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Laser Diode Motion Simulator: Extending the capabilities of Hardware-in-Loop Space Rendezvous Testing

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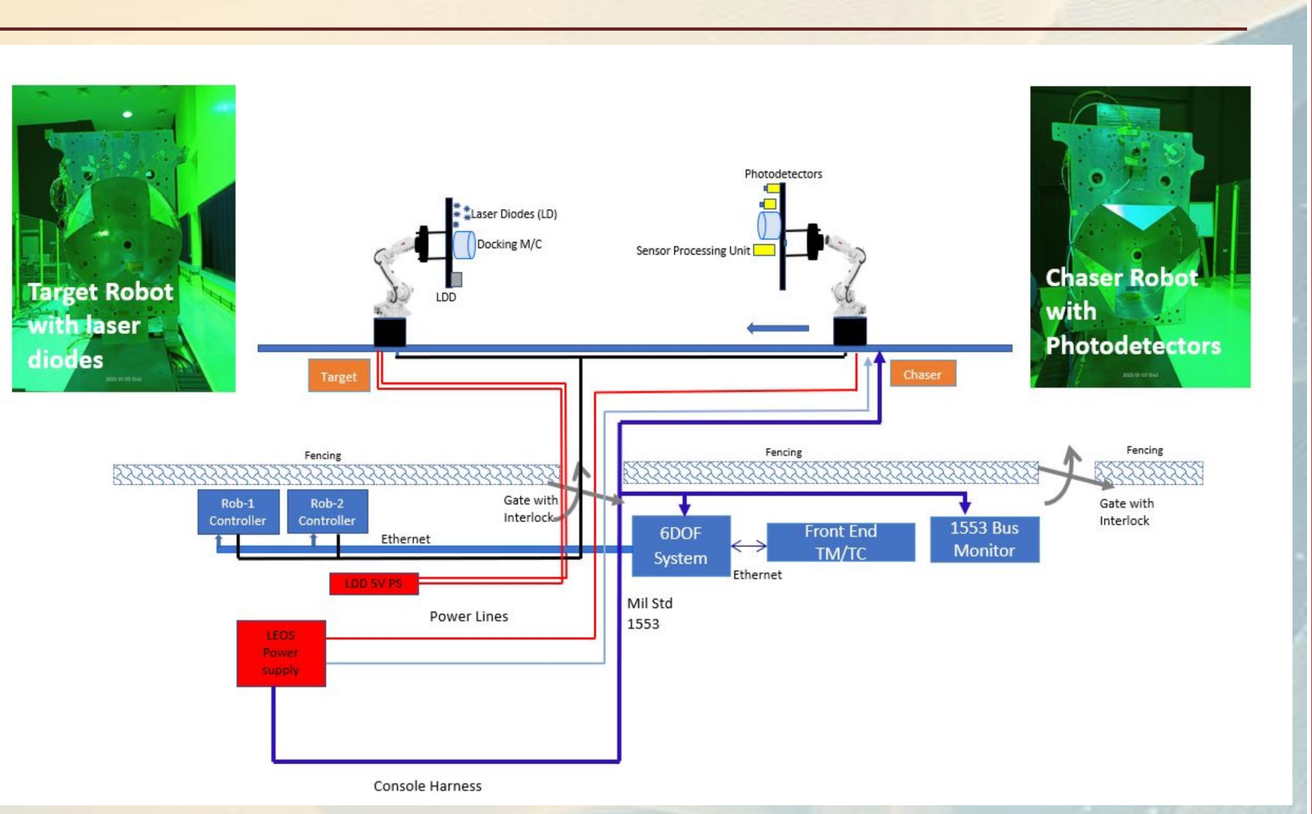
Background

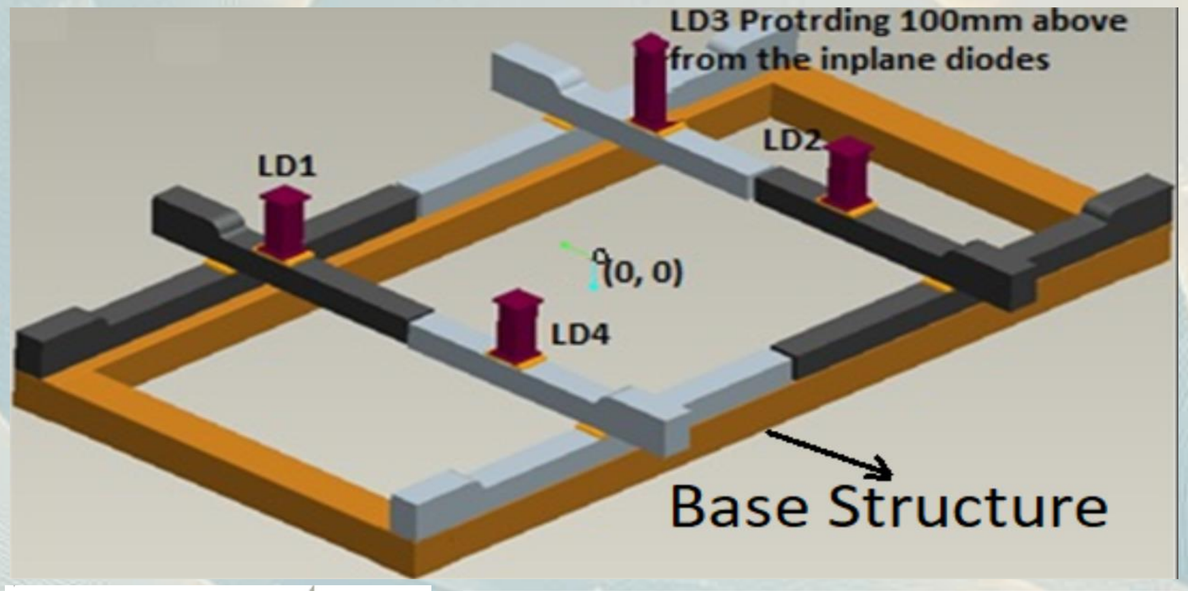
- Today, HILS facilities for spacecraft rendezvous testing have limited fidelity and scope of relative-motion emulation due to:
  - Restricted track lengths
  - High infrastructure costs and spatial requirements
  - Reduced realism in test when movement is simplified
- **This work:** we augment our testbed with an LD Motion Simulator, enabling:
  - ✓ Extended separation dynamics by "*stretching*" virtual track length with LDs on a secondary motion stage
  - ✓ Accurate optical navigation via photodetectors tracking the moving LDs

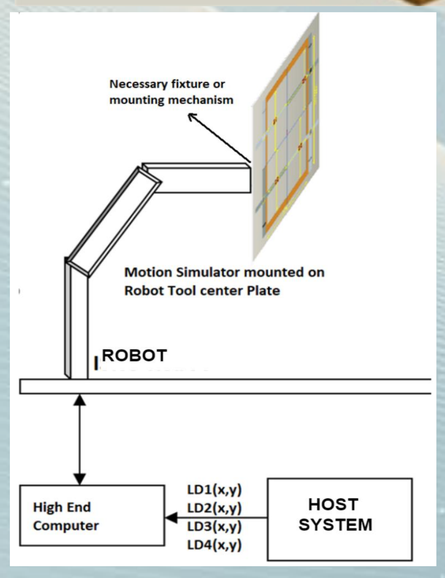
Space Rendezvous Robotic Testbed

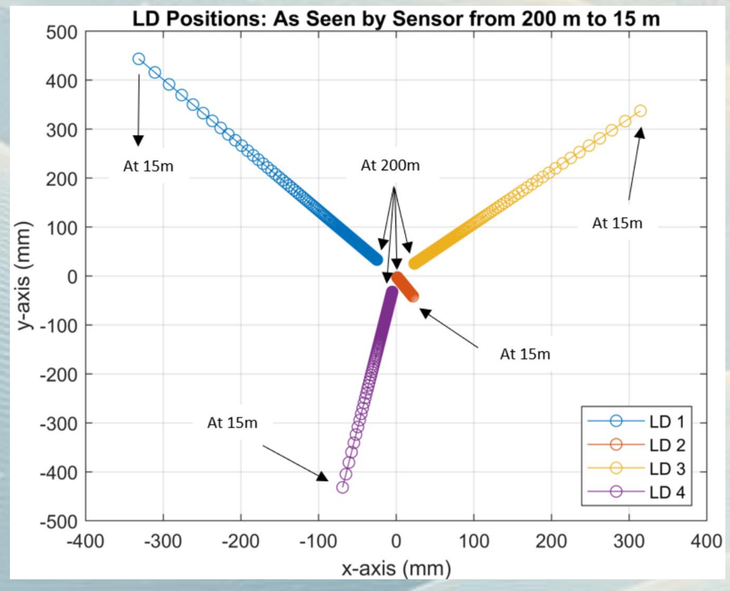
- **Dual-Manipulator 6-DOF Simulation:** Two six-link industrial robots mounted on a linear track provide full relative motion over a 15 m range.
- **Real-Time Closed-Loop Rendezvous:** Simulates terminal guidance by feeding live sensor data into NGC.
- **Optical Sensor Suite:** Chaser arm carries photodetectors, Target arm carries laser diodes.
- **Integrated Dynamics & Control:** A unified six-DOF spacecraft dynamics model runs in tandem with the NGC software, inverse kinematics, and robot drive interface.
- **Validation Approach:** NGC system performance is evaluated to build confidence in terminal docking accuracy and robustness.



Laser Diode Motion Simulator







- LD Motion simulator enables dynamic emulation of target–chaser separation within the compact simulator.
- **System Architecture Description:**
  - Four laser diodes are mounted in quadrant fixtures on a single-unit base machined to ±0.1 mm flatness.
  - Three diodes lie coplanar while LD3 is elevated by 100 mm to enable accurate pose triangulation.
  - Each LD is translated with ±0.1 mm positioning accuracy.
- Conducted end-to-end preliminary tests in simulation environment emulating a chaser's approach from 200m to 15m separation:
  - **Controlled Trajectory Tracking:** LDs commanded at 10 ms intervals through representative rendezvous kinematics.
  - **Velocity Profile Evaluation:** Analysed profiles with LD speeds spanning 34.8 mm/s down to 0.77 mm/s to confirm the system's ability to reproduce realistic spacecraft manoeuvre velocities under both minimum and maximum operational constraints.

Conclusion

- Demonstrated a high-precision method to emulate 15m–200m rendezvous dynamics without extensive physical tracks.
- Next, we plan to integrate a Laser Tracker and real-world photodetector trials to confirm end-to-end accuracy and reliability in extended-range docking scenarios.

References

[1] Benninghoff, Heike, et al. "European proximity operations simulator 2.0 (EPOS)-a robotic-based rendezvous and docking simulator."
[2] Romano, M., Friedman, D. A., & Shay, T. J. (2007). "Laboratory experimentation of autonomous spacecraft approach and docking to a collaborative target."

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