Flight Demonstration of Non-Cooperative Rendezvous using Optical Navigation

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ABSTRACT

The Advanced Rendezvous demonstration using GPS and Optical Navigation (ARGON) has been executed during the extended phase of the Swedish PRISMA mission. The related spacecraft operations have been conducted successfully in the time frame April 23-27, 2012 by two teams of engineers, respectively from DLR/GSOC and from OHB-SE, which were collocated at the PRISMA mission control center in Solna, Sweden. This paper summarizes the motivations, the experiment goals, the flight dynamics system, and the obtained flight results. Finally, the possible applications of this novel technology to current and future strategically relevant missions are outlined.

This work is motivated by the new generation of on-orbit servicing and debris-removal missions which are discussed at national and international level. Key examples are the DARPA Orbital Express (launched on March 2007) or the DLR DEutsche Orbitale Servicing Mission (DEOS, currently in Phase-B), which drive the demand to efficiently rendezvous, approach, inspect, and dock non-cooperative on-orbit objects. In this context, the ARGON experiment has been primarily conceived to demonstrate ground-based, man-in-the-loop, far-range rendezvous to a non-cooperative, passive, and unknown client using vision-based navigation. The primary instrument used for angle-only navigation is the vision-based sensor of the Danish Technical University (DTU) embarked on the Mango spacecraft of the PRISMA mission. This is used for vision-based navigation of Mango with respect to Tango, which act respectively as servicer and client vehicles during the experiment.

The key capabilities to be demonstrated within ARGON were 1) handover of servicer operations from Norad TLEs to vision-based navigation at large separations (>30 km), 2) planning and execution of safe unambiguous (observable) guidance strategies for far-range rendezvous, 3) collection, analysis, and processing of far-range camera images during rendezvous, 4) routine orbit determination and maneuver calibration of servicer s/c based on GPS measurements, 5) routine relative orbit determination (client vs. servicer) based on angle-only measurements, 6) ground-based maneuver planning and execution to track desired guidance profile, 7) acquisition of hold no-drift point at a prescribed mean along-track separation from the client (3 km) with (anti-)parallel relative eccentricity/inclination vectors.

The aforementioned tasks are representative of future on-orbit servicing mission scenarios, and have driven the design and development of a flight dynamics system for ground-based rendezvous which is described in the paper. The system is a collection of software tools integrated in the fully portable PRISMA Experiment Control Center of DLR/GSOC. Telemetry data from the servicer is down-linked during ground-contacts (over ESRANGE), and later

processed by the ground-based software. This is used for image processing, angle-only relative navigation, guidance and maneuver planning. The resulting Telecommands are sent back to the servicer spacecraft during up-link contacts for the execution of orbit control maneuvers.

A comparison of the relative state estimates obtained during the experiment with the GPS precise relative orbit determination products has been possible after the conclusion of ARGON. This has demonstrated navigation and control accuracies very similar to the rehearsal tests conducted during the preparation activities. The estimated relative orbital elements were affected by typical errors below 4m in the relative semi-major axis, 15m in the magnitude of the relative eccentricity/inclination vectors, and 300m in the mean along-track separation (i.e., 1% to 10% of the actual separation). The obtained angle measurements noise was around 20 arcsecs (i.e., 25% of the pixel size of 80 arcsecs). This allowed a smooth rendezvous from 30 km to the final hold point at 3 km mean separation selected before the start of the experiment. Figure 1 illustrates the resulting relative motion of Mango w.r.t. Tango as estimated by the GPS precise orbit determination after the execution of ARGON. The relative eccentricity/inclination vectors have been properly aligned in a safe anti-parallel configuration in a step-wise manner throughout the experiment. The magnitude of the radial and cross-track oscillations has been decreased from ca. 400 m to 150 m at the end configuration to always keep Tango in the camera field of view and, at the same time, guarantee a minimum separation perpendicular to the flight direction at all times.

The successful execution of ARGON represents a major breakthrough in the research and development roadmap of DLR/GSOC. For the first time, dedicated techniques and software modules specifically developed for vision-based relative navigation have been exercised during actual mission operations in a ground-in-the-loop fashion. In contrast to previous flight demonstrations such as on PRISMA and TanDEM-X, ARGON is a fully non-cooperative experiment where neither knowledge nor control of the client vehicle is available during execution. The ARGON technology could demonstrate reliable, safe and accurate far-range approach to a passively rotating vehicle using angle-only measurements. In addition, the post-facto availability of fully independent and accurate navigation information coming from carrier-phase differential GPS gave the possibility to properly evaluate the achieved accuracies and cross-compare different relative navigation sensors.

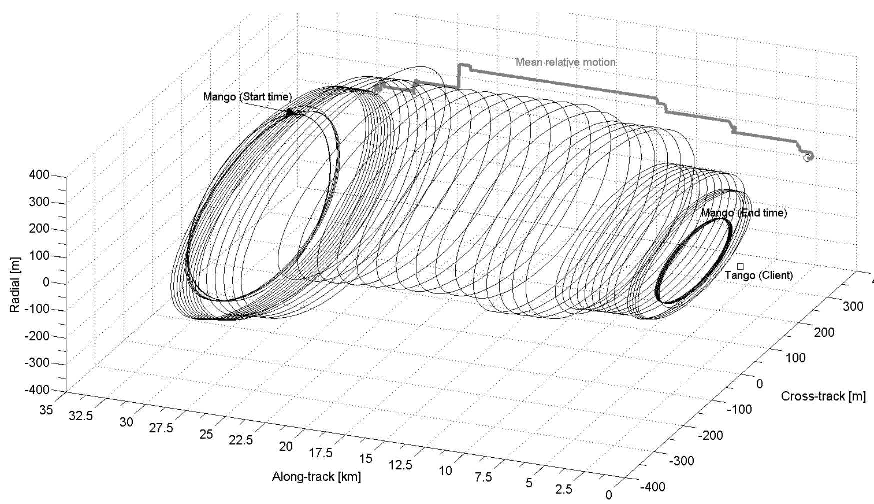

Figure 1. Actual relative position of Mango mapped in the orbital frame centered on Tango (origin) during ARGON (23-27 April, 2012). The true motion is provided by the precise orbit determination based on GPS data.