VISION BASED RENDEZVOUS EXPERIMENT PERFORMED DURING THE PRISMA EXTENDED MISSION

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ABSTRACT

PRISMA is a demonstration mission for formation-flying and on-orbit-servicing critical technologies that involves two spacecraft launched in low Earth orbit in June 2010 and still in operation. Funded by the Swedish National Space Board, PRISMA mission has been developed by OHB Sweden with important contributions from the German Aerospace Center (DLR/GSOC), the French Space Agency (CNES), and the Technical University of Denmark (DTU). During the nominal mission that ended in July 2011, CNES successfully demonstrated rendezvous and formation flying techniques based on a new radiofrequency metrology system (FFRF). CNES went a step further by participating to the extended mission phase and performing a complementary experiment in October 2011. A new on-board software was implemented that included this time vision based navigation using cameras accommodated on the chaser satellite. The presence of a two cameras (VBS) designed by DTU for long range and short range observations allowed to achieve two objectives: (1) validate the transition between RF based and vision based control during final formation acquisition, which is necessary for future formation flying missions, (2) demonstrate vision based rendezvous with a non cooperative object to prefigure future orbit servicing activities such as debris capture. The implementation started in May 2011 following the decision point. A new GNC software including the additional navigation functions was developed with Mathworks® code generation techniques, delivered to OHB-Sweden in August for validation purposes and uploaded on October 10th for the beginning of the operations. The paper is focusing on the vision based rendezvous experiment that has been performed successfully from ranges up to 10 km and destinations down to 50 m. The paper content includes a description of the navigation and guidance algorithms, the experiment setup, the whole validation process and a thorough discussion of the achieved results that are compared with other navigation techniques.

Context: The main challenge of vision based navigation comes down to the ability to estimate the full relative state relying on direction angles only. This problem addressed by numerous studies in the recent years can be tackled by the application of manoeuvres that provide some distance observability assuming a sufficient knowledge accuracy. A rendezvous approach relying heavily on cross track manoeuvres has been formerly tested on PRISMA by OHB-Sweden and successfully performed from 30 km down to 50 m. Even though cross track manoeuvres are more efficient for range observability, CNES implemented another approach relying mainly on manoeuvres in the orbital plane to fulfil the tight delta-V allocation. Some cross-track component was however present from the start to introduce some passive collision capability but this scheme introduces only small corrective thrusts.

*Navigation and Guidance***:** The navigation function relies on a dynamic model of the relative motion expressed in Cartesian coordinates (based on the Yamanaka Ankersen state transition matrix). The filter state includes the chaser relative position and velocity expressed in the predicted target Local Orbital Frame. The latter one is propagated on board and is initialized with some “a priori” absolute state consistent with TLE uncertainty. On-board guidance relies on a semi-autonomous approach which has proven its efficiency during the previous rendezvous experiments based on the radiofrequency sensor. The trajectory is not elaborated by the on-board system but predefined on the ground as a list of waypoints which spacing is properly chosen considering the expected range uncertainty profile. In addition, the chaser is told when to apply the different manoeuvres that will be computed on board using the navigation solution. The chaser aims at the waypoints that behave as “attractors” to bend in a progressive manner the real trajectory to the desired one. When the date of a waypoint expires, guidance ignores it and starts aiming at the next one. Efficiency can be actually achieved by allowing the guidance algorithm to skip a waypoint in case of some large variation of the estimated range.

Experiment scenario: Rendezvous experiment was demonstrated four times up to 10 km distance and down to 50 m. Durations were driven by delta-V considerations but could not be stretched too much for operational reasons: they went from 16 to 20 hours with a maximum 1 m/s allocation for the longer one. In all tests, the initial uncertainty was 10% for range, 100 m for radial / cross track components and up to 5 cm/s for velocity coordinates. For consistency, the target initial relative state was chosen on the envelope of the uncertainty domain centred on the a priori relative location.

*Experimental Results***.** All tests were functionally successful with the results detailed in the full paper. In all cases, target detection was achieved within a few seconds and the solution was regarded as valid by the filter. In long and intermediate regimes, VBS target tracking behaviour was very satisfactory and showed an excellent robustness in presence of bright celestial objects or other satellites crossing periodically the field of view. The flawless VBS performance allowed to reach destination within the allocated budget that was computed from ground simulation with conservative error models for VBS and accelerometer measurements. The typical relative range profile during rendezvous is shown on Figure 1.1 with a comparison of true and estimated data. The range uncertainty is slowly reduced when approaching the target and reach the metric level at a few tens of meters. However, the uncertainty at destination is actually higher than the targeted 1% value (it is typically in the 2-3% range) and the benefit of manoeuvres is not observable in flight above 2 km. A detailed analysis has been performed to fully understand this level of performance. Using flight data and ground replay tools, results have been reproduced and compared with simulation data to determine the possible experiment component weaknesses that are developed in the full paper. Finally, a performance comparison of several navigation algorithms is presented using the same metrology data set (ex: relative dynamic model with differential orbital elements versus Yamanaka Ankersen formulation, recursive filtering versus batch, …).

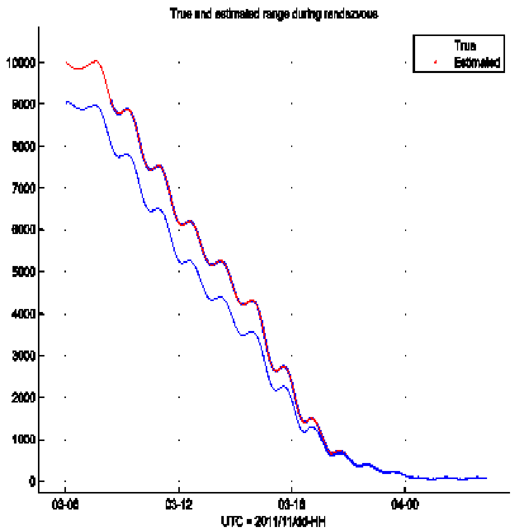

Figure 1.1: Range profile during rendezvous

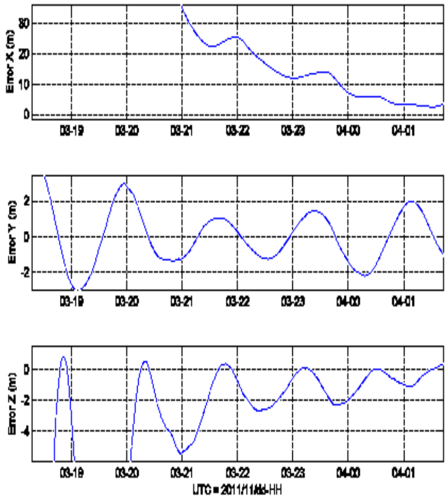

Figure 1.2: Performance at short range

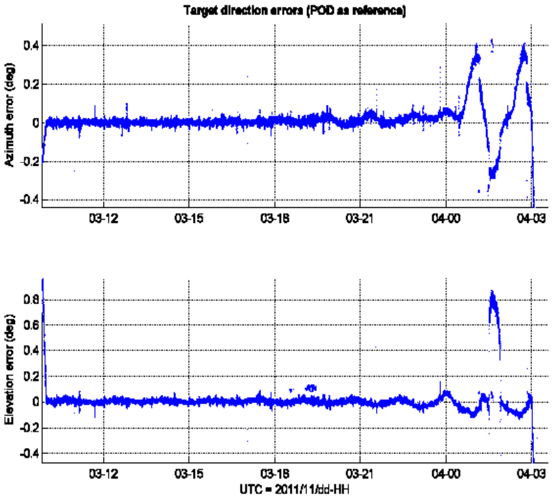

Figure 2.1: Difference between direction angles from VBS and reconstructed from POD data. *This signal is a valid representation of VBS measurement error at short range (beyond 04-00)*

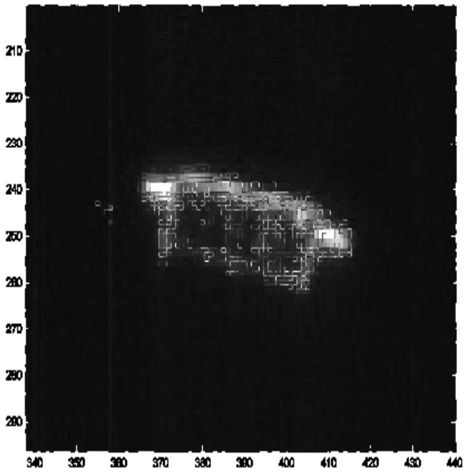

Figure 2.2: Target appearance at 50 m range. *Zoom on a Far range VBS image taken on November 4th 2011. Bright objects on both sides correspond to FFRF antennas.*