Optimal on-board guidance control and navigation for spacecraft landing based on vision and proprioception.

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ABSTRACT

The traditional approach to landing spacecraft on planetary bodies assumes a guidance profile computed off-line and uploaded to the spacecraft, a navigation system relying on sensors such as laser altimeters, and a control system able to close the loop and land the spacecraft safely. In this paper, in contrast, we propose an innovative alternative that does not require a guidance profile nor heavy, energy-hungry sensors, and yet leads to near-optimal landing with respect to mass. The guidance profile is substituted by an onboard computation of the optimal control problem solution simplified as to make the computations efficient enough for real time evaluation. The sensory apparatus consists of proprioceptive sensors such as accelerometers and gyro meters and a downward pointing camera.

Our algorithm for the on-board computation of a solution to the optimal control problem is based on novel findings on direct method computations and is able to return an approximation to the optimal feedback with a 50Hz frequency (on a 2.8GHz PC Intel processor). In our simulation we assume a 1 Hz performance for an intended future mission. The basic idea behind the method is to use a simplified internal spacecraft model and an as coarse as possible time-grid for the on-board computations. These simplifications become less and less relevant as the landing proceeds and thus the penalty they introduce on the final optimal value achieved becomes rather small.

The approach on the navigation algorithms makes use of optic flow for ego-motion estimation. The visual measurements of time-to-contact (a measure of the height divided by the vertical velocity) and ventral flow (a measure of the translational speed divided by the height) are combined with measurements from the accelerometers in order to reliably estimate h, vx, and vz with respect to the planetary surface. For these estimates, no knowledge on initial conditions is required, instead it is based on an estimate of the flight path angle. Moreover, gyrometers are only used in order to successfully separate rotational from translational optic flow.

We demonstrate the basic ideas behind our approach using a 2-D spacecraft trajectory model and images generated from PANGU software. Our results indicate that this approach to landing is viable and safe, thus introducing a real alternative to more consolidated technologies. The advantages of its use stems from its use of ultra-lightweight sensors and its implicit robustness due to the on-board computations of the optimal feedback law.