Recent / On-going Projects

- **SPHERES**
  - Synchronized, Position, Hold Engage and Reorient Experimental Satellites
  - Established in 2001-2002 by MIT, in partnership with NASA, DARPA, and Aurora Flight Sciences
  - Enables experimental research on autonomous GN&C algorithms critical to complex space missions
Recent / On-going Projects

- ISS-SPHERES
  - Microgravity
    - 6 DOF
  - Propulsion
    - 12 CO₂ thrusters
  - TI DSP
    - programmed in C code
    - 167 MHz
    - 16 MB RAM
  - EKF-based navigation
    - IMU
    - ultrasonic beacons
Recent / On-going Projects

- **Machine Vision for Uncooperative Targets (SPHERES)**

Recent / On-going Projects

- **Machine Vision for Uncooperative Targets (SPHERES)**

  - Data collection
    - 10 RPM intermediate axis spin
  - Offline map creation
    - using a laptop (45 min)

Recent / On-going Projects

- Machine Vision for Uncooperative Targets (Envisat)

Recent / On-going Projects

- Machine Vision for Uncooperative Targets (ISS-TriDAR)

Recent / On-going Projects

- Attitude Stabilization with Visco-Elastic Tether

Recent / On-going Projects

- ISS Stabilization for Robotic Free-Flyer Capture

Optimal Trajectory Guidance for Spacecraft Robotic Servicing Missions

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Optimal Trajectory Guidance

- Problem Statement

- Meets boundary conditions
- Avoids physical constraints
- Respects performance limits
- Minimizes the path length
Two-step Approach

- First step (sub-optimal solution)
  
  identify admissible trajectories as quickly as possible.

  \[
  f_{BC_1} = (x(t_0), \dot{x}(t_0)) = 0 \\
  f_{BC_2} = (x(t_f), \dot{x}(t_f)) = 0 \\
  f_{c_i}(x(t), \dot{x}(t), \ddot{x}(t)) \leq 0, \quad \forall i \in [1, n], \quad \forall t \in [t_0, t_f]
  \]

- Second step (optimal solution)
  
  uses any remaining computation time to refine the solution towards the optimal path (minimize length).

  \[
  S = \int_{x_0}^{x_f} ds = \int_{t_0}^{t_f} \sqrt{\dot{x}(t)^2 + \dot{z}(t)^2 + \ddot{z}(t)^2} dt
  \]
Augmented Cost Function

\[ J = f_s^2(S) + \sum_{j=1}^{n} K_j \max_{t \in [t_0, t_f]} f_{c_j}^2 \]

The relative weights need to be chosen to ensure that the constraint violations dominate the cost function.

Once a solution is found that drives the second term to zero, then the resulting trajectory is admissible.
Algorithm Overview

- Parameterize the trajectory with Legendre polynomials to simplify the nonlinear, constrained optimization problem.
- Define the constraints appropriately, such that a simple gradient descent search strategy will find the optimal solution.
- Start optimization with initial guess that meets the boundary conditions.
- Enforce the BCs by a projected gradient algorithm to quickly find sub-optimal solutions.

\[
x_i A C \delta C = \left[ I - P_{BC} \left( P_{BC} P_{BC}^T \right)^{-1} P_{BC} \right] \delta C
\]
Optimal Trajectory Guidance

Initial guess

Trajectory at 42 iterations

Trajectory at 45 iterations

Trajectory at 55 iterations

Trajectory at 65 iterations

Final trajectory at 100 iterations
Optimal Trajectory Guidance

ISS-SPHERES

- Static obstacle test
  - 0.3 m spherical obstacle
  - max. acceleration = 0.05m/s²
  - 17 seconds of computation time
Optimal Trajectory Guidance

- Translating Constraints

Optimal Trajectory Guidance

- Translating Constraints

Translating and Rotating Constraints

- Modeling of the geometric constraint (i.e., target satellite)

Loral FS1300

- 196 bodies
- 17 bodies
- 3 bodies
Optimal Trajectory Guidance

- Translating and Rotating Constraints
  - Safety buffer
Optimal Trajectory Guidance

- Translating and Rotating Constraints
  - Motion envelope traced out by boundary points
Optimal Trajectory Guidance
Conclusions

Summary

- Recent and on-going research projects related to uncooperative proximity operations GN&C were overviewed.

- A real-time trajectory guidance law to solve the proximity operation problem in the vicinity of an uncooperative, complex, spinning, spacecraft was proposed.

- The performance was evaluated in a numerical simulation environment for both a slow tumbling and a fast spinning target.