Advanced, Autonomous, Unaided Spacecraft Grappling

"Front End Robotic Enabling Near-Term Demonstration (FREND) Technologies and Associated Servicing Architecture"

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FREND

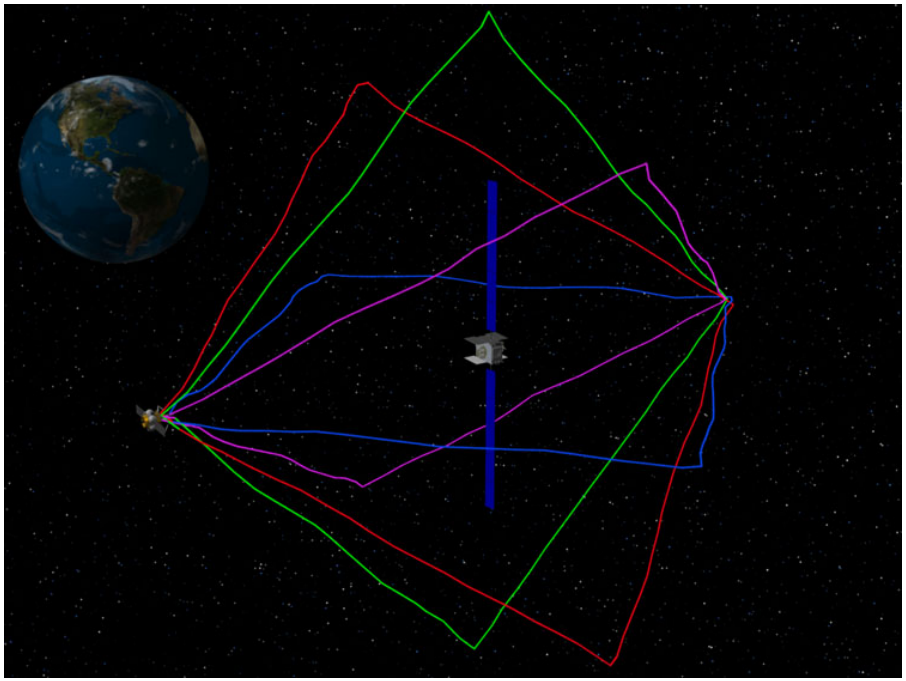
- **FREND = Front-End Robotics Enabling Near-Term Demonstration**
  - **The DARPA program to develop and demonstrate a flight robotic arm with associated end-effectors and algorithms that can perform autonomous, unaided grappling**
  - **Focused on "Space Tow Truck" Operations At GEO (Life Extension, Disposal, Slot Changes, …)**

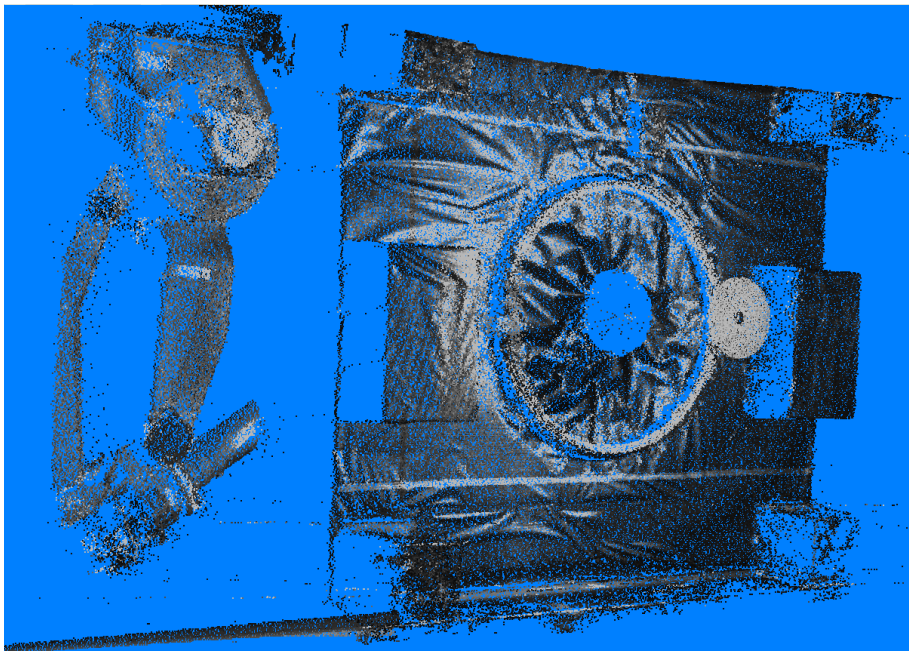
- **Three Key FREND Technologies Apply to On-Orbit Robotic Servicing**
  - **In-Situ Characterization**
  - **Hold Relative Pose at Close Range**
  - **Autonomous Robotic Capture**

No A-Priori Knowledge of Customer Required
No Standard Targets/Interfaces Required on Customer

In-Situ Characterization

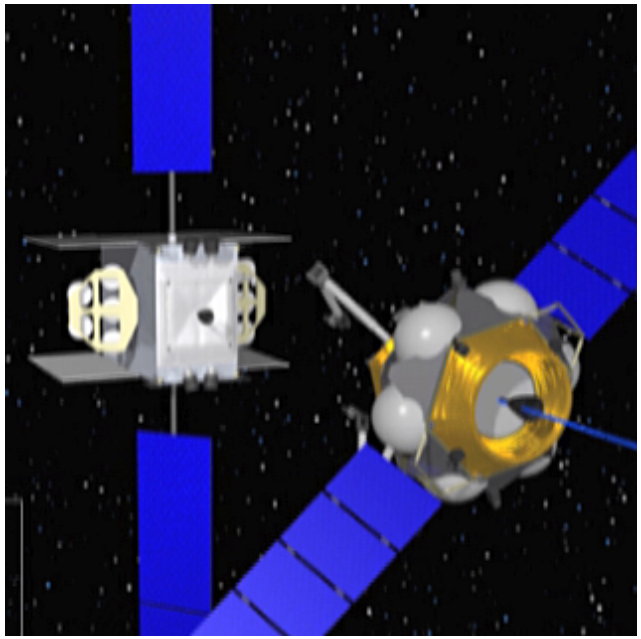
- **Techniques to perform in-situ characterization of customer satellites necessary to generate a detailed approach and grapple plan.**
  - **Forced Motion Circumnavigation while collecting Visual, IR, and LiDAR Data**
  - **Bring Data to ground to build 3D in-situ model, characterize tumble rates, and build rendezvous, approach, and capture plan**
  - **Initial demonstration of 3D model building from scanning LiDAR data**



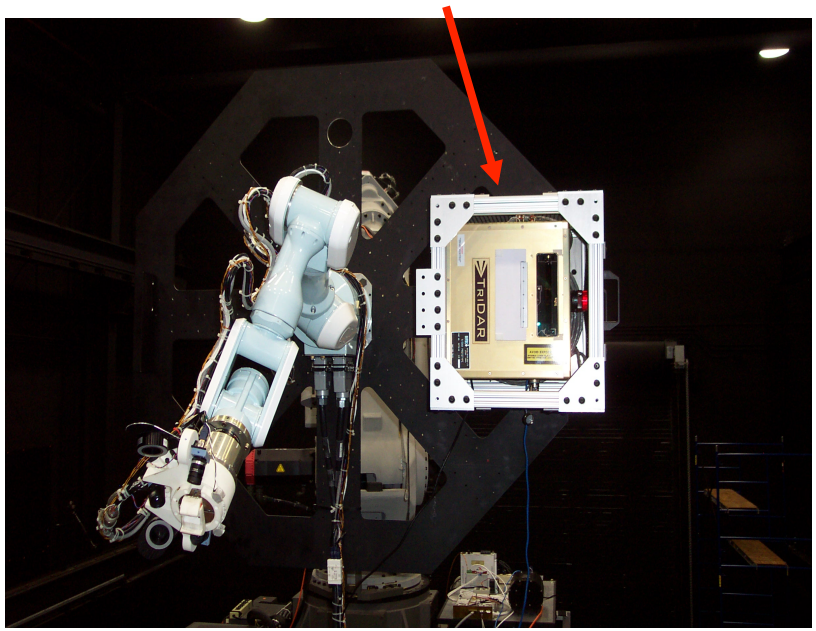


Hold Relative Pose at Close Range

- **Techniques to actively hold relative pose at ranges of less than 2 meters with objects tumbling up to 1 deg/sec in any axis.**
  - **1 pound thrusters support fine 6DOF bus control**
  - **Wide FOV LiDAR provides precision 6DOF Relative Pose at 5Hz rate**
  - **Designed, Simulated, and Demonstrated active relative pose control using simulated bus dynamics and scanning LiDAR with 6DOF Relative Pose Algorithm**

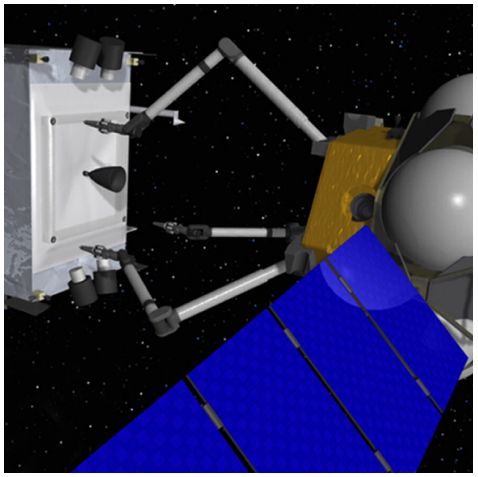


TriDAR in Proximity Operations Testbed



Autonomous Robotic Capture

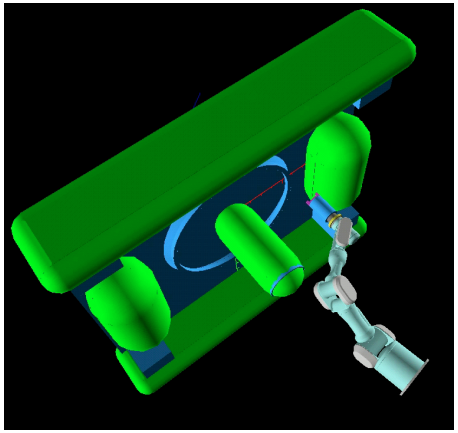
- **Developed robotic hardware and control algorithms to autonomously grapple a variety of hard points.**
  - **Use 6DOF pose data for coarse positioning**
  - **Use end-effector cameras and machine vision algorithms for final grapple positioning**
  - **Force-Torque sensor and compliance control algorithm provide "virtual soft docking"**
  - **Changeable end-effectors support marman rings, bolt holes, and other structural hard points**



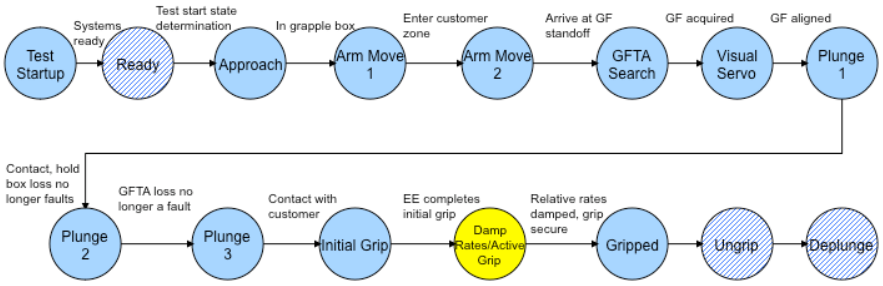
Fully Autonomous Grapple Was A Program Requirement To Support Tumbling Debris That May Prevent Ground Communications

Algorithms for Autonomous Capture

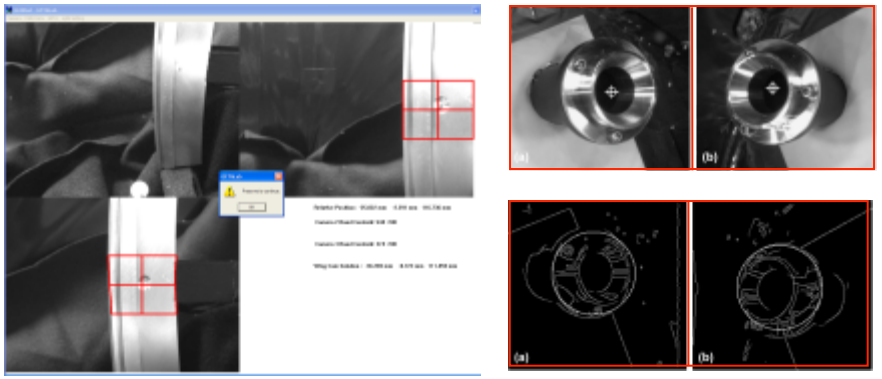
- **Mission Sequencer - payload functional coordination**
  - Provides payload function control and FDIR
- **Grapple Feature Tracking - precision arm guidance**
  - Designed for specific structural grapple points
  - Has been tested with bolt holes and marman rings
- **Trajectory Planner – real-time collision avoidance**
- **Compliance Control – virtual "soft dock" during grapple**
  - Algorithm reduces forces at contact to minimize customer disturbances, risk of damage, and to increase time for grapple



Trajectory Planner



Mission Sequencer States Diagram

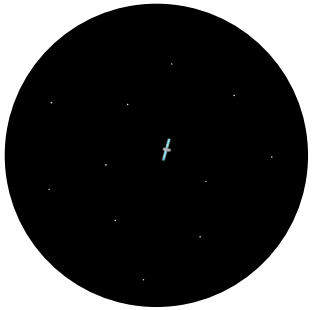


Grapple Feature Tracking Algorithms

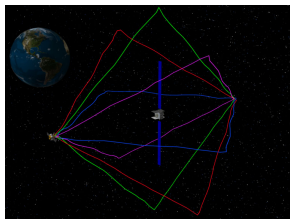
Notional Flight Demonstration Phases

Phase 0: Initial On-Orbit Deployment, Checkout, and Calibration

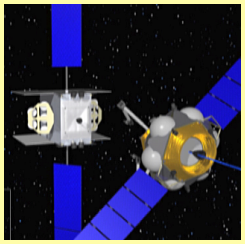
Phase 1: Acquire & Rendezvous
- 1.1: Long Range Navigation to 20 km Client Range and Bearing
- 1.2: Rendezvous 20 km ⇒ 1 km



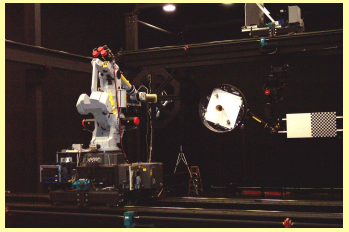
Phase 2: Survey & Inspection
- 2.1: Customer Survey
- 2.2: Data Downlink/Ground Process
- 2.3: Grapple Interface Detailed Survey



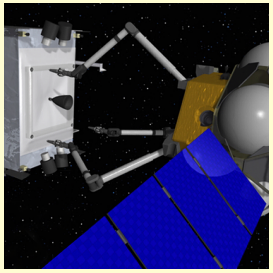
Phase 3: Approach to Capture
- 3.1: Grapple Final Preparation
- 3.2: Approach to Capture Box



FREND Demo



Phase 4: Grapple
- 4.1: First Arm Grapple
- 4.2: Three Arm Grapple
- 4.3: Grapple Rigidization



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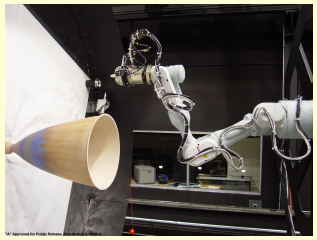
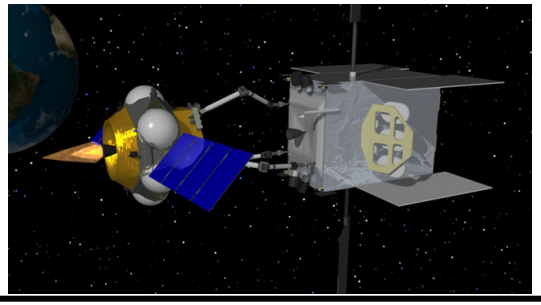
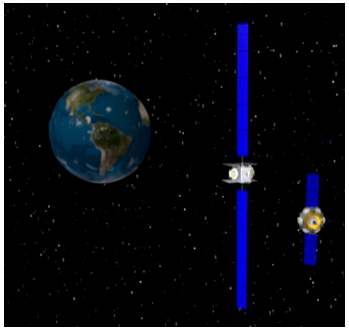


Phase 5: Orbit Modification
- 5.1: Coupled Vehicle Checkout
- 5.2: Coupled Vehicle Steady State
- 5.3: Coupled Vehicle Thrusting



Phase 6: Safe Retreat
- 6.1: Nominal Grapple Release
- 6.2: Nominal Bus Retreat



Phase 7: Intra-Mission On-Orbit Hold

Demonstration #4 Video