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Paving the Way for Future On-Orbit Servicing Missions: the AVANTI Experiment

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On-orbit servicing and debris-removal missions are currently drawing the attention of national and international space agencies due to the versatile and strategic applications they could enable. Indeed they are complex missions, which require the raising of the technology readiness level in several involved key technological fields (e.g., guidance navigation and control algorithms, robotics and clamping devices, communication architectures). In this frame, the Autonomous Vision Approach Navigation and Target Identification (AVANTI) experiment, scheduled to be executed in 2016, represents the in-flight technological demonstrator of one of the on-orbit servicing essential enabling technologies: the capability to approach, identify, rendezvous with a noncooperative, passive client from large distances (e.g., > 10 km) in an autonomous, fuel efficient, and safe manner. To this end, in fact, a fully vision-based approach becomes appealing, since it simplifies an aspect of the servicer spacecraft design by exploiting simple passive low-cost sensors (e.g., optical or infrared cameras).

AVANTI is one of the secondary scientific experiments to be accomplished within the FireBird mission, which is a DLR small-scale scientific mission for Earth observation and hot spot detection comprising a constellation of two satellites: TET-1, already launched in July 2012, and the Berlin InfraRed Optical System (BIROS), also designed on the TET-1 satellite bus. In addition, a third-party picosatellite will be released in-orbit by the BIROS spacecraft. AVANTI will be implemented on the BIROS spacecraft, which plays the role of the active servicer satellite, and will use this picosatellite as noncooperative target for the sake of the experiment.

The objectives of AVANTI consist in demonstrating the capability to perform autonomously far- to mid-range (i.e., 10 km to few hundreds of meters of separation range) noncooperative approaches and recedes making use of angles-only measurements. To this aim, the star-tracker embarked on the BIROS satellite is employed as far-range camera to take images of portions of the sky. Then the autonomous Guidance Navigation and Control (GNC) system accomplishes the target identification process to extract the line-of-sight angles to the picosatellite, the relative navigation to estimate the current relative state of the picosatellite with respect to the servicer spacecraft, and the maneuver planning to safely achieve an aimed target relative orbit defined via telecommand from ground.

The development of the AVANTI experiment represents a further step in the DLR roadmap to enhance the expertise in the field of noncooperative rendezvous. Previous flight activities consisted in the Formation Re-acquisition experiment in 2011 and in the Advanced Rendezvous Demonstration using GPS and Optical Navigation (ARGON) in 2012. Both these experiments took place within the Prototype Research Instruments and Space Mission Technology Advancement (PRISMA) mission, respectively at the end of the nominal mission timeline and during the extended phase.

Starting from the so tested ground-based GNC system, the development of the AVANTI exper-

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iment required further effort to achieve the technical advances entailed by its ambitious objectives. As a whole, the main challenge lies in passing from a ground-based approach to fully autonomous onboard operations. Nevertheless, besides this change of paradigm, several other aspects related to the specific orbit scenario, to the hosting platform, and to communication and ground segment requirements influenced the design and the implementation of the AVANTI GNC software. As a result, AVANTI constitutes indeed a realistic technological demonstrator since it aims at validating practical solutions to the following crucial topics, relevant for a general on-orbit servicing scenario:

- *General orbit scenario*
  AVANTI will take place in a low Earth orbit and the difference in the ballistic coefficients of the two satellites determine a strong effect of the differential drag on the relative dynamics. This aspect, intentionally avoided in the previous formation flying missions, becomes relevant for on-orbit servicing missions where the servicer spacecraft might have a definitely different ballistic coefficient with respect to the client. To that end, it was necessary to develop a relative-motion model able to reflect the effect of the differential drag. In addition, although AVANTI implements a vision-based approach, the BIROS orbit is all year long subject to eclipses and blinding of the camera due to the Sun, which impact the distribution of the available optical measurements.

- *GNC software flexibility*
  The flexibility requirement for the GNC software is motivated by the necessity to handle different possible typologies of constraints typically coming from space and ground segments. Regarding AVANTI, the system is able to allow the definition of time slots where no maneuver activities shall occur (e.g., to avoid interaction between maneuvers and payload, to slew for pointing the single-direction thruster system), and the selection of the most appropriate attitude mode (e.g., picture data take, power and thermal needs, communication pointing requirements). Some of these constraints determine a reduction of the time usable for imaging the client satellite, demanding more robustness to the relative navigation system.

- *Autonomy*
  The whole GNC software needs to be based on simple algorithms, given computational time and resources availabilities. Nevertheless it has to provide a reliable solution, robust with respect to the uncertainties that affect an autonomous in-flight application.

- *Safety concept independent from the availability of client absolute navigation data*
  The AVANTI experiment is truly noncooperative, since no absolute navigation data of the picosatellite will be available during the experiment execution. Consequently a specific safety concept has been developed, mainly based on passive safety and especially capable to account for long term effects of the differential drag and for maneuver execution errors.

The paper provides an overview of the the main design choices as well as the key technological advances developed for AVANTI. The expected performance of the experiment, supported by highly realistic simulation results, concludes the paper.