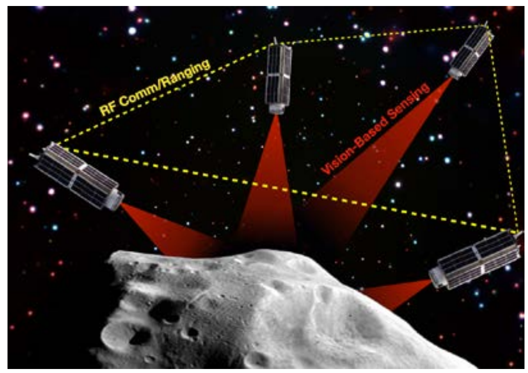
National Aeronautics and Space Administration

NASA facts

Autonomous Nanosatellite Swarming (ANS) Using Radio Frequency and Optical Navigation

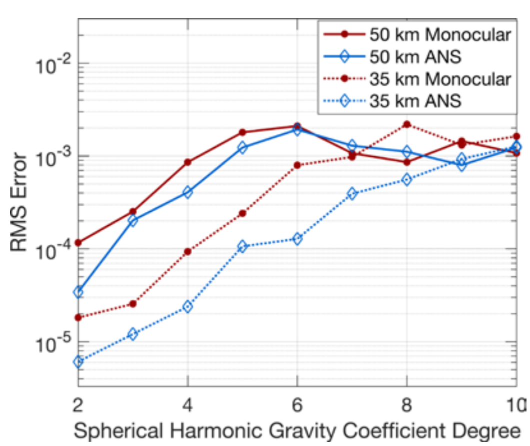
A Distributed Approach to Low-Cost Small Body Exploration

The Autonomous Nanosatellite Swarming (ANS) subsystem is a dynamics, guidance, navigation, and control software unit based on commercial-off-the-shelf avionics, which is distributed and deployed on a cluster of cooperative nanosatellites to enable future exploration missions to near-earth asteroids (NEAs). ANS allows multiple nanosatellites to act together as a single large spacecraft through radio-frequency (RF) cross-links, optical navigation, low-thrust control, and a learning-based guidance strategy. In particular, ANS-equipped nanosatellites can utilize images of a NEA taken from multiple viewpoints to achieve stereo-vision capabilities and characterize the target body's shape, gravity field, and dynamical properties. All of this is enabled by the fusion of major advances to the state-of-the-art in the astrodynamics of relative motion, RF and vision-based navigation, low-thrust control, and autonomous guidance using deep reinforcement learning (DRL).



Artist illustration of the Autonomous Nanosatellite Swarming (ANS) system for NEA characterization.

In order to limit dependence on ground-based systems, ANS provides autonomous 1) navigation and simultaneous asteroid characterization, 2) optimal trajectory planning, and 3) control. Autonomy has the potential to reduce mission costs and achieve more accurate asteroid characterization. First, autonomous navigation and asteroid characterization is accomplished using high-frequency RF links for inter-spacecraft communication and ranging as well as optical tracking of features on the asteroid surface. These measurements are fused in a novel unscented Kalman filter that reduces computation time with no loss of accuracy. The filter also leverages new adaptive and dynamically constrained process noise estimation algorithms for increased accuracy and robustness in the presence of dynamics model uncertainties. Second, ANS is able to autonomously plan the swarm motion online for optimal NEA characterization by leveraging advances in DRL. Third, ANS enables the swarm to deploy into, reconfigure between, and maintain formation geometries autonomously considering computational and thrusting limitations of small spacecraft. The control algorithms developed for these purposes utilize relative orbital elements (ROE) to simplify maneuver planning and execution as well as to guarantee safety and uninterrupted characterization operations.

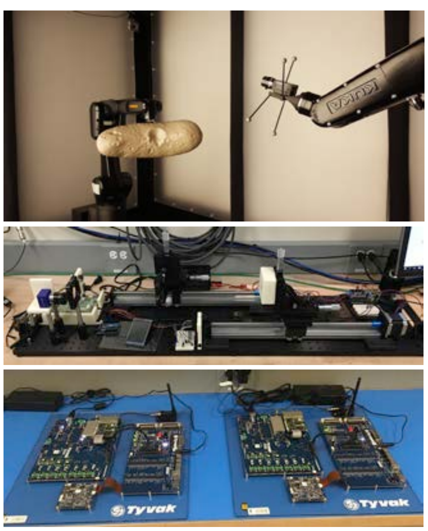


Gravity recovery comparison between ANS and monocular architecture from literature for 50 km and 35 km semi-major axis orbits.

The primary application of ANS is the robust onboard characterization of NEAs for their accessibility and resource value. However, ANS could be readily applied to the characterization of other space-resident objects, including main belt and trojan asteroids and man-made objects. The potential new applications are manifold, and ANS is designed to support the broadest range of operational scenarios and inter-satellite distances.

ANS is being developed by the Space Rendezvous Laboratory (SLAB) in Stanford University's Department of Aeronautics and Astronautics, in collaboration with NASA Ames Research Center. SLAB features custom high-fidelity virtual reality devices as well as a robotic testbed that includes both a 6 and a 7-degree-of-freedom robotic arm for real-time simulation of ANS in closed-loop under realistic illumination conditions. The project leverages algorithms, software, and hardware under development at SLAB, as well as state-of-the-art techniques demonstrated on recent formation-flying missions such as PRISMA (SSC, DLR, CNES) and CPOD (NASA).

The ANS project is managed and funded by the Small Spacecraft Technology program (SSTP) within the Space Technology Mission Directorate. The SSTP expands U.S. capability to execute unique missions through rapid development and in space demonstration of capabilities for small spacecraft applicable to exploration, science, and the commercial space sector.



SLAB's high-fidelity verification testbed. Top left: high-performance Kuka Agilus robotic arms in space environment simulator with photometrically-calibrated illumination panels. Top right: additively manufactured model of asteroid 433 Eros. Middle: virtual reality optical stimulator. Bottom: Tyvak flatsat microcomputers and satellite-to-satellite cross-link.

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The SSTP will enable new mission architectures through the use of small spacecraft with goals to expand their reach to new destinations, and challenging new environments.

For more information about SSTP, please visit:
https://www.nasa.gov/directorates/spacetech/small_spacecraft

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Publications:
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