VALIDATION AND VERIFICATION APPROACH FOR EUROPEAN SAFE PRECISION LANDING GUIDANCE, NAVIGATION AND CONTROL (GNC) TECHNOLOGIES

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Autonomous safe precision landing is an important capability required to ensure mission success for future robotics exploration landing missions. The landers will be able to automatically identify the location of the desired landing site while detecting hazardous terrain features within it during the final powered descent to the surface, to designate an alternate safe landing site, and to maneuver to the selected safe site. In this respect, the European Space Agency (ESA) has supported for many years the preparation of European solutions for autonomous safe precision landing Guidance, Navigation and Control (GNC) systems. The GNC technologies under development include autonomous vision-based and lidar-based navigation systems (image processing, autonomous navigation algorithms, APS camera and imaging Lidar breadboard) [RD1] and [RD2], terminal descent algorithms encompassing onboard capabilities for terrain relative navigation, hazard map generation, re-designation of safe target during powered descent [RD3]. These technologies are presently at different maturity level and are developed to support primarily safe precision landing missions to Mars and Moon.

The performance validation and verification approach for safe precision landing systems differs from traditional spacecraft system validation. As the main components of such systems, such as relative-terrain sensors, interact strongly with the planetary surface environments, the performance validation plan has to make use of a complex combination of analysis, simulation, and numerous Earth based flight and facility tests. For instance, the validation of the sensors and terrain analysis algorithms must be tested in the field to prove their performance in a relevant environment. These field tests will establish the accuracy and performance of the relative-terrain navigation systems under a range of descent velocities, attitude dynamics, and terrain. The field test results will also be used for validating high fidelity software models that are used in end-to-end simulations and avionics testbeds.

The incremental validation and verification approach consisting of one rapid prototyping of critical algorithms, software and hardware followed by integration into ground and terrestrial technology testbeds where critical interfaces can be validated, performances under representative planetary environment demonstrated, and integration and test procedures developed and verified will be discussed. The suite of simulation tools and ground test facility for the performance validation and verification of autonomous safe precision landing GNC systems will be presented with special emphasis on the high fidelity end-to-end Entry, Descent and Landing Simulator (EAGLE) and the Precision Landing GNC Test Facility (PLGTF).

EAGLE, for Entry and Guided Landing Environment, supports the entire life-cycle of an exploration mission, from conceptual design through to flight operations including non-real-time flight software development and testing, and real-time EDL testbeds with hardware-in-the-loop capabilities. A key feature of EAGLE is the ability to model relative-terrain sensors response and synthesize images for onboard vision based control algorithms. This is made possible thanks to PANGU (Planet and Asteroid Natural Scene Generation Utility) a software tool for simulating and visualizing the surface of various planetary bodies [RD4]: Moon, Mercury, Mars and Asteroids. The PLGTF is based on the Schiebel Camcopter® S-100 a highly versatile autonomous Unmanned Aerial Vehicle (UAV). The Camcopter is powered by an aviation-certified rotary engine, with a payload capability of approximately of 50 kg, a maximum speed of 67 m/s and a service ceiling above 4000 m. The PLGTF will support planetary landing related tasks, including “Vision / Lidar based hazard avoidance” and “Landmarks navigation for pinpoint landing” tasks [RD5].

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[RD3] F. Camara, P. Rogata and al., *Design and Performance Assessment of Hazard Avidance Techniques for Vision Based Landing,* Acta Astronautica, Volume 61, Issues 6-1, June-August 2007, Pages 63-77

[RD4] S.M. Parkes, I. Martin, P. Mendham and S. Mancuso, *Planet Surface Simulation for Testing Vision-based Autonomous Planetary Landers*, 57^{th} International Astronautical Congress, October 2-6, 2006, Valencia, Spain

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