# Swarm Enhancement of Autonomous Navigation When Operating Near Rubble Pile Asteroids

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## Motivation

Navigation around small interplanetary bodies is a significant challenge, especially when the gravity environment is at the microgravity level consistent with rubble pile asteroids such as Bennu or Ryugu. This project explores an autonavigation technique for nanospacecraft swarms, using mutually reinforcing line of sight measurements to derive ongoing position and velocity estimates.

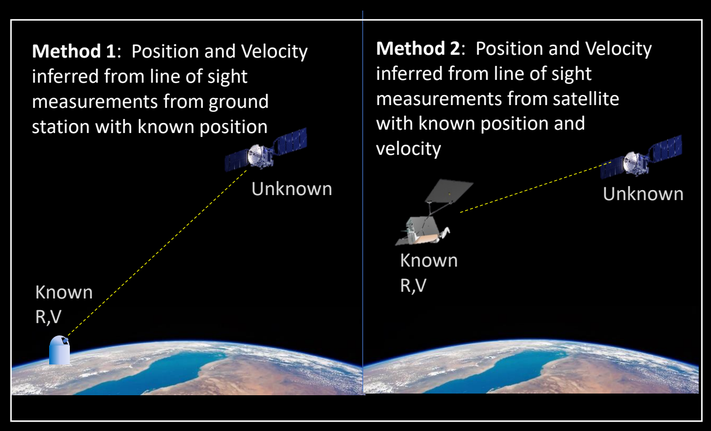
## Research Objectives

1) Establish navigation in a microgravity environment using passive measurements of line of sight between two objects

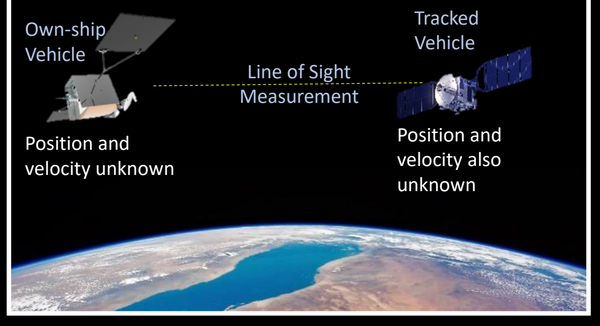
2) Enhance navigation performance with a swarm by sharing estimates and covariances between swarming spacecraft

## Basic Autonavigation Concept

It is well established that orbital position and velocity can be inferred with sequential line of sight measurements from a known location using Extended Kalman Filter (EKF) techniques…



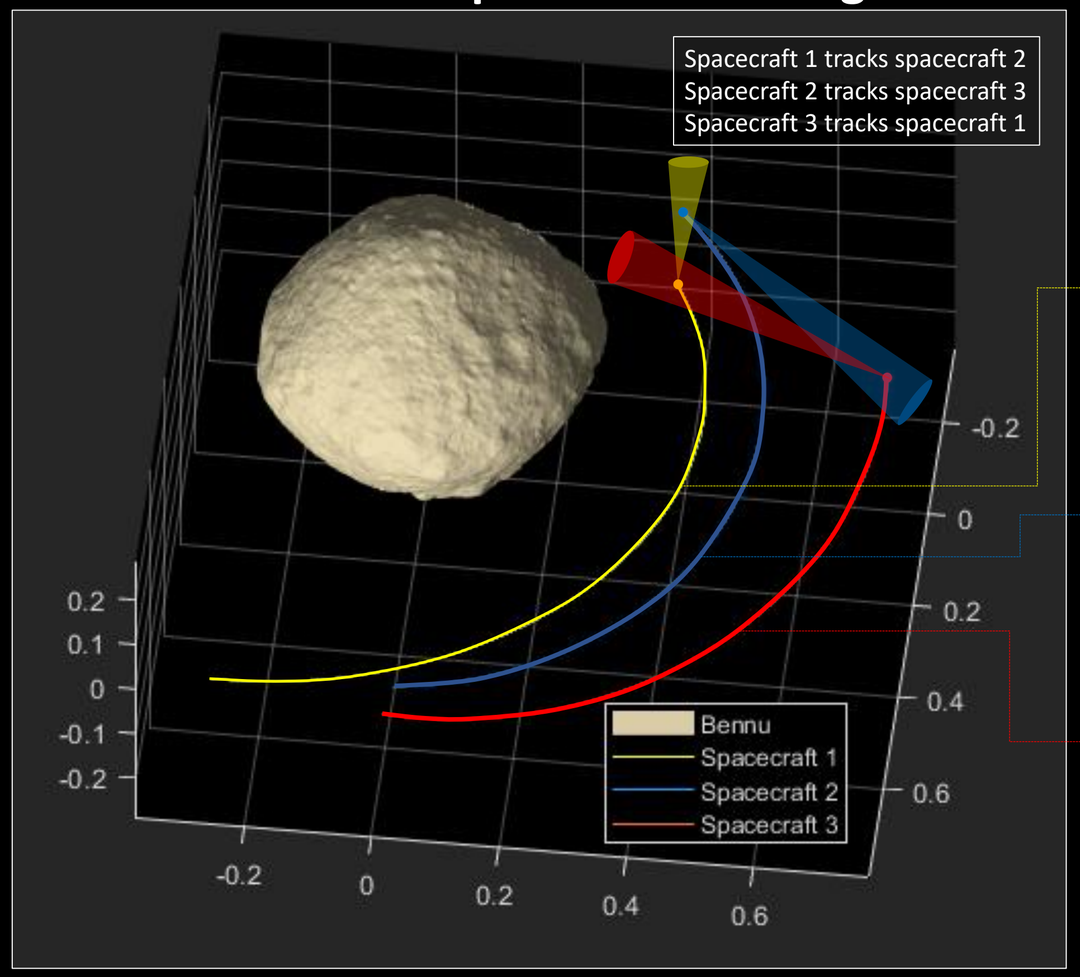

**Method 3**: (And subject of this Research) Position and Velocity of both satellites inferred from line of sight history




…However, analysis also shows that position and velocity for both own-ship and tracked vehicle can be inferred from a single line of sight history

Note that this basic technique does not require cooperation from tracked vehicle

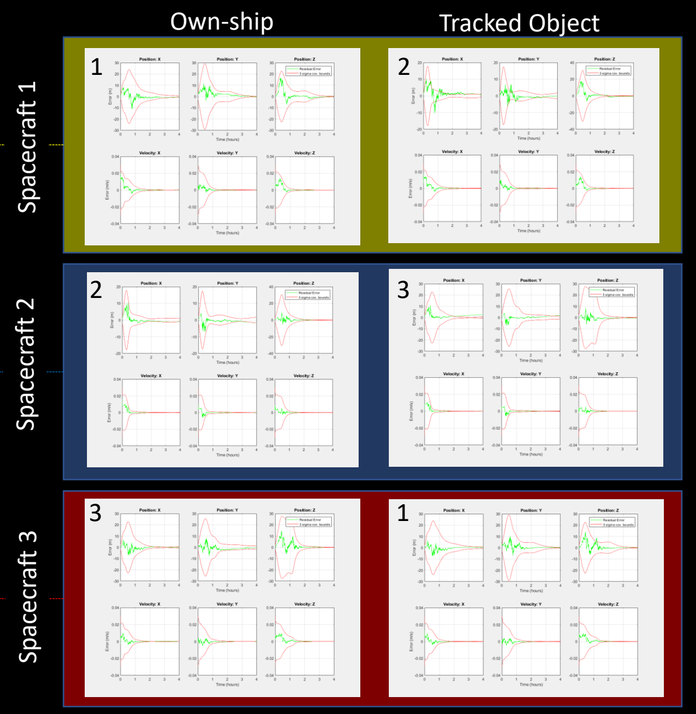
## Test Case: Three spacecraft orbiting Bennu




Estimates are established implementing a point mass gravitational model into a 12 state Extended Kalman Filter with states comprising components of position and velocity for ownship and tracked object respectively

## Individual Filter Performance

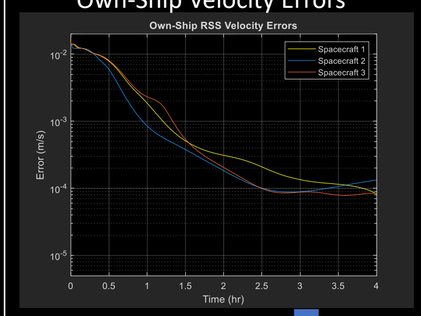
Individual 12 state filters demonstrate convergence for position and velocity with both own-ship and tracked objects respectively



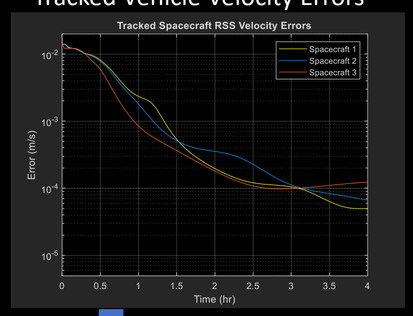

Since there are two estimates for each spacecraft, ie, spacecraft 1 provides and estimate for itself and spacecraft 2 etc., these estimates can be combined to improve performance

## Combining Swarm Estimates

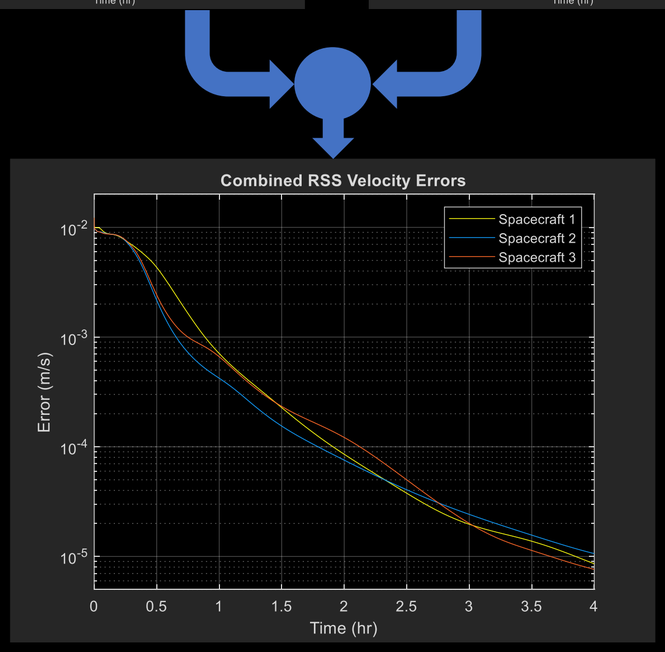
Own-Ship Velocity Errors




Tracked Vehicle Velocity Errors




Independent estimates with known covariances can be combined using a subset of the EKF equations for updating estimates




Given 2 state estimates and 2 covariance matrices, calculate best combined estimate & covariances

$$x_c = x_1 + K(x_2 - x_1)$$

where:
$x_c$ = combined state estimate
$x_1$ = state estimate 1
$K$ = gain matrix
$x_2$ = state estimate 2

$$P_c = (I - K)P_1$$

where:
$P_c$ = Combined covariance matrix
$P_1$ = Covariance matrix 1
$I$ = Identity matrix

$$K = P_1(P_1 + P_2)^{-1}$$

where:
$P_2$ = Covariance matrix 2

**Combined estimates demonstrate nearly an order of magnitude improvement in performance over individual filter estimates**

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