State Estimation and Targeting for Autonomous Spacecraft Rendezvous and Proximity Operations

Introduction

Spacecraft rendezvous and proximity operations are required for such essential operations as docking, servicing, inspection, diagnosis, reconnaissance, and formation flying of space vehicles. As such, they require some of the most important and challenging maneuvers in spacecraft GN&C.

Historically, rendezvous and proximity operations were developed early on from such programs as Gemini and Apollo, and further developed with the Space Shuttle, the International Space Station (ISS), and others. Traditionally rendezvous and proximity operations have been executed with man-in-the-loop systems. These systems require considerable ground station support, and often manned spacecraft

Autonomous Operation

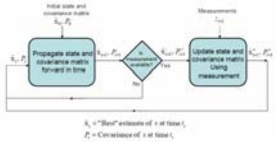
The development of autonomous rendezvous and proximity operation capabilities would greatly simplify ground operations, eliminate the risk associated with manned spaceflight, and increase the flexibility and capability of space systems. In, addition the development of autonomous space servicing would significantly increase mission duration, reduce effects of system failure, and reduce launch mass of future satellites.

Examples
- •XSS-11
- •DART
- •ETS-VII
- •Progress
- •Orbital Express
- •CEV/Orion

Chaser Requirements
- •On board sequential state estimation
- •On board maneuver targeting
- •Accurate Relative Position estimation
- •Accurate Attitude estimation
- •Communication with Target not necessary

Kalman Filter

The Kalman filter is an optimal sequential state estimation tool derived from stochastic models of dynamic systems and stochastic models of the sensor measurements. The two steps of a Kalman Filter are propagating and updating the state and state covariance.



Stochastic modeling is essential due to errors in measurements and dynamic models. Sequential state estimation is required for maneuver targeting "on the fly", A Kalman filter allows the chaser to accurately determine its relative position with respect to the target, and carry out maneuvers as necessary.

Rendezvous Targeting

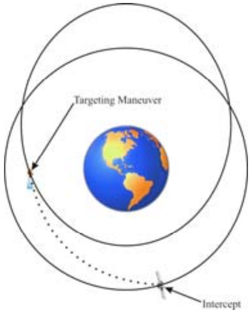
Autonomous rendezvous and proximity operations require on board targeting algorithms to plan and execute the required ΔV thrust maneuvers.

Targeting algorithms generally function in the following manner: Given the position of a spacecraft at time t_1, what is the ΔV that must be imparted in order for the spacecraft to be at a desired position at time t_2.

Two common types of algorithms are CWH targeting and Lambert targeting.

Lambert Targeting
- •Inertial position and velocity
- •Non-linear dynamics (2-body w/o J2)
- •Iterative Process

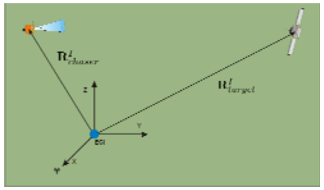
CHW Targeting
- •Relative position and velocity
- •Linear dynamics (CWH equations)
- •No iterations required



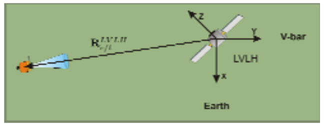
Objective: Inertial vs. Relative

The objective of this project is to compare the performance of two navigation and targeting systems.

Inertial System
- •Kalman filter estimates inertial position and velocity
- •Lambert targeting



Relative System
- •Kalman filter estimates relative position and velocity
- •CWH targeting



Under what condition will one system estimate the relative position and perform the required rendezvous and proximity operations more accurately than the other?

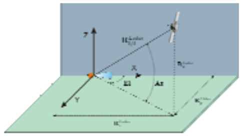
Will there be a trade off between system performance and CPU time?

Simulation

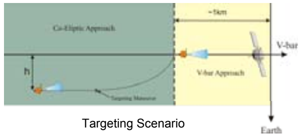
A simulated LIDAR system on the chaser vehicle is used to generate the relative range, azimuth, and elevation measurements processed by the filters.

Simulated star tracker and gyro measurements are used to determine the attitude of the chaser. They are also used to provide the inertial to body coordinate frame transformations.

The primary scenario used to evaluate the filters begins with a co-elliptic target approach transferring to a v-bar approach.

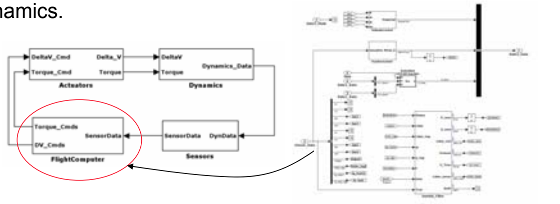


Relative Measurements



Targeting Scenario

The Matlab/Simulink environment is used to simulate and evaluate the systems. Included in the simulation are flight computer, chaser actuators and sensors, and chaser and target dynamics.



Mechanical & Aerospace Engineering

David K. Geller
Utah State University
4130 Old Main Hill
Logan, Utah 84322
dgeller@engineering.usu.edu

Scott C. Jenkins
Utah State University
4130 Old Main Hill
Logan, Utah 84322
scottj@cc.usu.edu

Utah State University