32nd IAA SYMPOSIUM ON SMALL SATELLITE MISSIONS (B4)
Small Spacecraft for Deep-Space Exploration (8)

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RADIO-FREQUENCY RELATIVE NAVIGATION FOR MULTI-SPACECRAFT DEEP-SPACE EXPLORATION

Abstract

Small-body sample-return missions have greatly advanced our knowledge on our solar system, as exemplified by the Hayabusa missions, OSIRIS-REx and the upcoming MMX. However, the touch-and-go sample-collection manoeuvre remains one of the riskiest manoeuvres to the spacecraft and the mission. This is a significant hurdle for multi-point landing and sampling, as this risk compounds for every touchdown attempt, where all samples collected previously are put at risk. To enable safer multi-point sampling, future sample return missions are exploring multi-spacecraft architectures, whereby one or more detachable sampler spacecraft perform the risky landing and sampling manoeuvres, while the transfer vehicle maintains a safe distance from the small body during this manoeuvre.

To enable this architecture, a relative navigation system is required which operates in the absence of the GNSS. For sub-kilometre ranges, conventional sensors (cameras and/or lidars) may be used. For further distances however, especially for small spacecraft, a new navigation architecture is required. In the presented paper we propose the use of Radio Frequency (RF) communication link established between the transfer vehicle and the sampler, which is effective for tens to hundreds of kilometres. These sensors should: 1) determine both the direction of arrival (DoA) and range to the sampler spacecraft; 2) enable relative navigation at long distances, ideally exceeding 50 km; and 3) be compact, light-weight and low-power to enable cube-sat explorations.

The presented work is a feasibility study of the above sensors, and in our current iteration direction-finding and range-finding are performed by separate instruments. For direction-finding, a prototype has been fabricated for an x-band link consisting of an array antenna, front-end amplifiers and phase detectors, each realised on small Printed Circuit Boards (PCBs). This prototype was verified to fulfil the required 50 km minimum range and better than 1 degree DoA precision. The RF beacon to be tracked has been miniaturised on a single PCB to under 3 cm by 4 cm. For range-finding, several approaches are under consideration, the simplest form of which modulates the RF beacon signal to enable Time of Flight (ToF)

measurement. This architecture was prototyped with positive results. More sophisticated architectures using small Software Defined Radios (SDRs) are also considered.

This work presents the findings from designing and the testing the proposed RF-based relative navigation sensors, aiming to enable future deep-space exploration missions using multiple small spacecraft, from micro-satellites to PocketQubes.