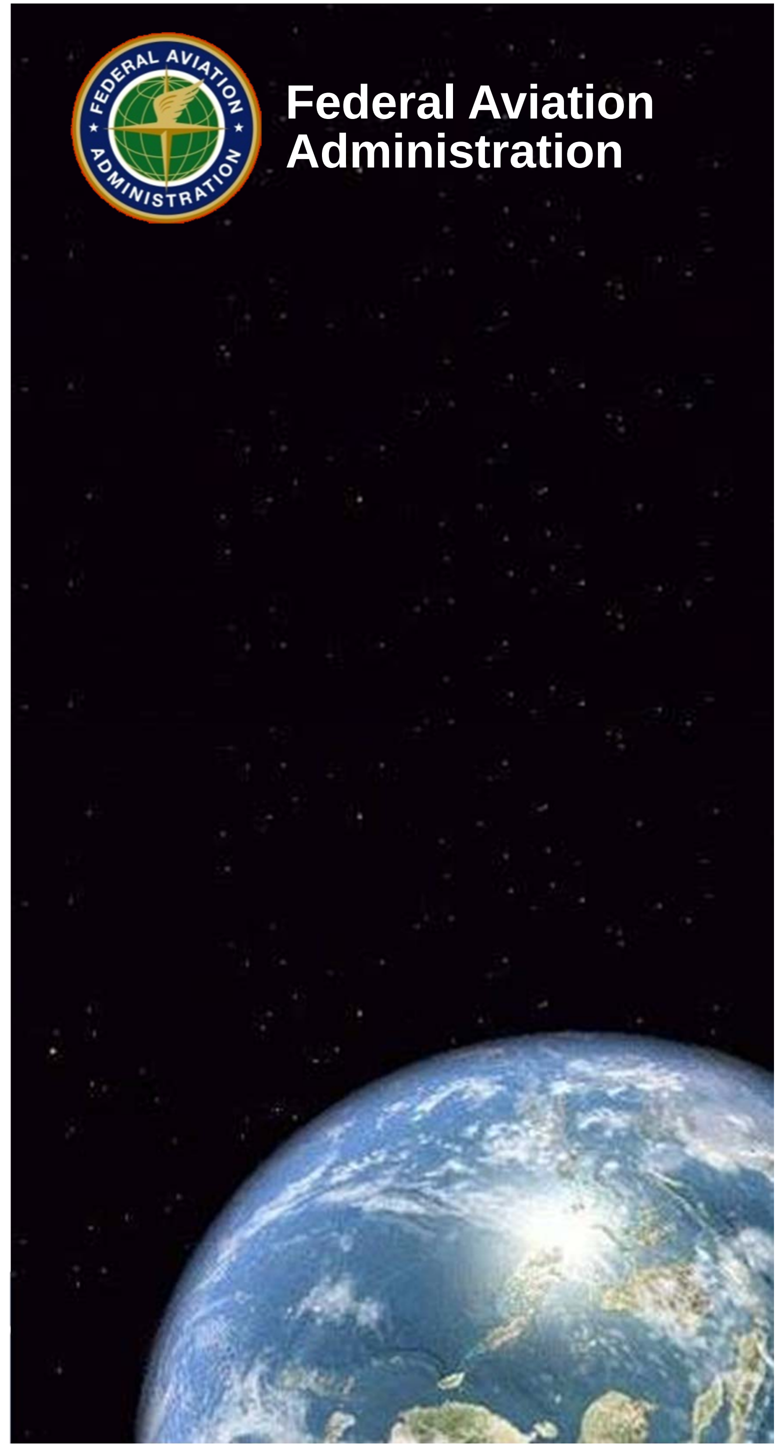
COE CST First Annual Technical Meeting:

Autonomous Rendezvous and Docking for Space Degree Mitigation: Fast Trajectory Generation

Emmanuel Collins
Florida State University

November 10, 2011



Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results or Schedule & Milestones
- Next Steps
- Contact Information

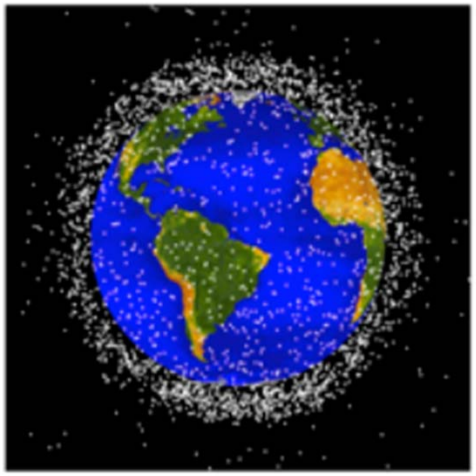
Team Members

- Emmanuel Collins
- Griffin Francis, Mechanical Engineering, PhD Student
- Oscar Chuy, Assistant Scholar Scientist

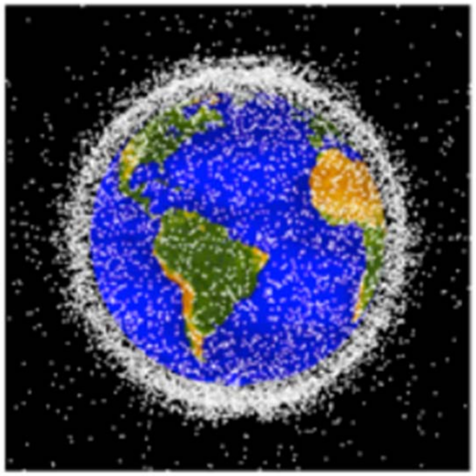
Purpose of Task

- **Purpose**: As indicated by a recent NASA study, there is an immediate need to develop space debris mitigation technology.
  - The development of "Space Tow Truck" capabilities is a promising approach toward direct debris removal.
  - Requires automated guidance to approach target debris.

Space Debris



1981



2011

Purpose of Task

- **Objectives**: Develop the onboard ability to quickly (within a few seconds) generate dynamically feasible trajectories that enable a space tow truck to approach debris for docking.

This is the main propellant tank of the second stage of a Delta 2 launch vehicle which landed near Georgetown, TX, on 22 January 1997. This approximately 250 kg tank is primarily a stainless steel structure and survived reentry relatively intact.

Taken from the web site of the NASA Orbital Debris Program Office.

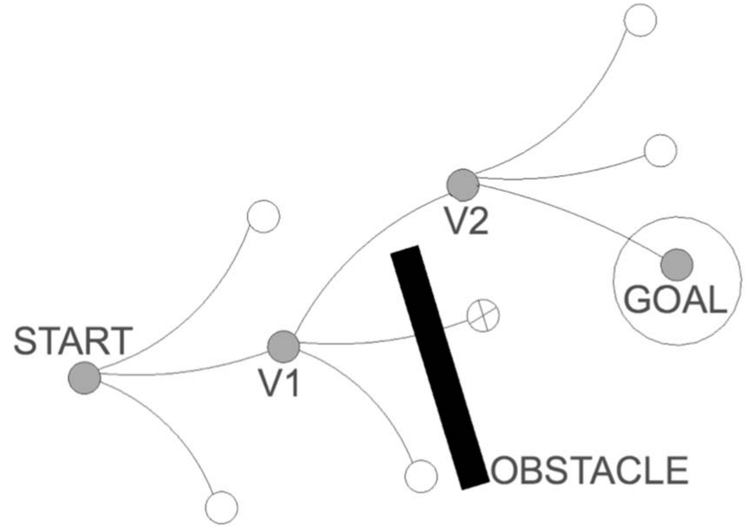
Purpose of Task

- **Goals**:
  1. Use of space tow truck dynamic model to account for actuator characteristics and vehicle momentum.
  2. Effective planning of position, orientation, and velocity with respect to target debris.
  3. Optimization of relevant trajectory metrics such as distance, time, or energy.
  4. Avoidance of moving debris.
  5. Fast replanning using prior trajectory plan.

On 21 January 2001, a Delta 2 third stage, known as a PAM-D (Payload Assist Module - Delta), reentered the atmosphere over the Middle East. The titanium motor casing of the PAM-D, weighing about 70 kg, landed in Saudi Arabia about 240 km from the capital of Riyadh. (NASA Orbital Debris Program Office)

Research Methodology

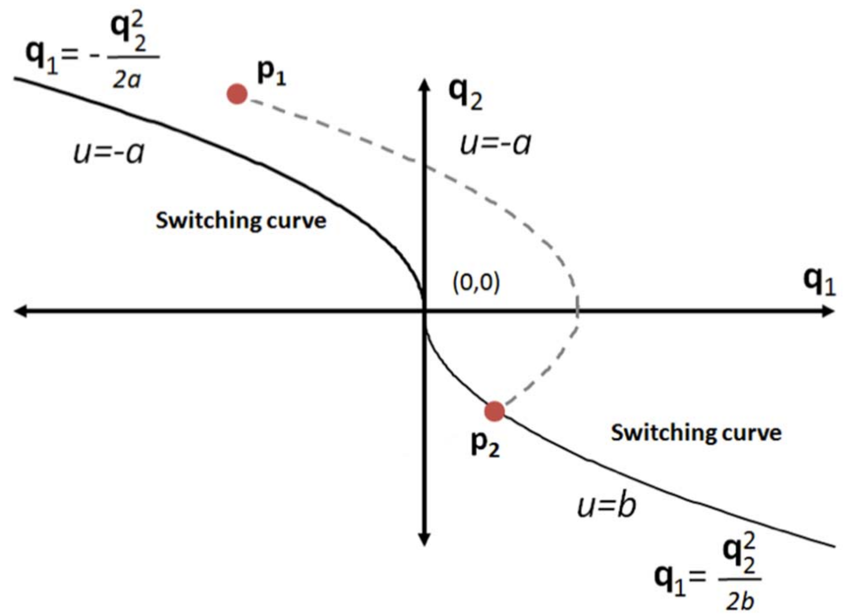
- The primary tool used is Sampling Based Model Predictive Optimization (SBMPO).
- SBMPO is a graph search method, which has the following characteristics:
  - Graph is based on sampling model inputs;
  - Uses A* optimization;
  - Enables rapid replanning;
  - Result is a trajectory, not simply a path.



Illustrative Graph, Including Collision Detection

Research Methodology

- The key to fast computations with SBMPO is wise choice of an optimistic A* “heuristic” (i.e., a rigorous lower bound on the cost from the current node to the goal).
- For example, for minimum time optimization for problems requiring specification of an end velocity and position, a heuristic can be based upon the solution to a “simple” minimum time control problem.



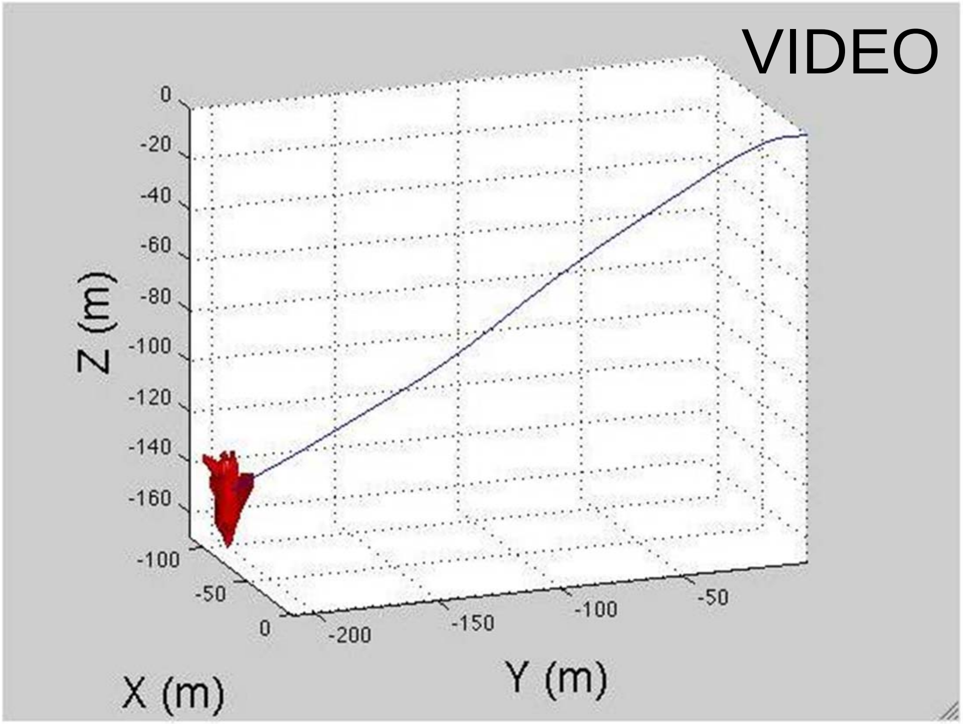
Miniimum Time Control Curve for $\ddot{q} = u$

Research Methodology

Beginning in January, the research will take place in the new AME (Aeropropulsion, Mechatronics, Energy) Building.

Results

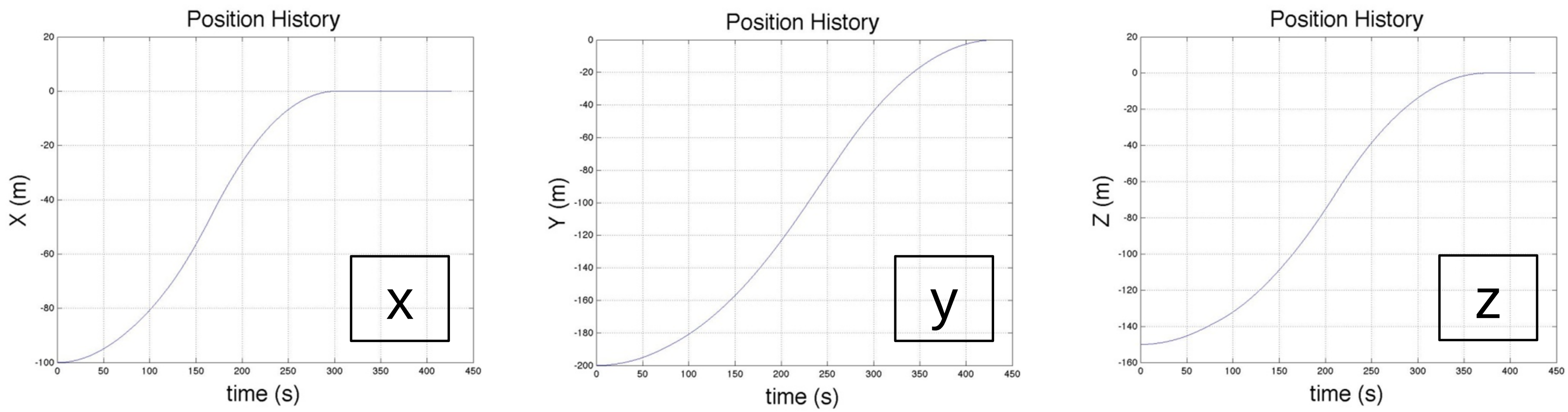
- **3D Trajectory Generation**
  - Initially spacecraft is disoriented and trailing the target by 270 m.
  - SBMPO sampled thrusters and rotation wheels aligned to the body axes (6 inputs).
  - Distance was optimized.
  - Zero relative velocity at goal enforced.
  - Route shown to goal position and orientation computed in ~0.1 sec.



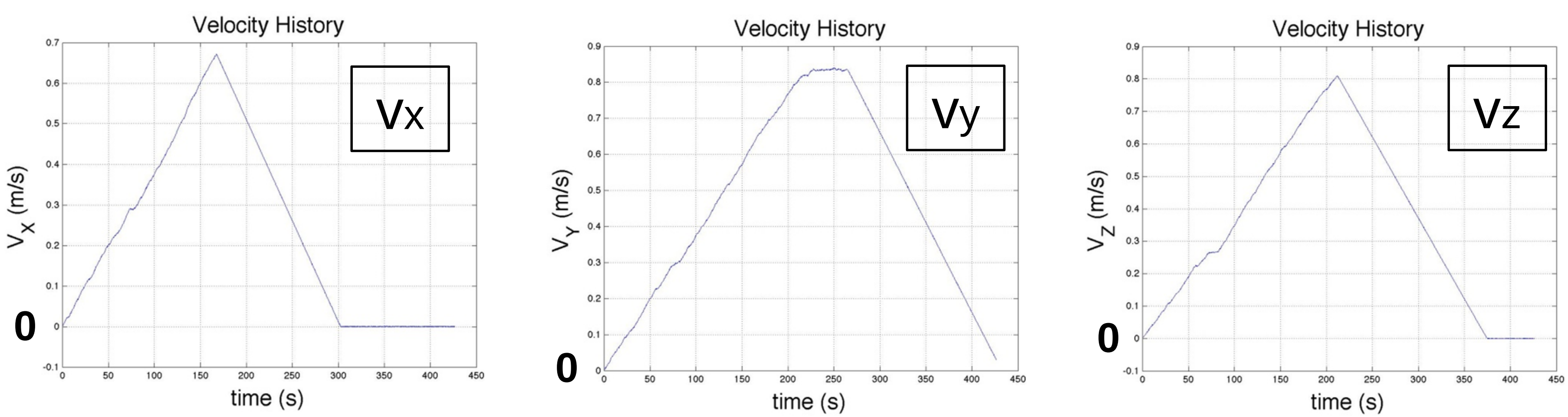
- Have generated 3+ km trajectories in 0.1-0.5 sec.
- Other approaches compute similar trajectories in 25+ sec.

Results

Relative Position History (450 sec)

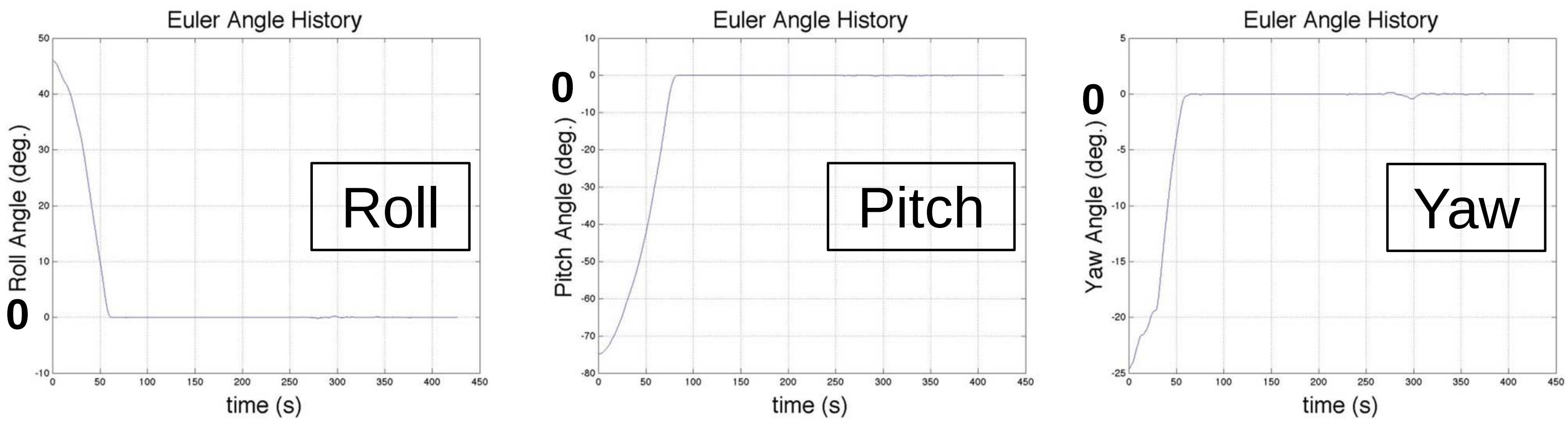


Relative Velocity History (450 sec)

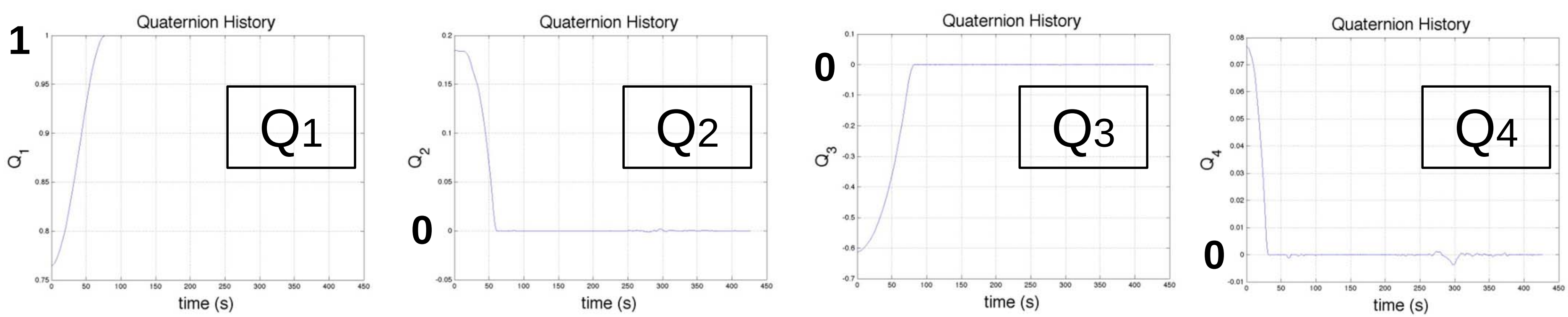


Results

Euler Angle History (450 sec)

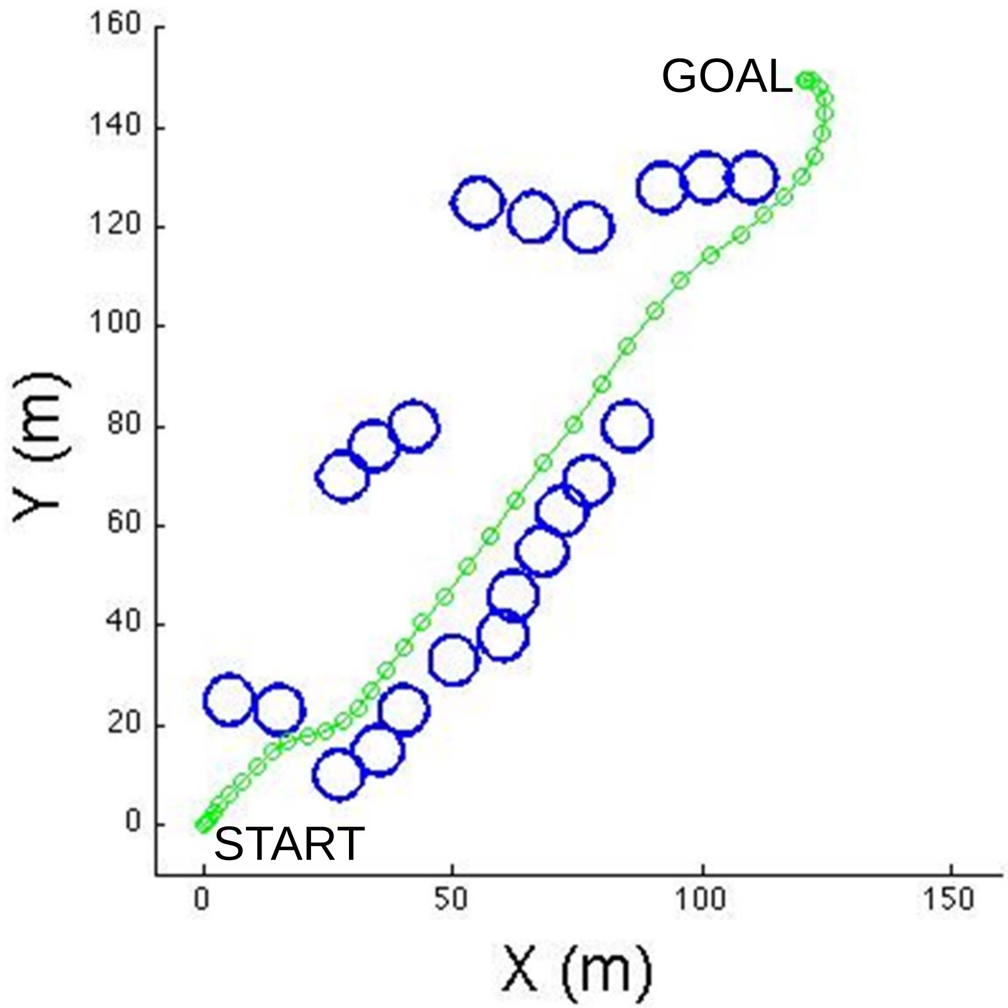


Quaternion History (450 sec)



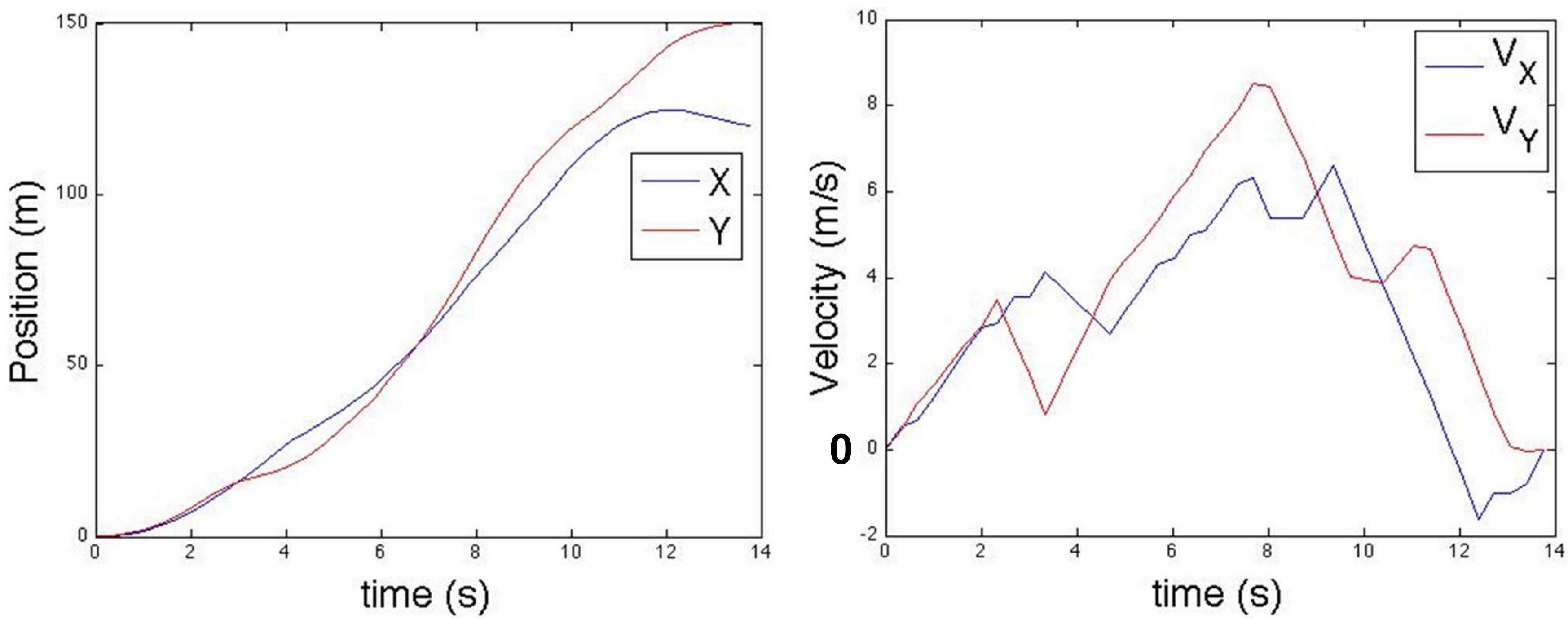
Results

- **Planar Trajectory Generation with Obstacles**
  - SBMPO sampled thrusters aligned to body axes (2 inputs).
  - Distance was optimized.
  - Zero relative velocity at goal enforced.



Results

Motion History Relative to Target (14 sec)



Next Steps

- Apply collision avoidance to 3D planning environment with orientation goal.
- Consider moving obstacles.
- Demonstrate minimum time trajectories.
- Develop a spacecraft power consumption model and demonstrate minimum energy consumption.
- Demonstrate rapid replanning to accommodate newly sensed obstacles.
- Implement trajectory constraints based on research of Penny Axelrad (U Colorado).
- Use research of Steve Rock (Stanford) and Norm Fitzcoy (U Florida) to determine final pose constraints.

Contact Information

Emmanuel Collins
ecollins@eng.fsu.edu
850-410-6373

Griffin Francis
gdf05@fsu.edu
850-410-6347

Oscar Chuy
chuy@eng.fsu.edu
850-410-6517