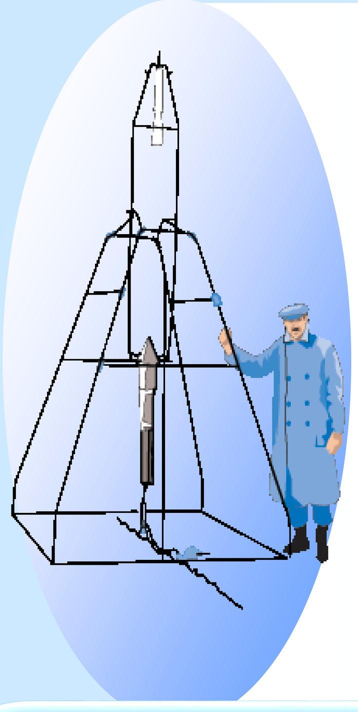
PI: Dr. Anne-Marie Novo-Gradac, 671

Starting TRL: 4 , Ending TRL: 4 .



High Precision Relative Position Sensing System for Formation Flying Spacecraft

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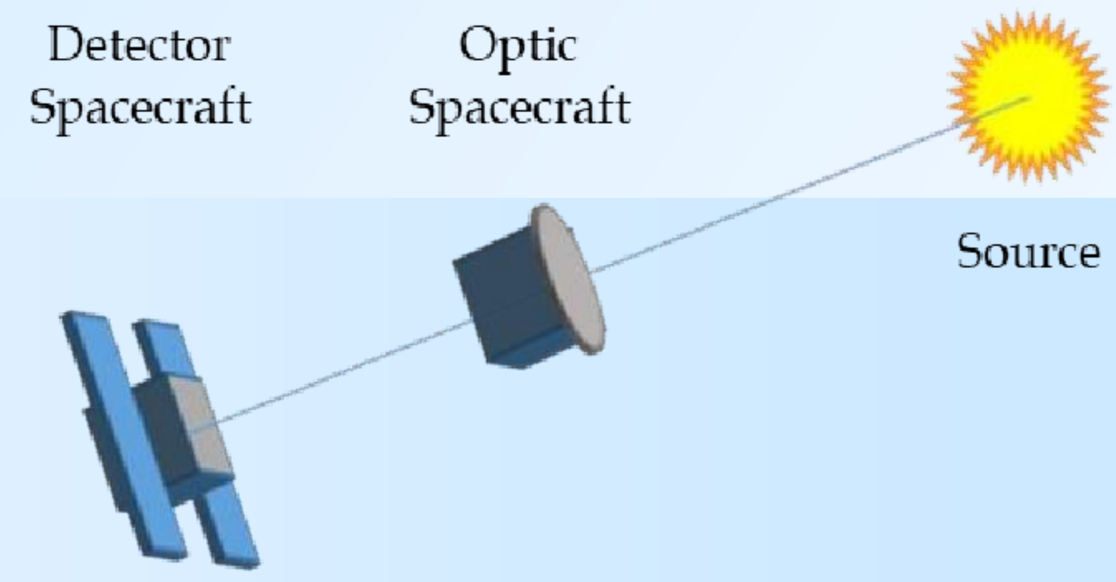
Summer Interns: Sam Kowing & Jon Hille

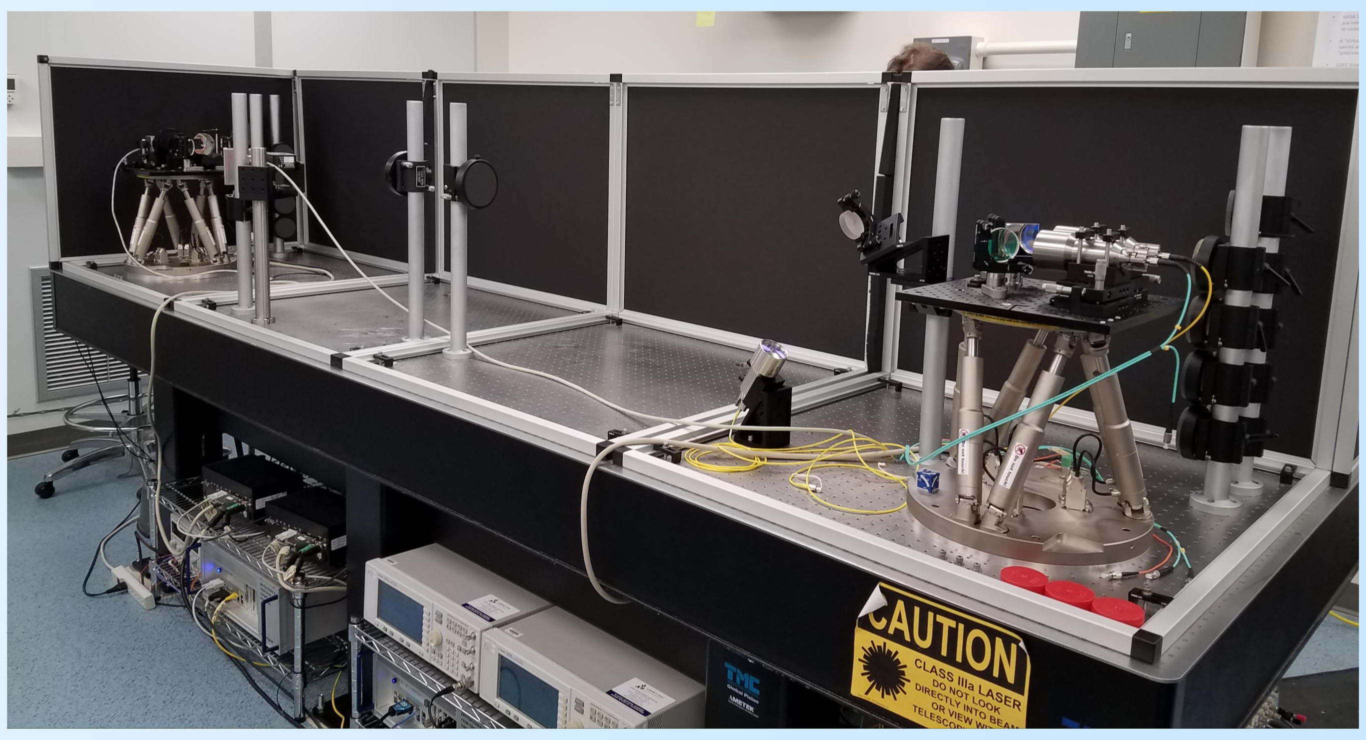
Motivation/Problem Statement:

- *Our goal is to develop laser based relative position sensors that will enable two spacecraft to maintain a high precision formation. Data from these sensors will be used to command low force thrusters.*
- *High precision sensing will enable long focal length telescopes where the focusing optic and imaging camera are carried on separate spacecraft.*
- *Spacecraft separation = telescope focal length:*
  - *Longitudinal alignment goal = 100m $\pm$ 1mm*
- *Must avoid image smear/jitter on detector:*
  - *Transverse alignment $\pm$ 1 camera pixel ~$\pm$100 microns*

Project Summary: Three candidate sensors under development

- *Longitudinal Sensing: Precision Laser Ranger (PLR)*
  - *Periodic laser pulses are reflected off a distant target.*
  - *Heterodyne analysis of returning pulses enables high resolution ranging..*
- *Transverse Sensing = Transverse Alignment Sensor (TAS)*
  - *Laser beam is focused onto distant laser position sensor.*
  - *Analog sensor provides coordinates of spot on sensor..*
- *3D PLR: Alternative approach to transverse sensing:*
  - *Combine PLR with 3D target covered with retroreflective material.*
  - *6 degree of freedom sensing using PLR.*
  - *May eliminate need for TAS.*

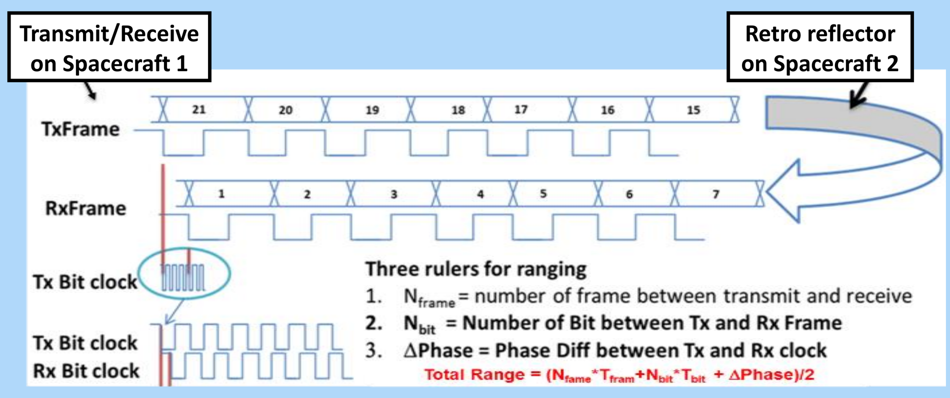




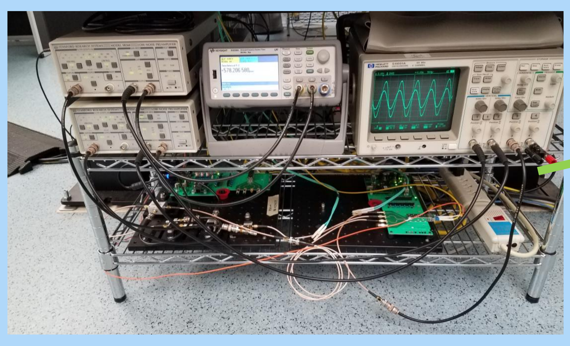
Precision Formation Flying Testbed: Two separate spacecraft simulated by hexapod platforms while a series of 20 mirrors can produce up to a 100m optical separation.

Precision Laser Ranger (PLR):

- *Underlying Principle of Operation*
  - *Instead of transmitting a single pulse and measuring time of flight of that pulse, a series of data packets is transmitted. Each packet has an index number and then a series of identical bits*
    - *Course sensing: Comparing index number on transmit and receive packets*
    - *Medium sensing: Count bits inside packet*
    - *Fine sensing: Heterodyne phase analysis of individual bit*



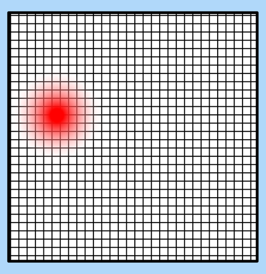
- *Lab unit: Telecom transceiver transmits 1550nm laser pulses through free space. Reflected pulses directed into receiver telescope and delivered to receiver electronics. Lab instrumentation provides raw data which is analyzed later in spreadsheet.*
- *Previous results: Lab system demonstrated 23 micron range resolution at 150m distance.*
- *Near term goal: Transition PLR from lab based analog system to software version which can be loaded onto field programmable gate array (FPGA) and provide real time results.*



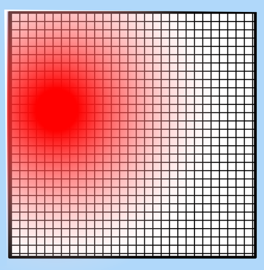
- *FY23 progress:*
  - *Completed programming of Matlab version of ranger, which has demonstrated real time 1cm range resolution using simulated input data.*
  - *Range resolution limited to 1cm due to communication/calculation latency issues between FPGA and controller software.*
- *Next Steps:*
  - *Finish hardware interface software such that software drives laser transmitter, receives data from optical receiver, and analyzes real data.*
  - *Investigate trades between range precision and computation time to improve range resolution*

Transverse Alignment Sensor (TAS):

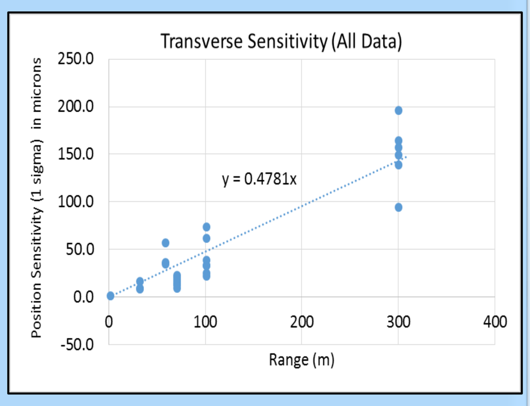
- *Underlying Principle of Operation*
  - *A continuous wave (CW) laser beam is transmitted from one spacecraft toward a lateral effect position sensor mounted on the second spacecraft. A telescope is used to focus the laser to a small spot on the detector.*
  - *Lateral effect sensors provide the (x,y) coordinate of the beam centroid.*
  - *Resolution is dependent on the size of the diffraction limited spot size. If the laser spot overfills the sensor, resolution is substantially degraded.*

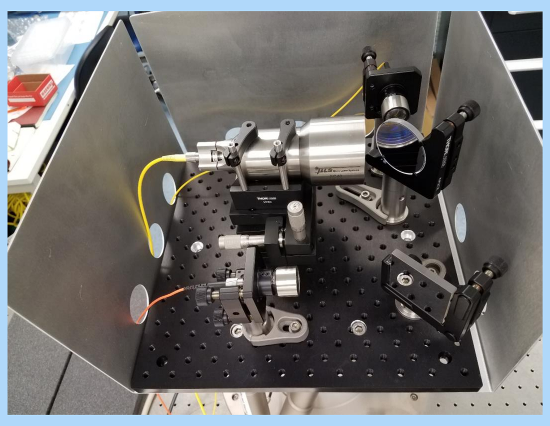


Small spot on detector

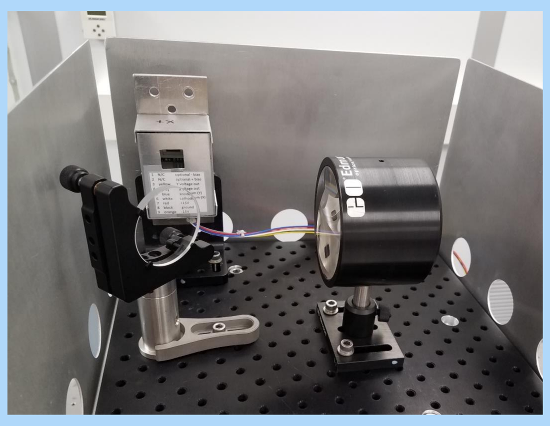


Large spot on detector





TAS & PLR Transmitters, PLR Receiver

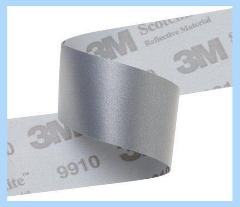


TAS Sensor & PLR Retro

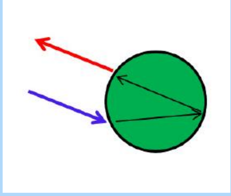
- *Previous results:*
  - *Demonstrated 150 micron resolution at 150m.*
  - *Sensitivity is dependent on spot size, which means diffraction limit of transmit telescope drives resolution.*
  - *Single sensor can not discern transverse relative motion from pitch/yaw motion. Second sensor pair operating in opposite direction will be required.*
- *FY23 Progress:*
  - *Preliminary set-up for two-unit system installed in testbed.*
  - *Updated computer interface for sensor*
- *Next Steps:*
  - *Conduct performance testing of 2-unit system*
  - *Develop flight-like packaging*

3DPLR

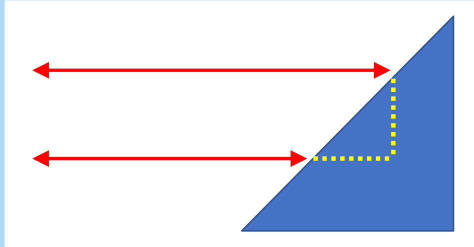
- *Underlying Principle of Operation*
  - *PLR is combined with a retroreflective material mounted on a 45° angled reflector. The retroreflective material has millions of small glass beads imbedded in it, each functioning as a cats-eye retroreflector. If the target displaces transverse to the line of sight, the laser spot will ascend or descend the 45° surface. A set of six rangers pinging a 6-sided pyramid target would provide all six degrees of freedom in relative position.*



Retro-reflective Tape



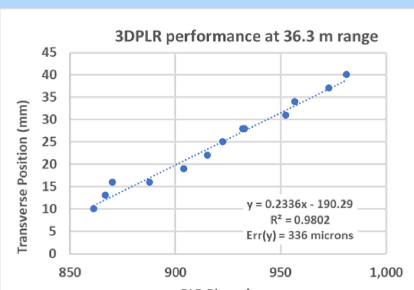
Spherical Retroreflector



Ranger can be used to measure transverse offset by applying retroreflective surface to 45° angle target. Change in transverse position produces change in range.

- *Using the ranger for transverse measurements is attractive because the PLR has finer resolution than the TAS and will likely be scalable to greater distances because spot size will be less of an issue.*
- *Previous results*
  - *In FY22 we conducted an initial proof of concept at 0.3m range and obtained 0.7mm resoltuion.*
- *FY23 progress:*
  - *Completed longer range testing of 3DPLR and achieved sub-mm resolution.*
  - *Light returning from target is diverging. As range distance increases, amount of light collected into receiver declines. We must increase the signal to noise ratio to extend range further and improve resolution.*

Range distance (m)	Measured Transverse resolution (microns)	Solid angle subtended by receiver telescope (nanosteridians)
9.9	123	1400
23.1	142	260
36.3	336	100



Example of 3DPLR data set

- *Next Steps:*
  - *Improve signal to noise ratio by implementing a low-noise detector and improving efficiency of receiver telescope.*
  - *Conduct longer range testing*
  - *Implement multiple channels simultaneously to advance toward goal of 6 simultaneous channels.*

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Future Funding & Applications

- *We intend to submit an H-Fort proposal in FY24*
- *This sensor suite is a key enabling technology for several Heliophysics mission concepts, including the Coronal Microscale Observer (CMO).*