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# HAZARD RELATIVE NAVIGATION FOR PRECISE PLANETARY LANDINGS

## Abstract

Landing autonomously in hazardous environments is a very likely scenario for future exploration missions. Landing in hazardous but scientifically interesting sites on Mars or the Moon, returning to the surface of Venus or a landing on Europa are just a few examples for missions where hazards might be encountered during landing. These missions will need the ability to sense surface hazards, to select a safe landing site, and to avoid the detected hazards during touchdown. This will require autonomous landing site evaluation, but also more accurate navigation capabilities than the current state-of-the-art.

Building upon our previous developments in the field of hazard detection and landing site evaluation, we developed a hazard relative navigation filter capable of limiting the relative error with respect to detected hazards and the selected safe landing site in the surface plane, as well as reducing any absolute navigation error accumulated in the altitude measurements.

Using an error-state Kalman filter and measurements based on images and surface DEMs obtained from a hazard-detection method, we were able to greatly improve both landing accuracy and landing precision with respect to the current state of the art.

With our filter we are able to reduce the hazard relative landing ellipse size by a factor of 3, while also reducing the ranging error to the surface by almost 99% thus enabling accurate altitude estimation during the descent. The developed method proofed to be robust with less than 1% of outliers created.

Performing a hardware-in-the-loop test at the TRON facility at DLR Bremen concluded the work. The results of the test verified the results from the software-in-the-loop testing.

This shows that hazard relative navigation techniques are a good candidate to enable a new class of exploration missions, capable of autonomous landing in unsafe and potentially even unknown landing regions.