

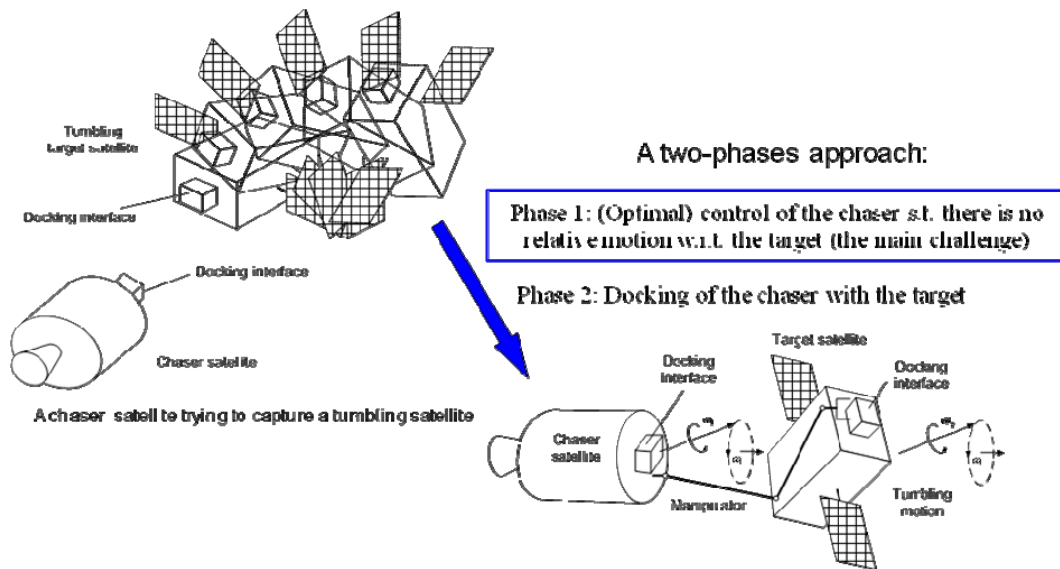
Optimal Control of Rendezvous and Docking with a Non-Cooperative Satellite

Goals

Conduct theoretical and lab-experimental investigations of a control problem of a spacecraft rendezvous with a non-cooperative satellite in order to capture it in an optimal manner. The optimum can be in the sense of minimum time, minimum fuel consumption, or a rationale combination of both.

Motivation:

There is a growing interest in autonomously servicing satellites on orbit for economical and other reasons. A key enabling technology for on-orbit servicing is autonomous rendezvous and capturing (AR&C). Most of the current research and all the past missions are aiming at capturing very cooperative satellites only. In the future, we may also need to capture non-cooperative satellites such as the ones tumbling in space or not designed for being captured. AR&C of a non-cooperative satellite is an extremely difficult problem requiring further research to advance the enabling technologies.



Approach

A control system for autonomous rendezvous may consist of three parts: a sensing/estimation system, a feedforward control, and a feedback control. This study focuses on the feed-forward part, which is to establish optimal approaching trajectories of position, attitude, and velocities within a proximity range. Such a control is essential not only for providing a goal for the operation but also helping the feedback control system by removing large errors which otherwise have to be compensated by the feedback controller if using sensor-based feedback control alone. The goal of the chaser is to rendezvous with (align with) the target in an optimal manner for a subsequent capture operation. In the theoretical investigation the Maximum Principle of Pontryagin is applied to generate an optimal approaching trajectory and the required control forces/torques to bring the chaser to a given close distance and orientation to the target and then maintain that distance and orientation without further relative motion with respect to the tumbling target, as shown in the figure.

Selected Publications

- Ma, Z., Ma, O., and Shashikanth, B., “Optimal Approach to and Alignment with a Rotating Rigid Body for Capture”, *Journal of the Astronautical Science*, Vol.55, No.4, 2007, pp.407-419.
- Ma, Z., Ma, O. and Shashikanth, B., “Optimal control for spacecraft to rendezvous with a tumbling satellite in a close range”, *Proc. IEEE Int. Conf. on Intelligent Robots and Systems (IROS’06)*, Beijing, China, Oct.9-15, 2006, pp.4109-4114.
- Ma, O. and Yang, G., “Validation of a satellite docking simulator using the SOSS experimental testbed”, *Proc. IEEE Int. Conf. on Intelligent Robots and Systems (IROS’06)*, Beijing, China, Oct.9-15, 2006, pp.4115-4120.

On-Orbit Identification of Spacecraft Inertia Properties

Project Objectives

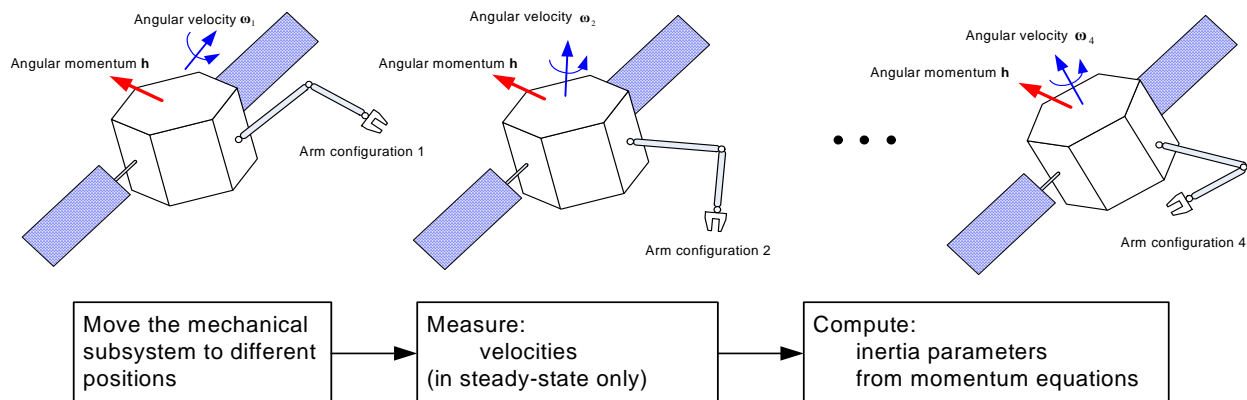
Develop new technology for on-orbit identification of inertia properties of spacecraft. The basic research of this project is to prove (in both theory and experiment) the hypothesis that the unknown or changed inertia properties of a spacecraft can be identified using an onboard controllable mechanism such as a robotic arm and solar panels without firing thrust (i.e., no fuel consumption).

Motivation

The inertia properties (i.e., mass, center of mass, inertia tensor) of a spacecraft can change in orbit for many reasons such as fuel consumption, fuel transfer, hardware reconfiguration, payload deployment, capturing a flying object (satellite), docking with another spacecraft, or some mechanical malfunctions like an unexpected deployment problem. In many missions the inertia properties of the involved spacecraft systems need to be known. For example, state-estimate and control systems need to know correct inertia parameters; space vehicles need to know how much fuel remains; a servicing spacecraft needs to know the inertia of the target satellite that it captured or docked to in order to stabilize the compound system; spacecraft needs to update its inertia parameters after deployment of appendages, etc. Therefore, it is desirable to develop technology for on-orbit identification of spacecraft's inertia properties. If the technology is successfully developed, it will be able to estimate gross fuel consumption, detect deployment status of spacecraft appendages, and assist on-orbit refueling, repairing, and rescuing.

Approach

The method makes use of an already existing onboard mechanical subsystem to change the inertia distribution of the spacecraft system. As the result of the redistribution of the inertia, the velocity of the spacecraft will change correspondingly because of the conservation of momentum, as shown below. The velocity changing is measurable, from which the inertia properties of the spacecraft can be identified.



Compared with the existing force-based methods, the proposed momentum-based method has three major advantages: 1) it does not consume any fuel because a robot or another onboard mechanism is energized by solar power; 2) it requires to measure velocity only while the force based methods require measuring velocity, acceleration, and force data; 3) it does not need to worry about any internal energy dissipation factors in the system because internal forces cannot change the system's overall momentum.

A simulation study has demonstrated the above-mentioned benefits of this method. Experimental investigation of the method using a 2-D air-bearing based testbed is underway. A student-designed flight verification experiment has been scheduled with NASA's C-9 0-gravity flight test program.

Selected Publications

- Ma, O., Dang, H., and Pham, K., "On-orbit identification of inertia properties of spacecraft using robotics technology", *Proc. of the AIAA Guidance, Navigation, and Control Conf.*, Hilton Head, SC, Aug. 20-23, 2007, also accepted for publication in *AIAA Journal of Guidance, Control, and Dynamics*.