

**SENSOR DATA FUSION FOR HAZARD MAPPING AND PILOTING.** K. Kanani<sup>1</sup>, R. Brochard<sup>1</sup>, F. Hennart<sup>1</sup>, A. Pollini<sup>2</sup>, P. Sturm<sup>3</sup>, O. Dubois-Matra<sup>4</sup>, S. Vijendran<sup>4</sup>, <sup>1</sup>Airbus Defence & Space, 31 rue des cosmonautes, 31402 Toulouse Cedex, France ( [kyvan.kanani@airbus.com](mailto:kyvan.kanani@airbus.com), [roland.brochard@airbus.com](mailto:roland.brochard@airbus.com), [florent.hennart@airbus.com](mailto:florent.hennart@airbus.com)), <sup>2</sup>CSEM, Rue Jaquet-Droz 1, CH-2002 Neuchâtel ([Alexandre.POLLINI@csem.ch](mailto:Alexandre.POLLINI@csem.ch)), <sup>3</sup>INRIA Grenoble Rhône-Alpes, Inovallée, 655 Avenue de l'Europe, Montbonnot, 38334 Saint Ismier Cedex, France ([peter.sturm@inria.fr](mailto:peter.sturm@inria.fr)), <sup>4</sup>ESA-ESTEC, Keplerlaan 1, 2201 AZ Noordwijk, The Netherlands ([Olivier.Dubois-Matra@esa.int](mailto:Olivier.Dubois-Matra@esa.int), [Sanjay.Vijendran@esa.int](mailto:Sanjay.Vijendran@esa.int)).

**Introduction:** Autonomous landing on Mars, Moon or asteroids may require a Hazard Detection and Avoidance (HDA) system on-board the lander. Past studies on HDA dealt with the use of camera or LiDARs separately to detect dangerous slopes, boulders and shadow areas. The present work, performed in the frame of an ESA TRP, proposes to use jointly a camera and a LiDAR to take advantage of each while mitigating their drawbacks, consequently improving the HDA performances. Various algorithmic solutions and sensor configurations are proposed and tested in the Mars and asteroid landing cases.

**Challenge of slope mapping:** In the present work, we focus on the computation of the slope map, which is deemed the most challenging part of HDA. The other components of the GNC and HDA system (roughness and shadow, decision making...) are mainly reused from previous studies. In order to meet the requirements of slope mapping, the relative navigation is improved with altitude measurements from the LiDAR.

Considering the requirements on the LiDAR, especially for Mars landing, in terms of mass, power, resolution and frame rate, LiDAR alone is not sufficient to meet the slope mapping requirements. We therefore consider the joint use of LiDAR and camera data to perform slope mapping. The selected LiDAR is a last-generation flash LiDAR built by CSEM [2], whereas the chosen camera is based on heritage from ESA and NASA studies. The retained algorithmic solution for slope mapping is composed of (1) Shape from motion (3D reconstruction) [2] and (2) Machine learning.

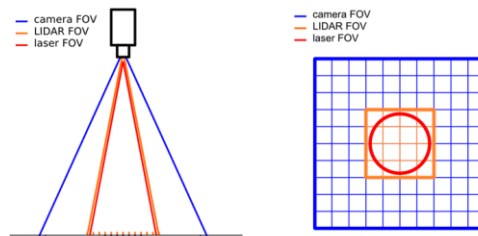
**HDA framework:** Given the low power of the LiDAR and the high altitude at which hazard mapping has to be performed, LiDAR data is very noisy. HDA thus starts with a temporal and spatial denoising of the LiDAR signal. The 3D reconstruction is then performed using LiDAR and camera measurements. A classification step, based on machine learning, is then applied, using the 3D reconstruction output and the camera images, to provide a improved slope map. The slope map is finally combined with shadow and roughness maps, using a fuzzy logic technique to select a safe landing site, with false positive rate less than 1%.

**Evaluation with a high-fidelity GNC simulator:**

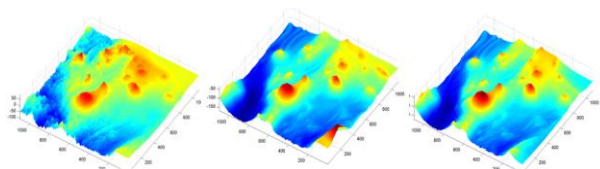
The HDA system is assessed within a whole GNC simulator, including image simulation and image processing in the loop. It includes realistic sensor data simulation, taking into account a model of the flash LiDAR developed by CSEM, and considering real Mars and asteroid terrains, extracted from NASA's PDS database. HDA solutions are integrated into a complete GNC framework, to assess the end-to-end performances of the solutions. The performances of our HDA system, as well as an analysis on on-board implementation, will be presented in this paper.

**References:**

- [1] "Multi-view 3d reconstruction of asteroids". A. Delaunoy, K. Kanani, P. Sturm, O. Dubois-Matra. 5th International Conference on Astrodynamics Tools and Techniques. May 2012.
- [2] "Flash optical sensors for guidance, navigation and control systems". Alexandre Pollini, 35th Annual AAS guidance and control conference, Feb. 2012.



*Example of considered sensor configuration: the LiDAR and the camera have the same resolution but the LiDAR has a narrow FoV.*



*Example of 3D reconstruction: (left) with realistic navigation errors, (right) with perfect navigation, (middle) ground truth.*