# OPTICAL NAVIGATION SIMULATION AND PERFORMANCE ANALYSIS FOR OSIRIS-REX PROXIMITY OPERATIONS

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## ABSTRACT

The Origins Spectral Interpretation Resource Identification Security Regolith Explorer (OSIRIS-REx) mission will rendezvous with near-Earth asteroid Bennu (101955), conduct an extensive campaign of observations, collect a sample of regolith, and return it to Earth. OSIRIS-REx, a NASA New Frontiers mission, launched in September 2016, will begin its final approach to Bennu in late 2018. With Bennu being one of the smallest objects to ever to be visited by a planetary spacecraft, the mission presents many navigation challenges, and optical navigation techniques are essential to the successful execution of the mission. Optical Navigation (OpNav), a sub-function of the Flight Dynamics System (FDS), uses information extracted from spacecraft images to assist in the orbit determination (OD) of the spacecraft. While radiometric data are needed for OD throughout the entire mission, these data are most useful in determination of spacecraft position relative to Earth, and their use in establishing the spacecraft state relative to other bodies is highly dependent on the ephemeris knowledge of those other bodies. When such knowledge is limited or uncertainties are relatively large when compared to the scale of the body, use of Earth-based radiometric data types is insufficient to meet mission objectives and ensure spacecraft safety. Therefore, processing of OpNav images near small bodies like Bennu is essential to ensure an accurate determination of the spacecraft ephemeris relative to the asteroid.

OpNav for the OSIRIS-REx mission uses both starfields and asteroid landmarks for navigation. Star-based OpNav is utilized in early mission phases, before global imaging data and digital terrain maps (DTMs) are available for landmark navigation. The objective of star-based OpNav is to determine the position of the target body center relative to inertial star positions. To solve for a more accurate inertial camera pointing in the presence of pointing knowledge errors, the pointing is estimated to minimize the differences between imaged background star locations and the cataloged star positions. Accurate inertial camera pointing allows for precise calculation of the predicted location of the Bennu center of mass (CM). The observed location of the Bennu CM is derived using a variety of algorithms available in the KinetX Star-Based Image Processing Suite, KXIMP. The OD estimation filter minimizes the difference between observed and computed (pixel, line) body centers, along with other radio metric tracking data measurements. Landmark navigation utilizes DTMs to correlate landmark features in an image. These landmark

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measurements are used to sufficiently reduce large pointing knowledge errors once stars are no longer observable in the NavCam frame. The landmark (pixel, line) centers and camera pointing are the key measurements extracted from the images and fed into the OD filter. Once global shape models and DTMs are available, the transition from body-centric to feature-relative positioning can occur. Landmark tracking affords better accuracy and is required to meet challenging ephemeris prediction accuracy requirements for the highest resolution science observations, as well as the delivery requirements for initiating the autonomous touch-and-go (TAG) sample collection event.

This paper will first present an overview of the OpNav concept of operations for the OSIRIS-REx mission. Then, it will present OpNav simulation results and performance analysis for various phases of proximity operations. In late 2017, the navigation team began a series of operational tests using realistic simulations of proximity operations. In addition to providing performance results, the tests and simulations also serve to validate the concept of operations and improve procedures. The test began with a simulation of the Approach phase, where the star-based optical navigation technique was practiced. This simulation spanned the phase where Bennu grows from a point source to an extended object in the imager field of view. The test then simulated insertion into a 1.5 km radius orbit about Bennu, the final critical event for star-based OpNav before the team transitions to ground-based landmark navigation during the first orbital phase, Orbit-A. These tests allowed the team to employ and assess the performance of different centerfinding algorithms and techniques, the results of which will be presented.

This material is based upon work supported by the National Aeronautics and Space Administration under Contract NNG13FC02C issued through the New Frontiers Program.