


Rigorous propagation and convolution of physically-based error sources for LiDAR sensors

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- For P3DL
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US Army Corps of Engineers

ERDC ENGINEER RESEARCH & DEVELOPMENT CENTER

DISCOVER | DEVELOP | DELIVER

Overview

- Problem
- Introduction
- LiDAR Hardware Model
- LiDAR Error Sources
- Results
- Conclusion

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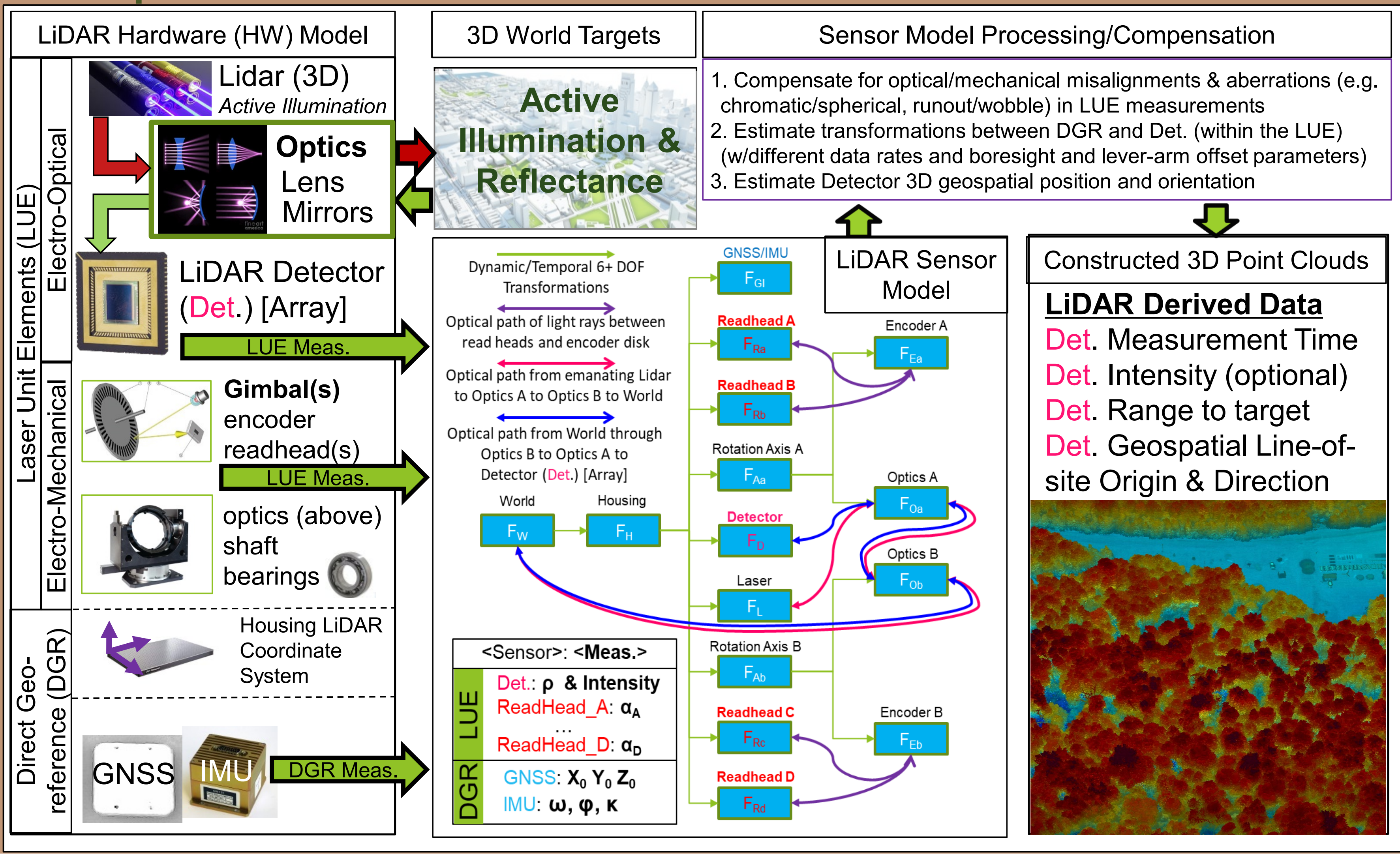
Problem: How do we discover physical sources of mechanical and optical aberrations, misalignments, and measurement timing errors on 3D point clouds constructed from LiDAR measurement data?



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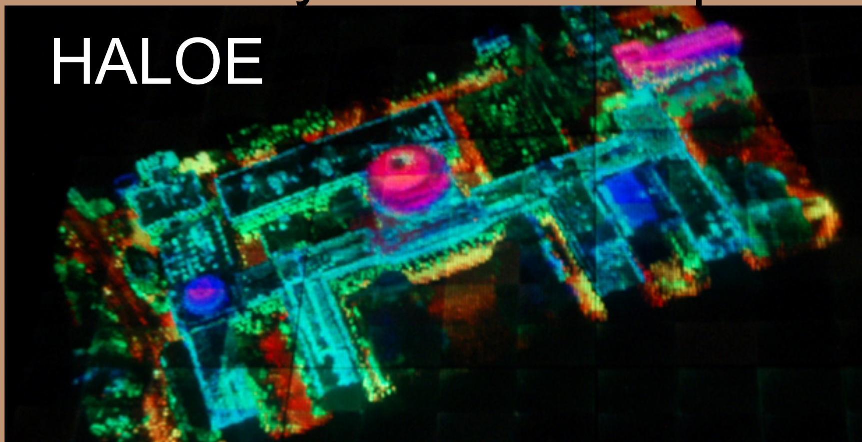
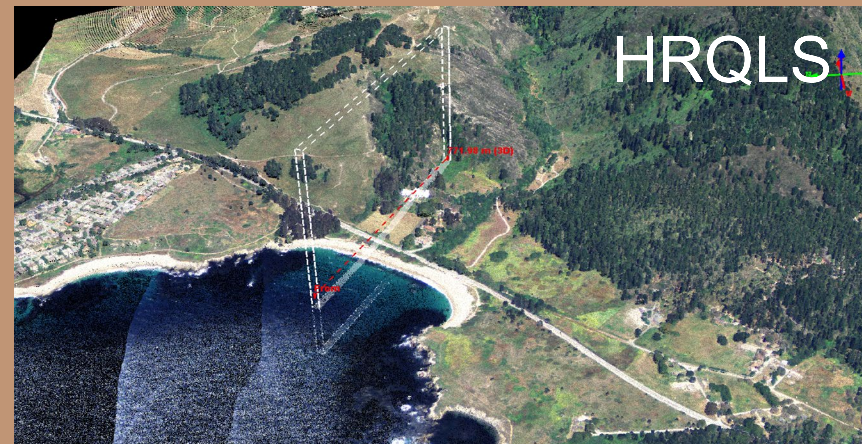
Calibration of high altitude LiDAR sensors can be challenging and expensive

Initially constructed point clouds have distortions/biases



https://www.darpa.mil/about-us/timeline/lidar

System-driven calibration
Non-physical empirical models
Data-driven calibration



http://www.sigmaspace.com/blog-post/sigmas-hrqls-lidar-highlighted-laser-focus-world-top-product-2014

System-driven calibration
Non-physical empirical models

New calibrations applied post-deployment
Expensive/time-consuming studies to develop empirical models
Data-driven calibration remains expensive/time-consuming
Neither system has fully identified physical sources of distortion/bias errors

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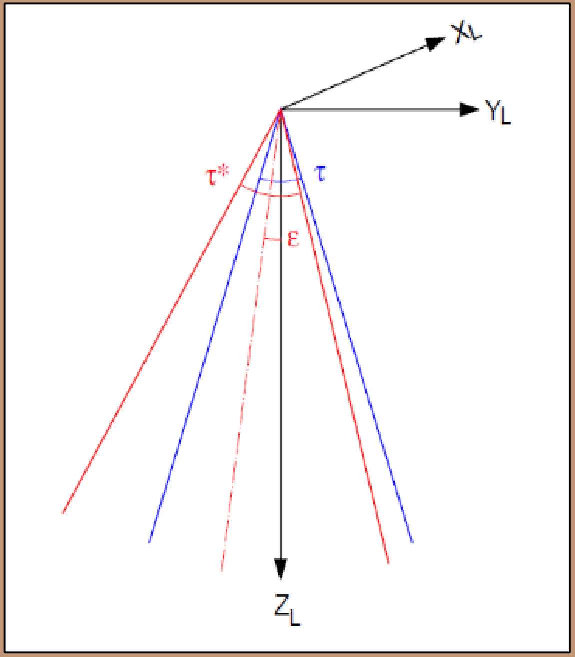
System compensation parameters for LiDAR scan angle errors may not directly relate to physical errors

T. Schenk, "Modelling and analyzing systematic errors in airborne laser scanners," *Technical Notes in Photogrammetry,* vol. 19, 2001.



$$\tau_i^\star = \frac{\tau + \Delta\tau}{2} - i\frac{\tau + \Delta\tau}{n-1} + \epsilon$$

$$\Delta\tau_i = \tau_i^\star - \tau = \epsilon + \frac{\Delta\tau}{2} - \frac{\Delta\tau}{n-1}i$$

Uncompensated total scanner angle range τ

Compensated total scanner angle range τ*

Scale of total angle error $\Delta\tau$ is scaled linearly with distance from ϵ

$\beta_C(t) = \beta_M(t)\ S_\beta$

$\alpha_C(t) = \alpha_M(t)\ S_\alpha$

M: measured
C: compensated
S_β, S_α : Scan angle scale factors

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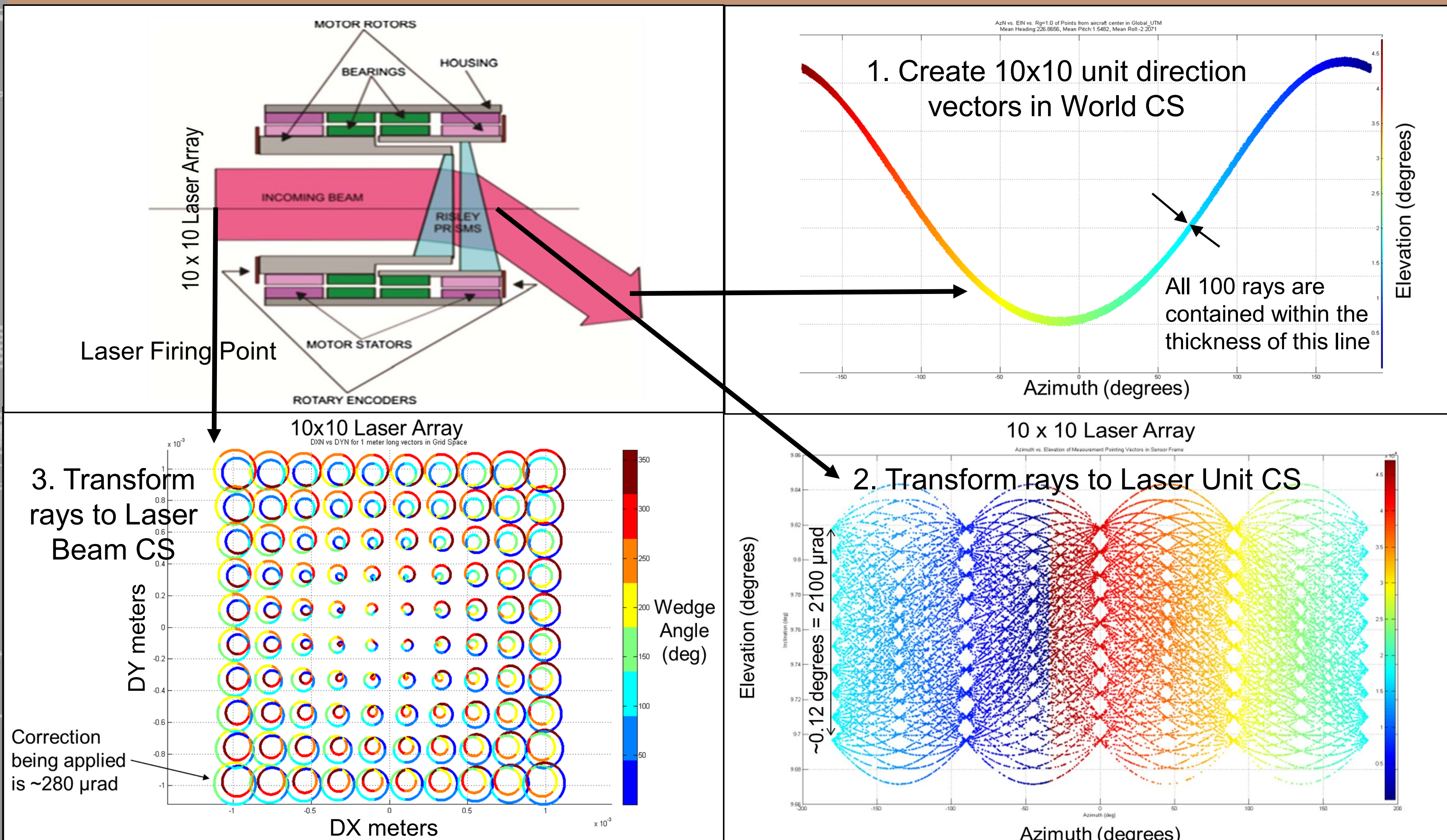
Genesis for the research – trying to identify the Risley Prisms world orientation (and surprise correction found)



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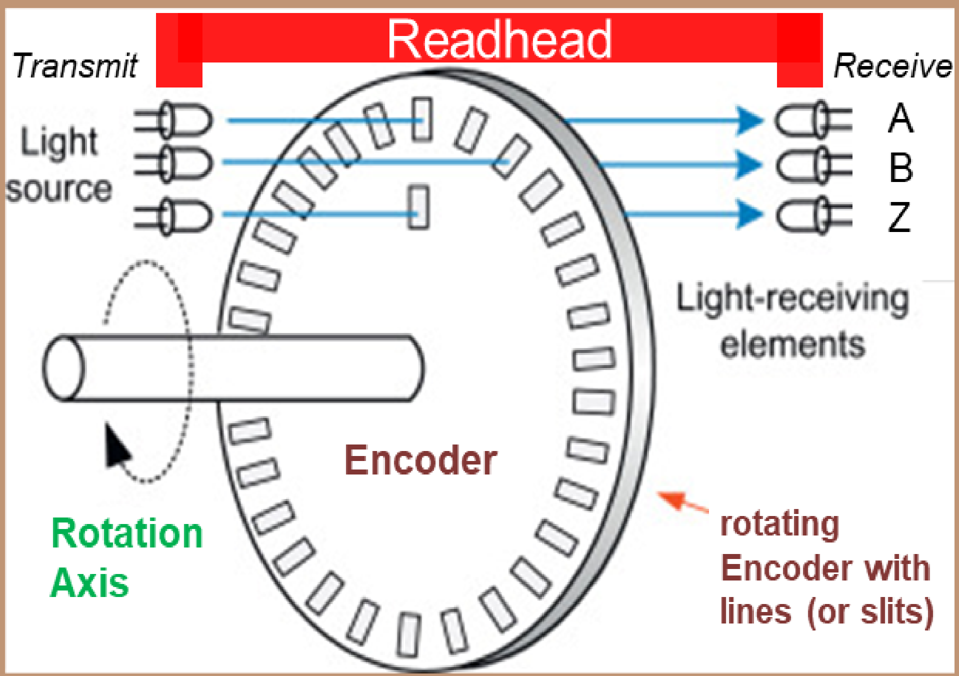
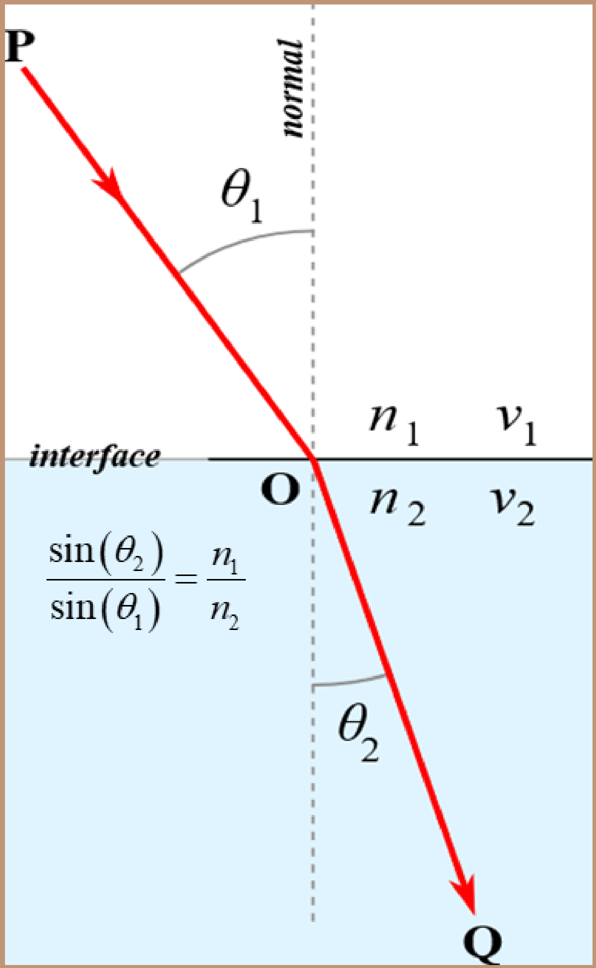
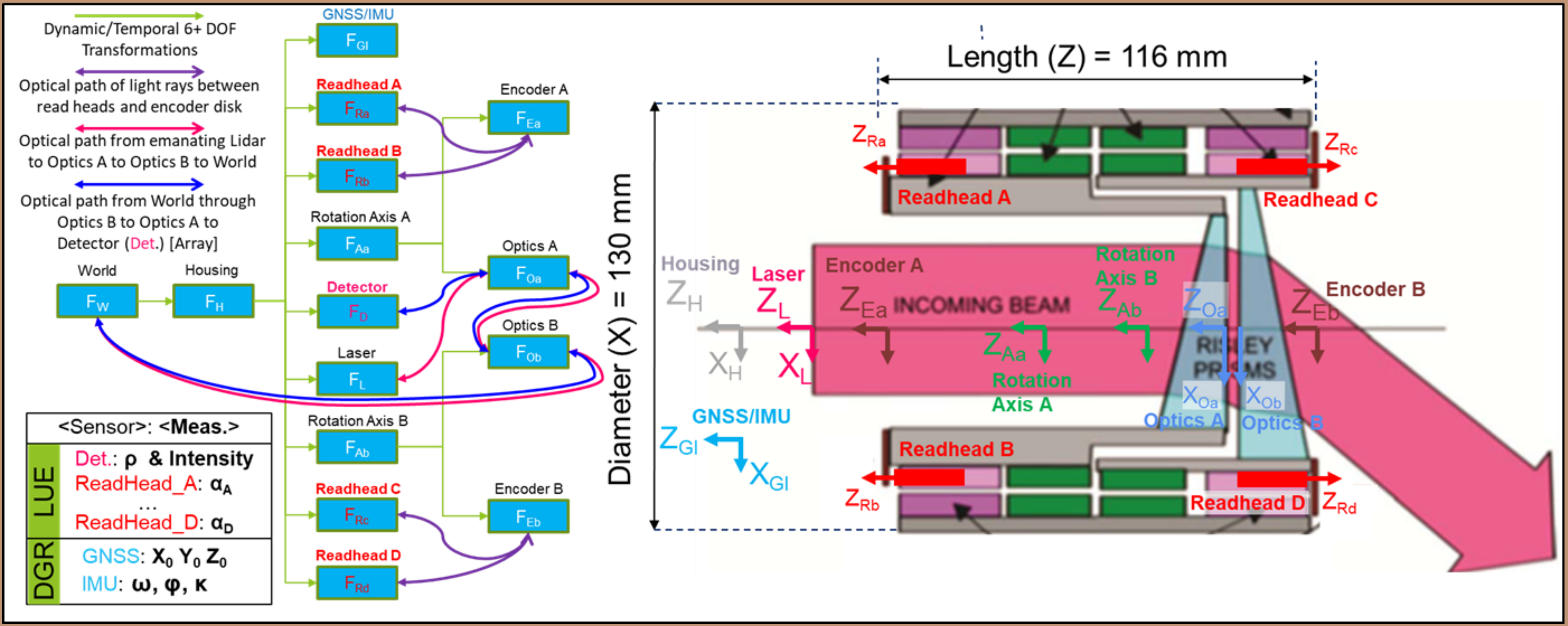
Ray tracing can be used to determine readhead/encoder measurements and application of Snell's law (prisms)





Proposed transformation origins, orientations, and child/parent links between different hardware components



13 of 15 child/parent transformation links are gimbal based

Rotation Axes A & B transformations propagate to position/orientation of encoders and optics

Ray tracing convolves all errors into angle measurements and laser/detector line-of-site

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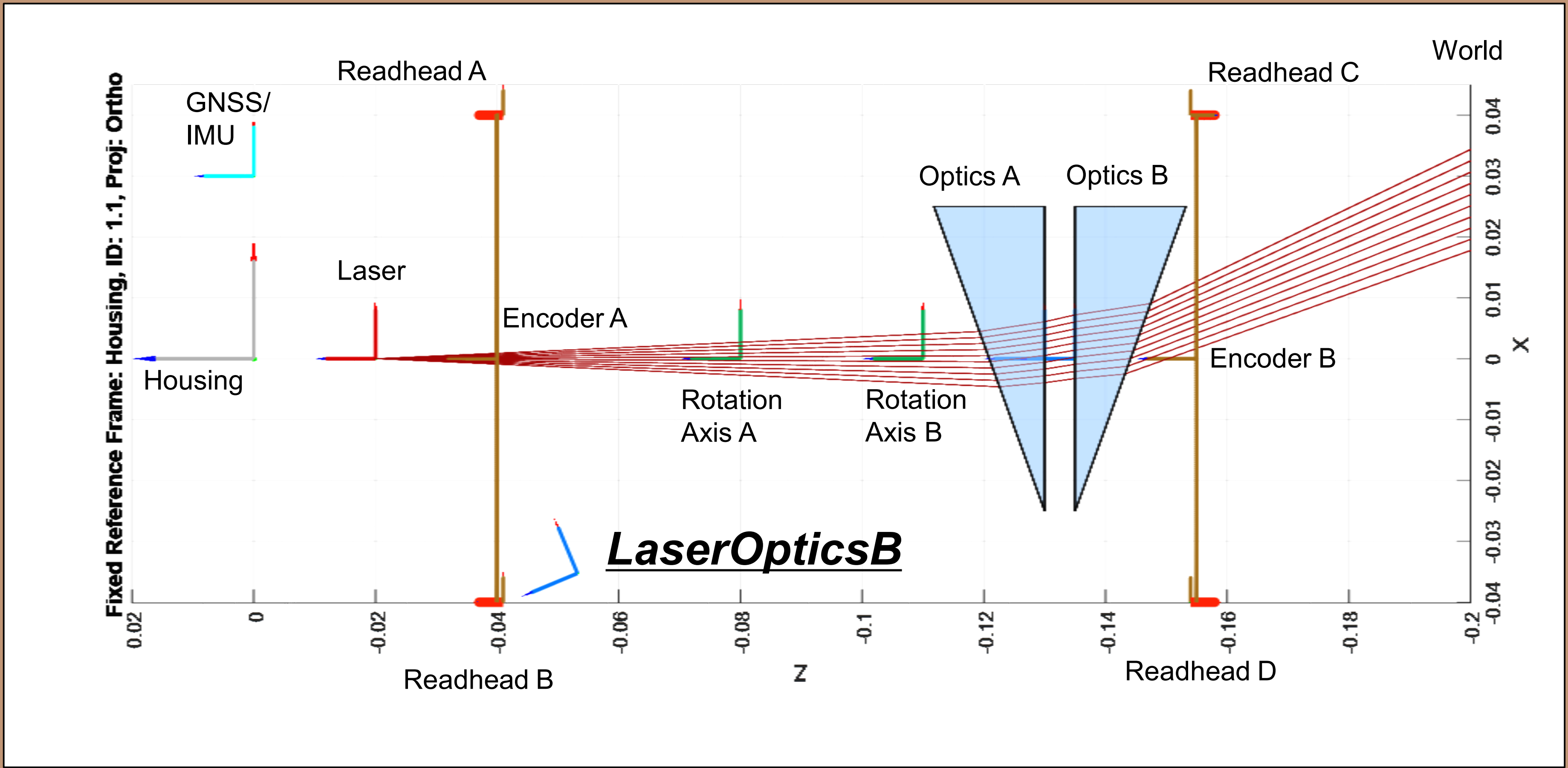
Additional reference frames defined by laser light as it interacts with optical elements (using Snell's law)



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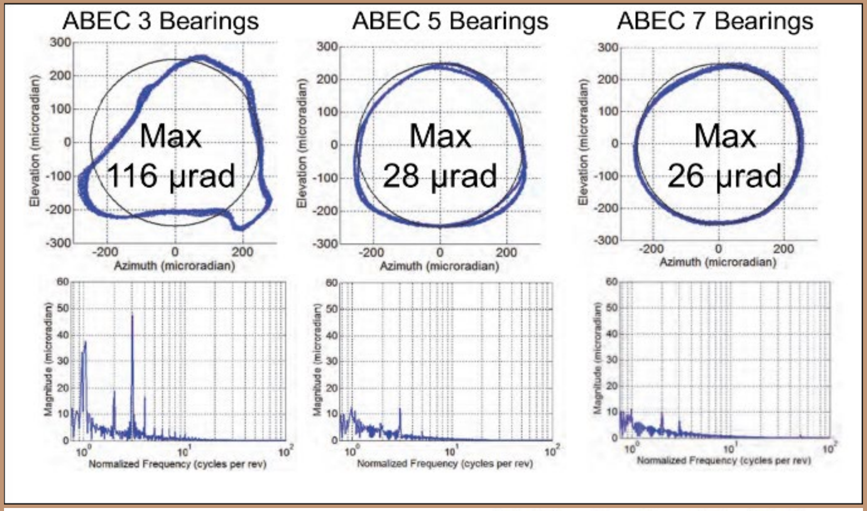
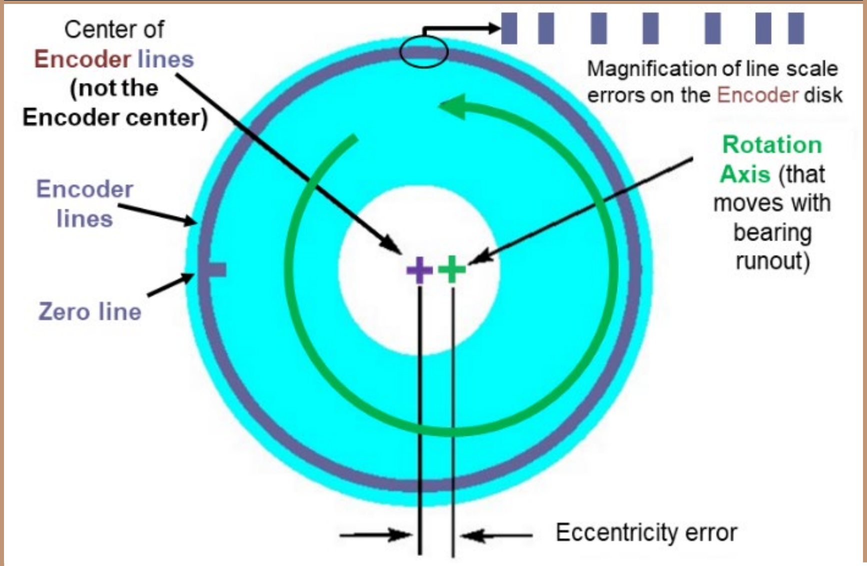
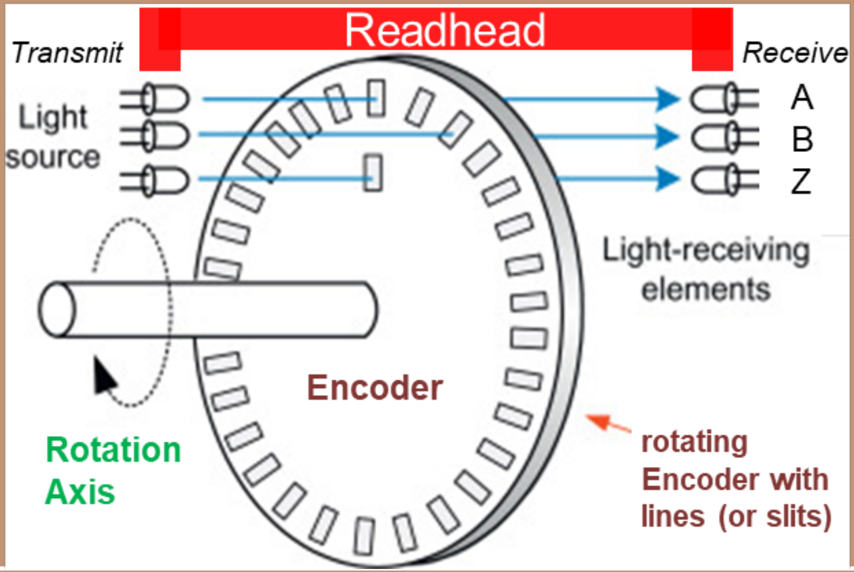
The hardware error sources that we account for in model

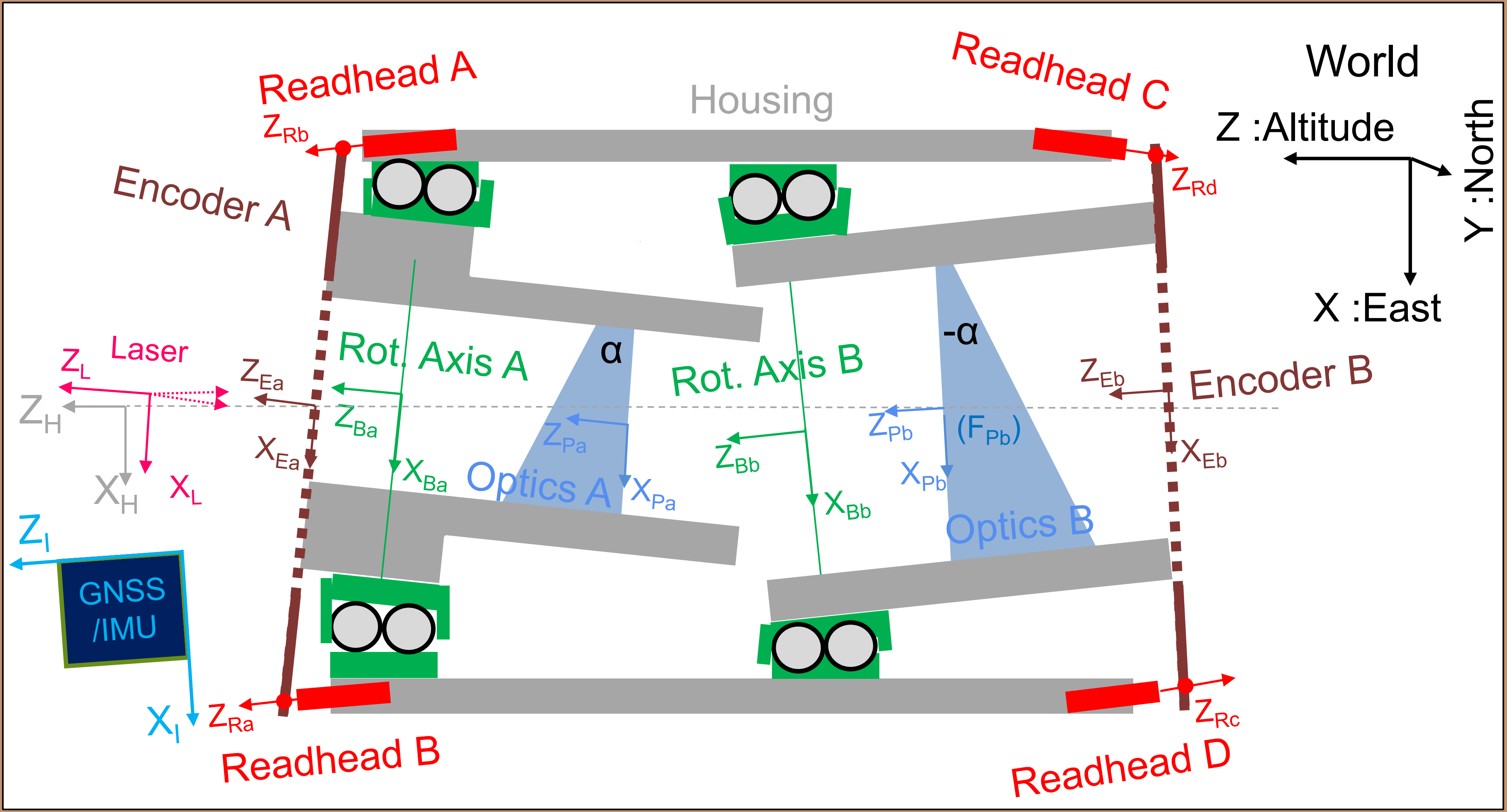


Rotation Axis: bearing runout -> radial & axial runout
Encoder: eccentricity, swash, line scale errors
Readhead: clock timing bias, parallax
Optics: n1,n2 index of refraction, wedge angle
Laser/Detector: clock timing bias





All components can have misalignments in position and orientation



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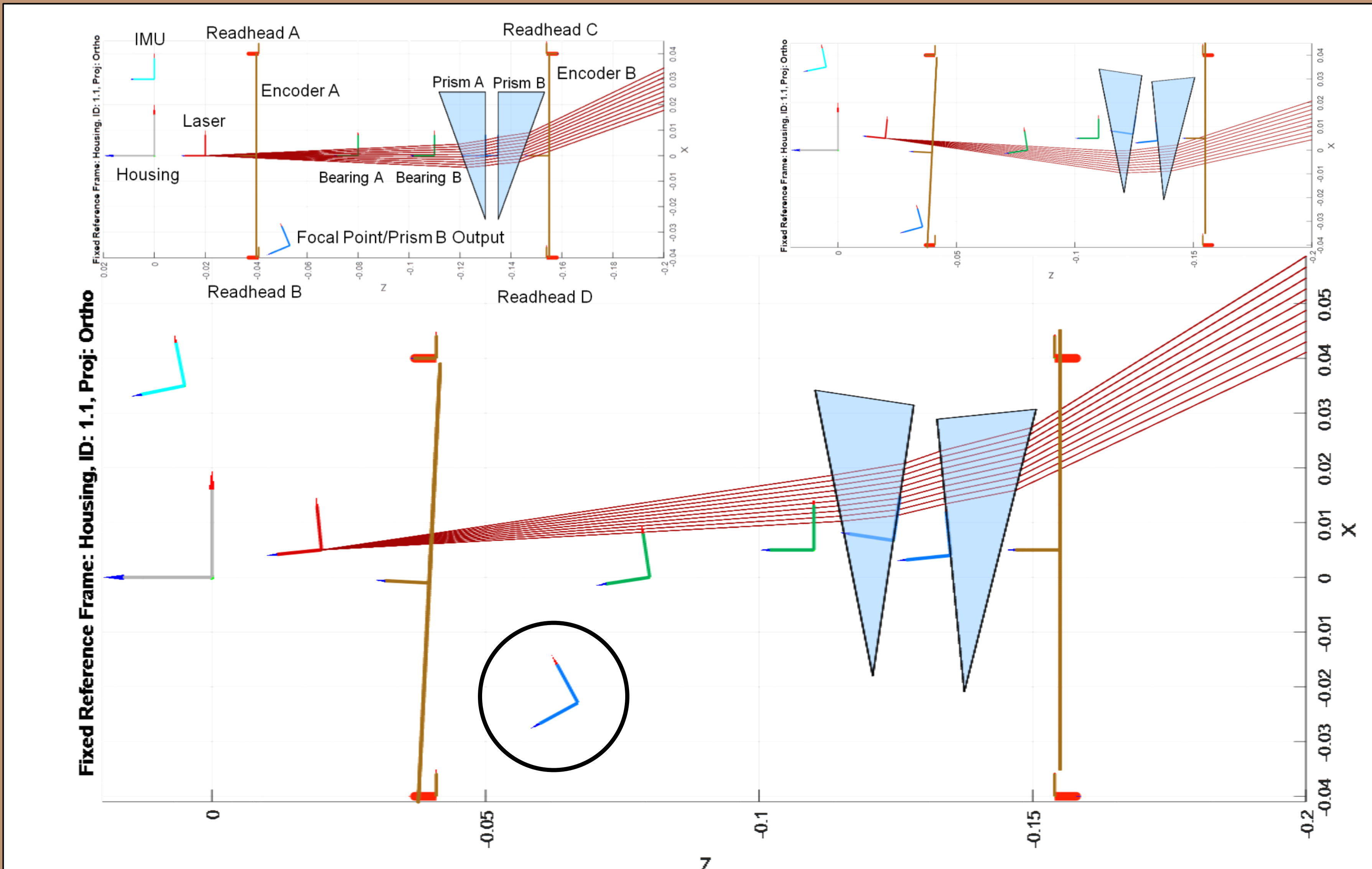
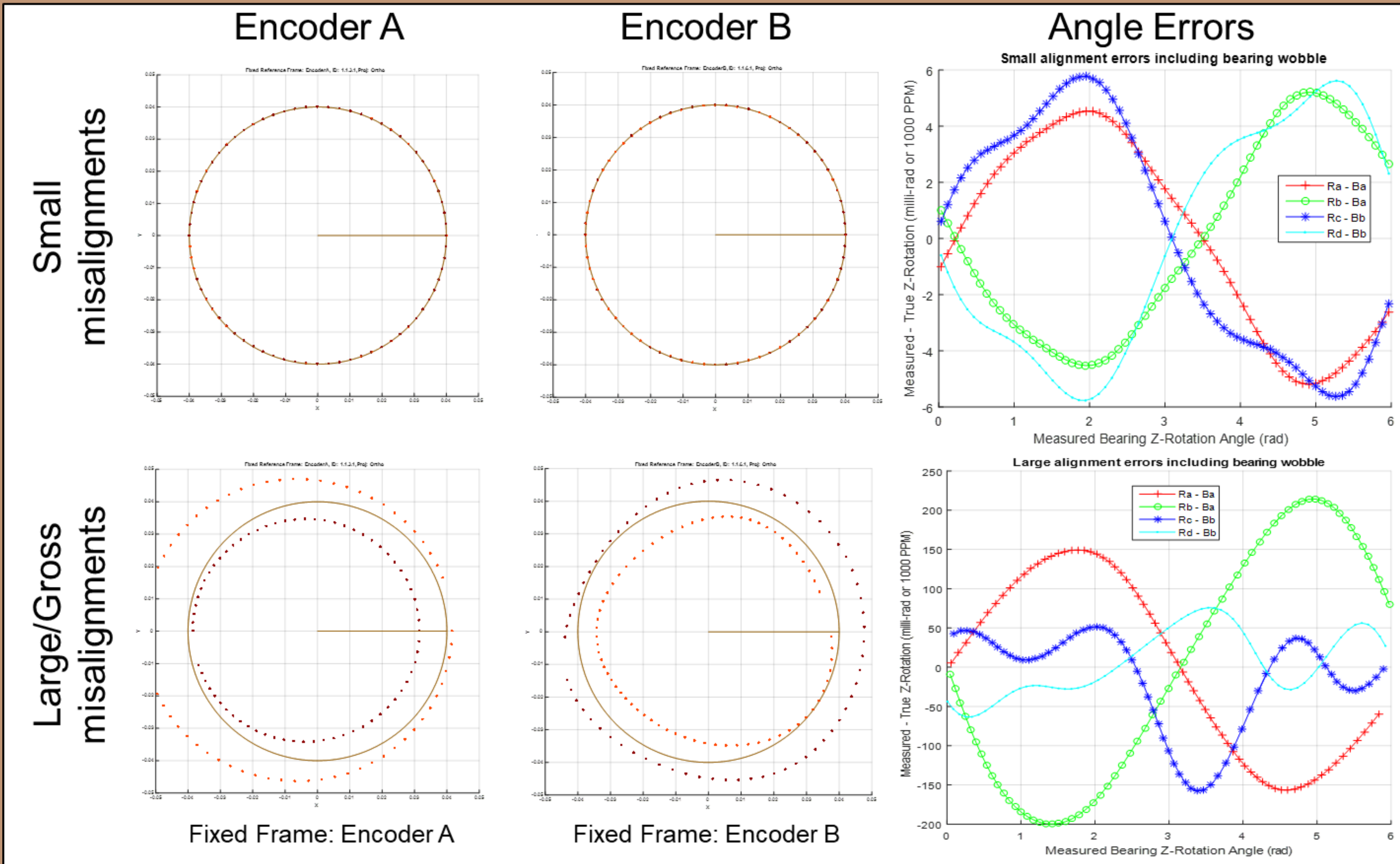
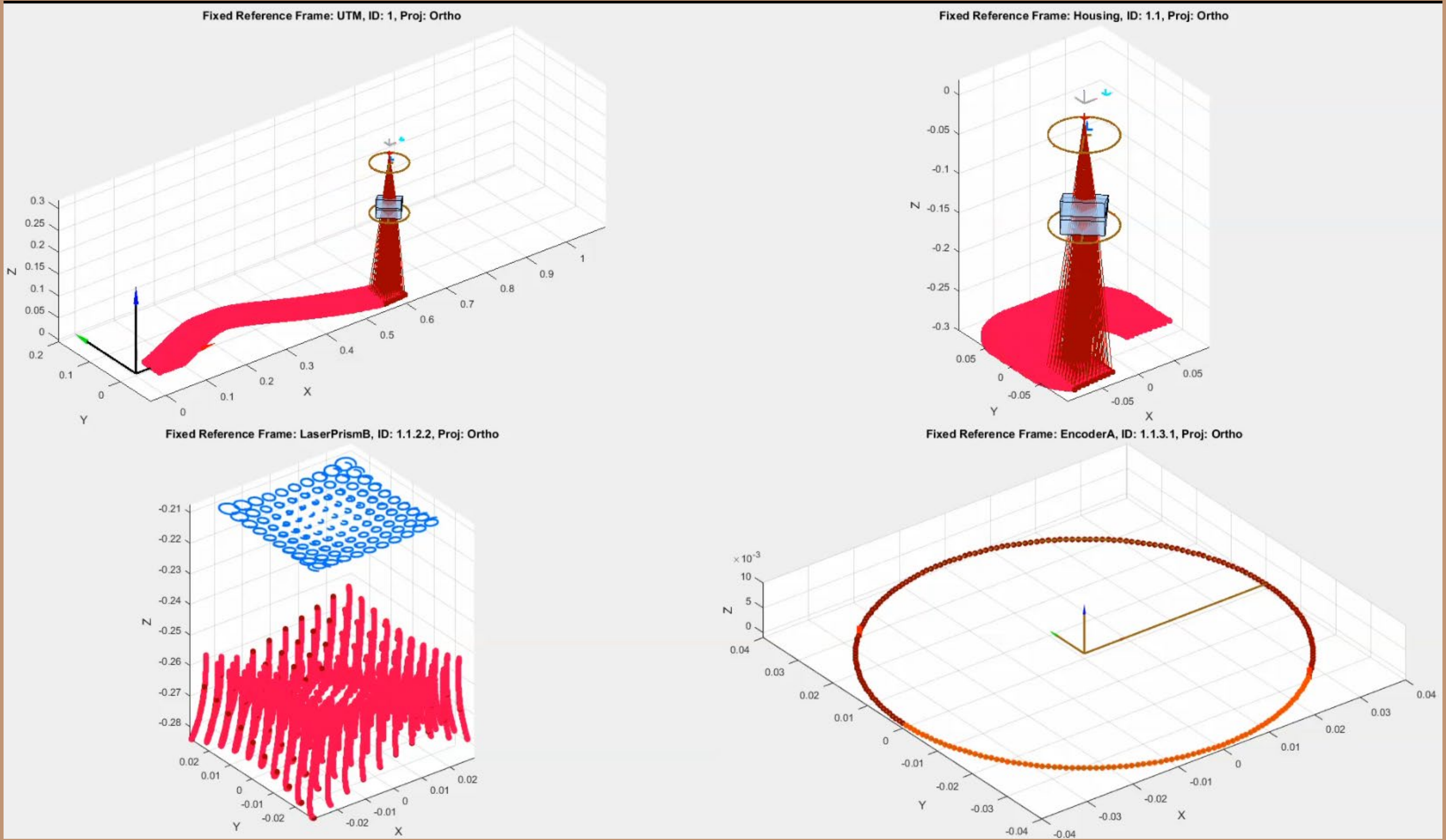
Simulated misalignments and effect (using Snell's law)



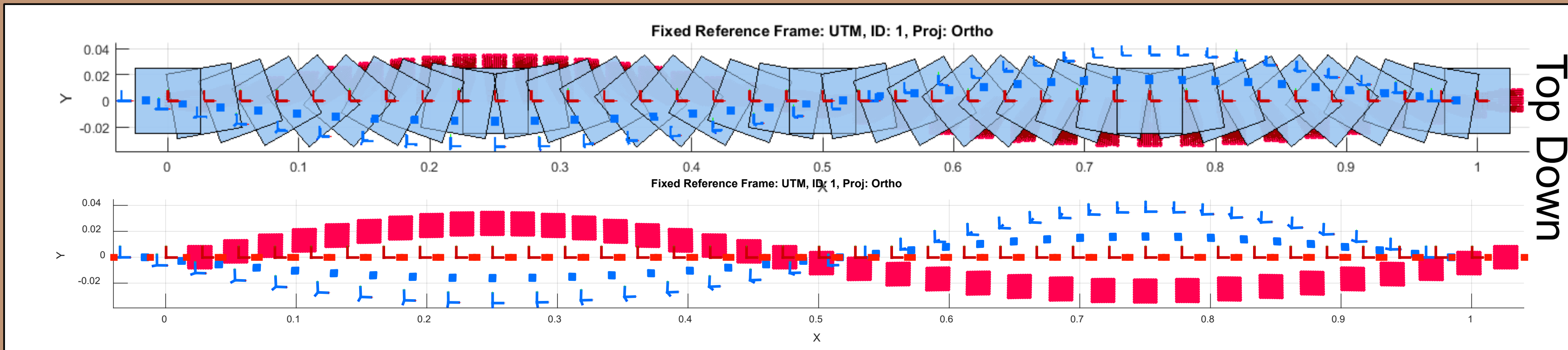
Simulated misalignments on readhead/encoder angles

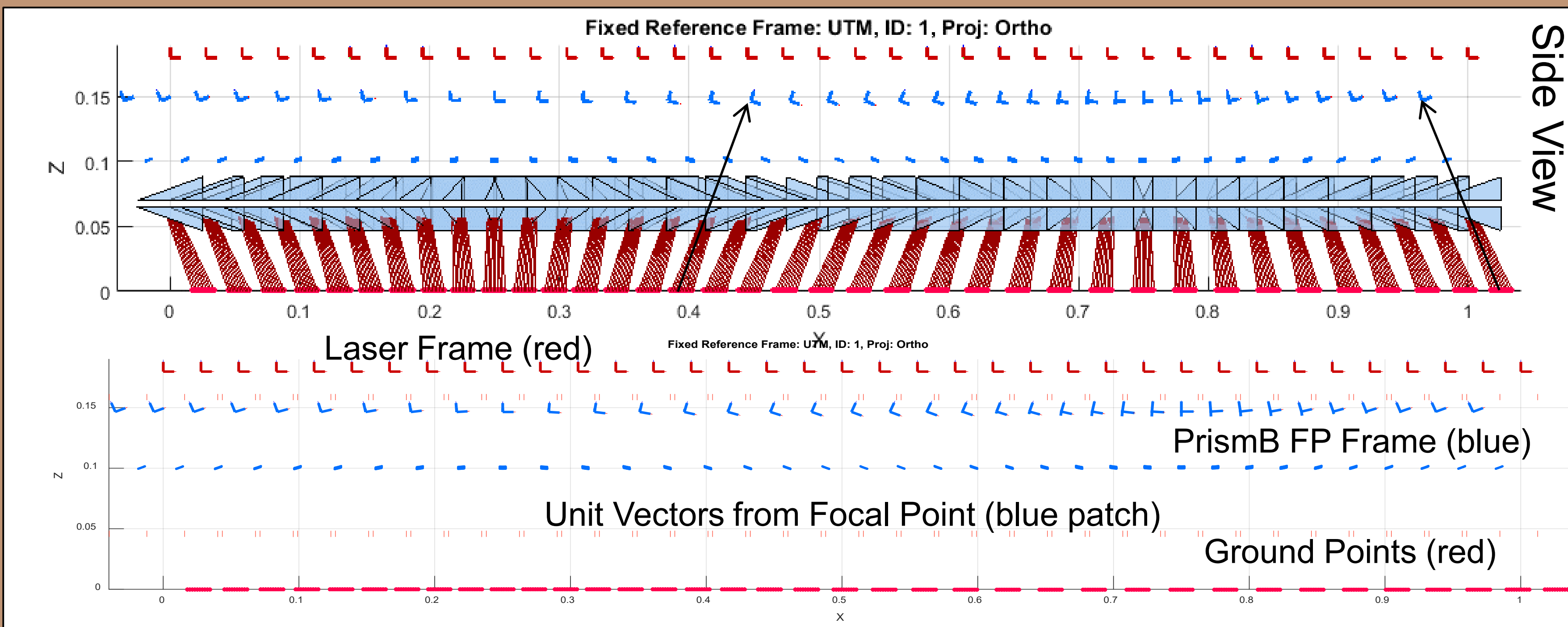


Static visualization of Risley Prism in operation

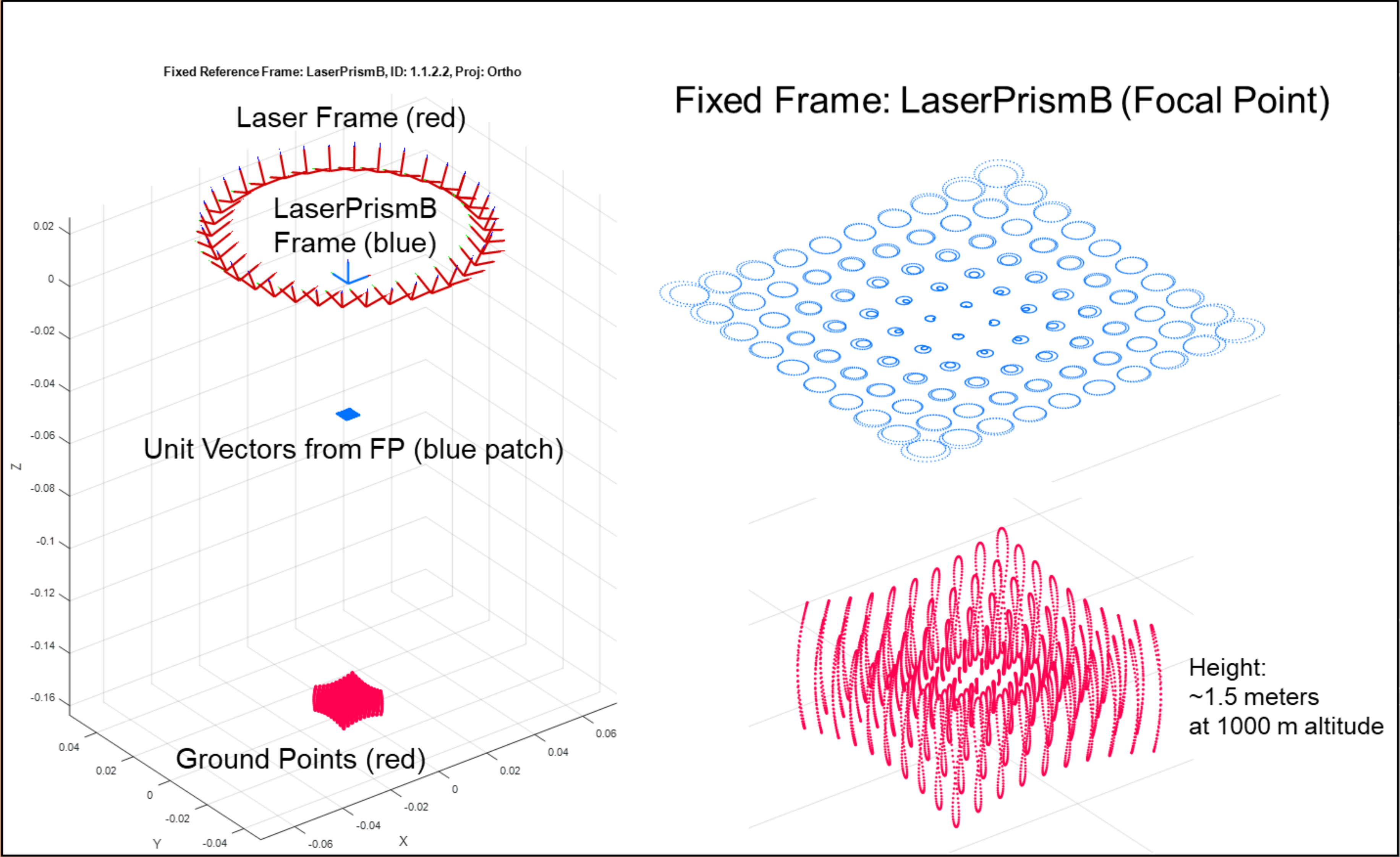


Removal of Prisms and Ray Traces (no misalignments)

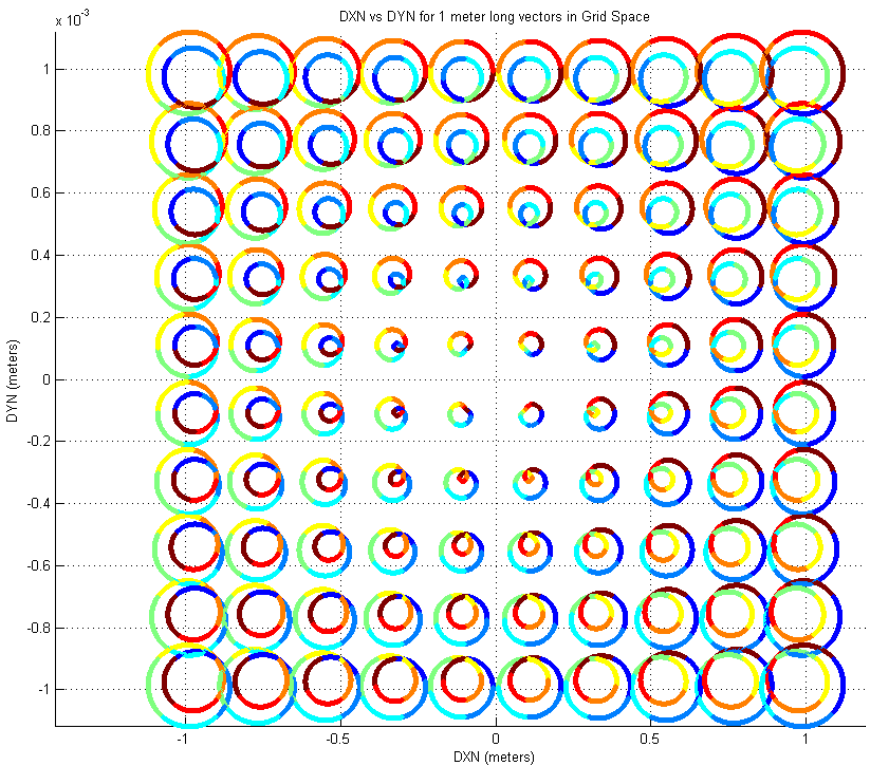




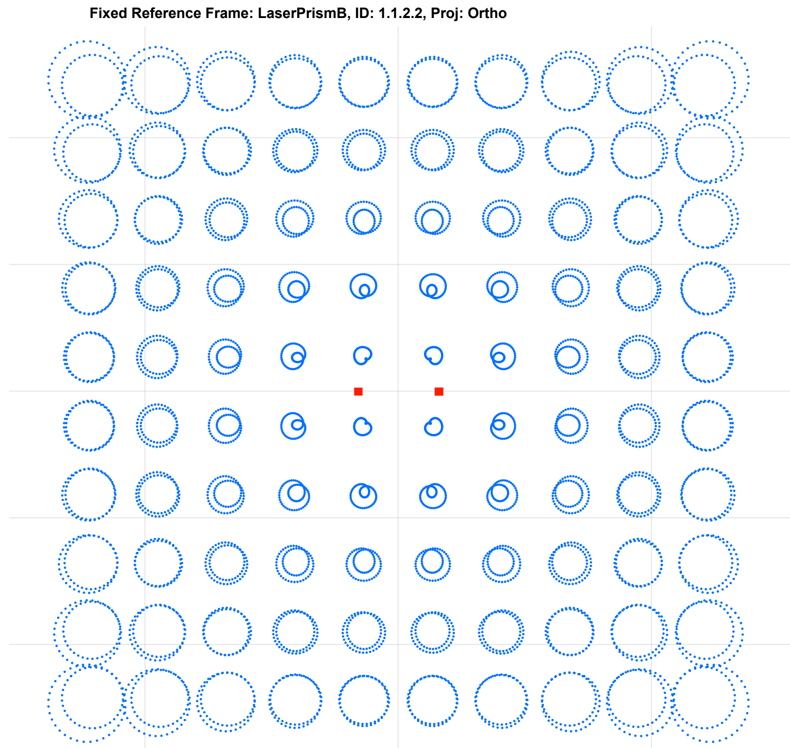
Looking at simulated data in other fixed frames



Comparison of genesis data vs. simulated sensor data



Pattern extracted from collected data



Pattern created from HW Model

Simulated data is from "perfectly aligned prisms"

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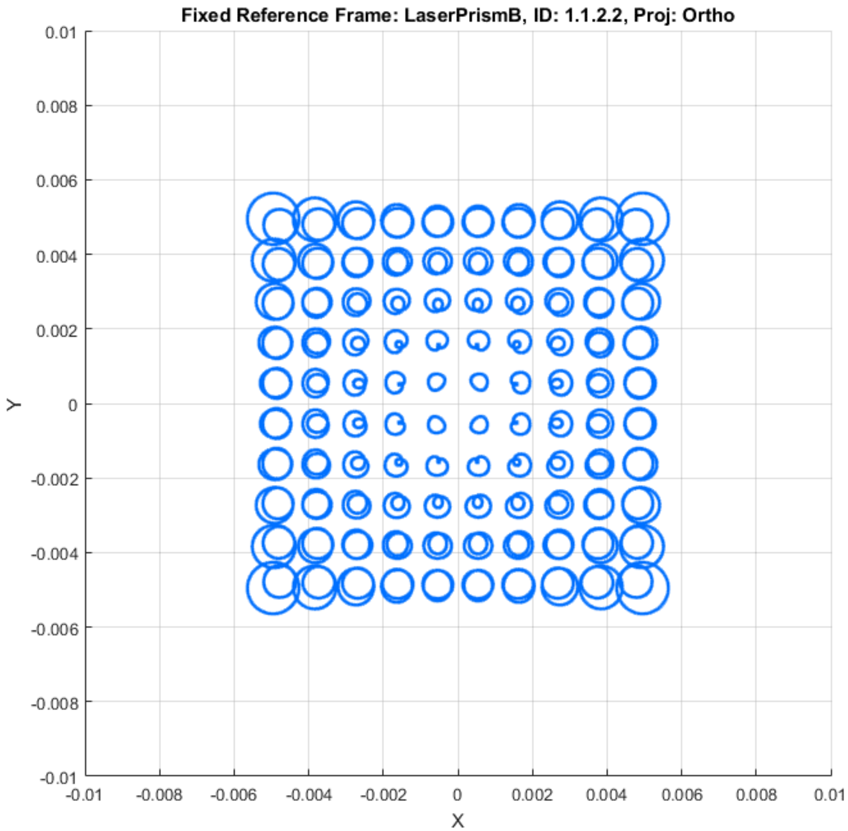
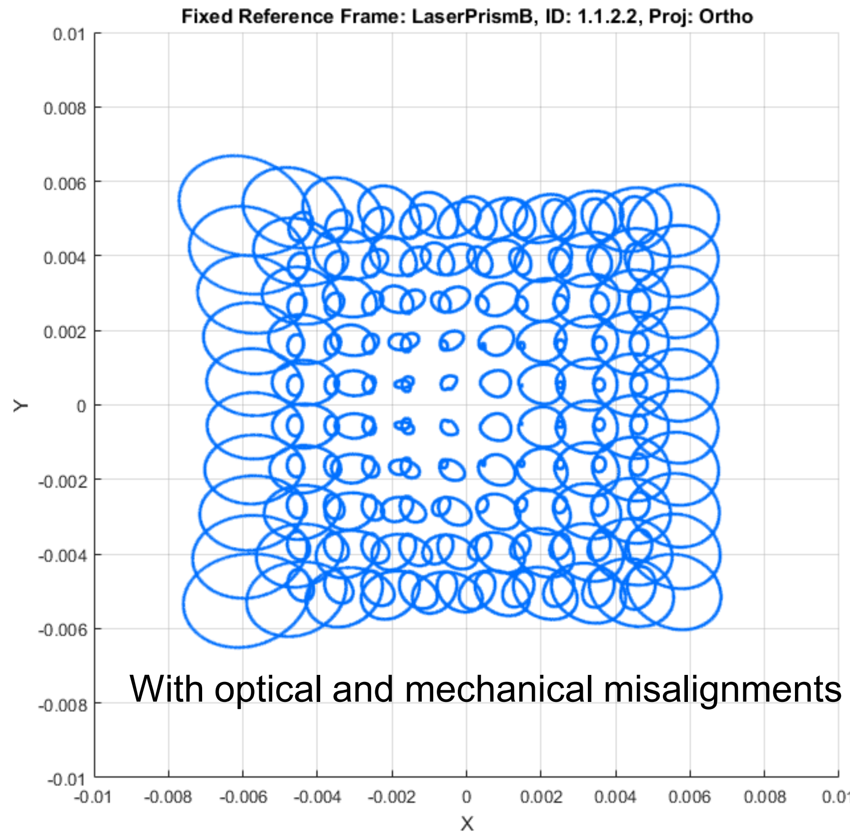
Comparison of aligned and misaligned data

Perfect Alignment



Non-Perfect Alignment



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We can model physical aberrations and misalignments of mechanical and optical components and measurement timing errors on LiDAR measurement data

Other benefits for new models

- Streamline trade-studies and critical investment decisions across the entire imaging sensor acquisition lifecycle including Analysis of Alternatives, CONOPS, HW & Sensor Model design, and sensor fusion
- Perform comprehensive and rigorous virtual studies on the complex interactions and dependencies between HW design and component specifications, sensor model compensation parameterizations, and sensor calibration
- Provide unprecedented insight into error propagation enabling new research into techniques and approaches to improve and/or automate calibration
- Verify numerically and graphically the illumination (or IFOV) of sensor coverage for a given sensor mission, HW operational settings, and 3D target geometries
- Visually validate "HW Model" component selection and assembly
- Evaluate new signal processing and conditioning algorithms

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