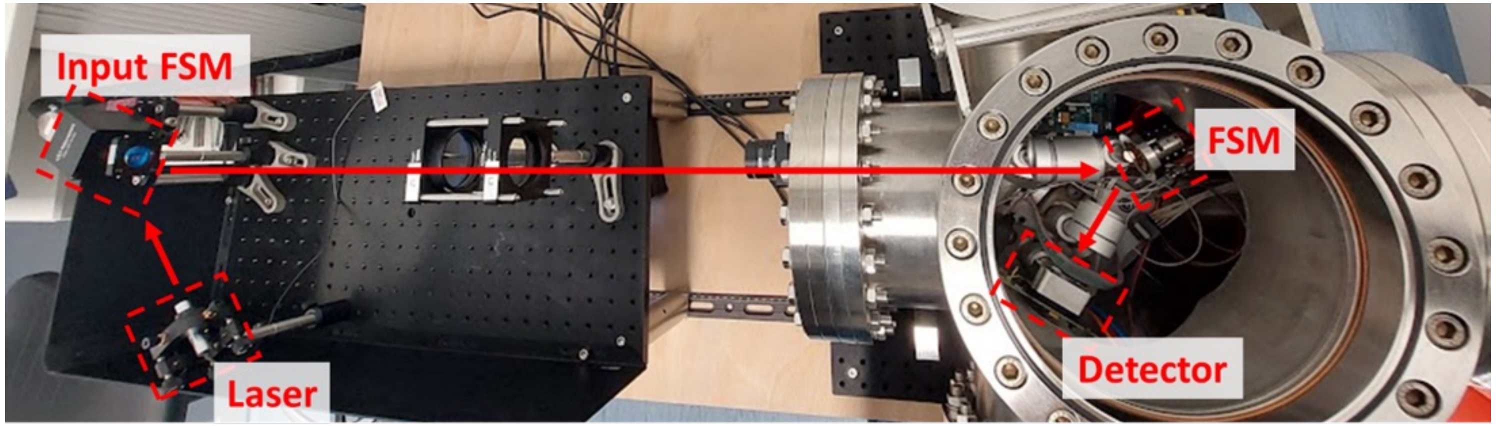

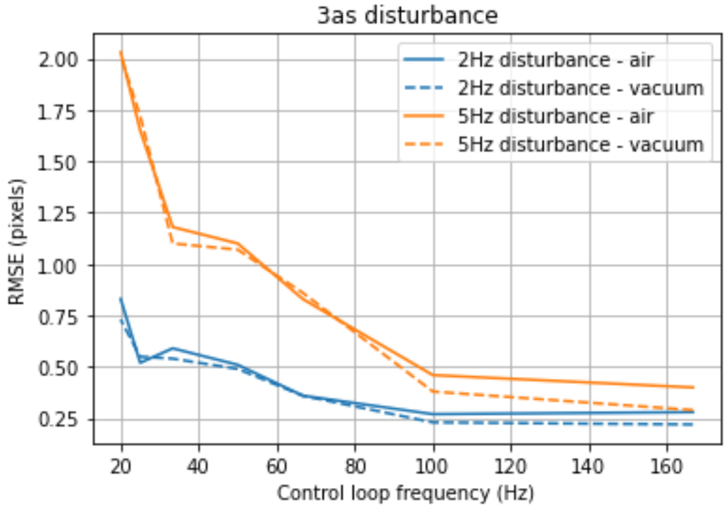

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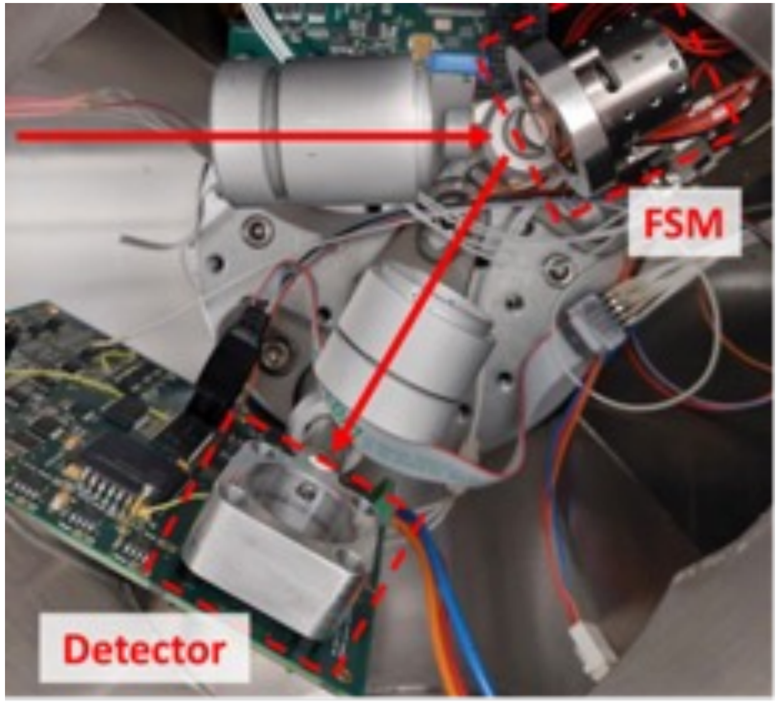
Project achievements

- Designed and assembled the proposed active alignment system
- The system is compliant with all project requirements
    - Can control for the kind of disturbances expected in the optical comms application
    - System performs well in vacuum environment
- TRL level raised from 3 to 5



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Future work

- Explore opportunities to increase loop speed
  - Perform more of the spot processing on the FPGA
  - More powerful PFGA and processor
  - Alternative image readout methods
- Future commercial applications
  - Develop active alignment system into commercial or customisable unit as part of full satellite optical alignment system
  - Extend wavelength range
  - Integrate ground hardware system
  - Extend pointing capability with gimballed mount
  - Large scale manufacture would be challenging

Deliverables (1)

Type	Ref. No.	Name/Title	Description	Replacement Value (EUR)/ Other	Location (1)	Property of	Rights granted/ Specific IPR Conditions (2)
Documentation	D1	Milestone Test Report 1	Report on activities undertaken in WP1	N/A	Supplied to ESA	ESA	None
Documentation	D2	Milestone Test Report 2	Report on activities undertaken in WP 2 and WP3	N/A	Supplied to ESA	ESA	None
Documentation	D3	Milestone Test Report 3	Report on activities undertaken in WP 4	N/A	Supplied to ESA	ESA	None
Documentation	D4	Technical Data Package	Complete description of all the data compiled during the project	N/A	Supplied to ESA	ESA	All rights to the data granted to ESA
Documentation	D5	Executive Summary Report	Summary of all activities in the project for a non-technical audience	N/A	Supplied to ESA	ESA	
Documentation	D6	Final Report	Accumulation of the Milestone Reports and the Final WP	N/A	Supplied to ESA	ESA	
Documentation	D7	Contract Closure Documentation	Closure Pack	N/A	Supplied to ESA	ESA	

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Deliverables (2)

Type	Ref. No.	Name/Title	Description	Replacement Value (EUR)/ Other	Location (1)	Property of	Rights granted/ Specific IPR Conditions (2)
Hardware	HW1	Fine Steering Mirror (FSM)	Software Controlled Mirror	£30,000	RAL SPACE *	ESA	N/A
Hardware	HW2	FSM Drive Electronics Breadboard	Custom designed and built electronics assembly	£10,000	RAL SPACE *	ESA	N/A
Hardware	HW3	Detector Electronics Breadboard	Custom designed and built electronics assembly	£10,000	RAL SPACE *	ESA	N/A

❖ With ESA Permission

Closure

- *RAL SPACE request closure of the contract and approval of MS3*