A LiDAR-less Approach to Autonomous Hazard Detection and Avoidance Systems based on Semantic Segmentation.*

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Landing on celestial bodies has become one of the most important challenges in the pursuit of space exploration and exploitation. Some missions in the past years have achieved huge milestones towards this goal, by taking advantage of different strategies. The Rosetta mission ([7] and [3]) deployed a lander, *Philae* [1], whose objective was to obtain information about the comet's gravitational field and surface properties. Hayabusa [4], OSIRIS-REx [5], and Hayabusa2 [8] used a different approach, where they performed Touch and Go (TaG) manoeuvres, which consist on a controlled touch-down on the surface of the celestial body, followed immediately by a powered ascent.

Interacting with the surface of the body of interest has, thus, gained prominence in the mission design and analysis component of the current space exploration activities, even if it poses some of the most challenging points. Landing sequences require very high degrees of autonomy due to latency communication with ground stations on Earth, so being able to rectify the original instructions given to the spacecraft based on the inputs that the sensors it carries receive is fundamental. One of the systems that takes care of this is the Hazard, Detection and Avoidance (HDA) system, whose typical tasks include (but are not limited to) shadow detection, feature detection, slope estimation, or surface roughness estimation.

In this work, the use of passive HDA systems using Convolutional Neural Networks (CNNs) is studied. CNNs offer the benefit of achieving higher accuracy rates, at the cost of a stronger training phase. Three separate layers are proposed for the complete system: shadow detection, feature detection, and slope estimation. The input to the algorithm is the raw image as it would be taken by a camera. Unlike previously mentioned works, the algorithm developed under this research (named *astroHDA*, and included the Astrodynamics Simulator (*AstroSim*) suite [6]) is intended to be capable of generalising for any body it could encounter, instead of being trained for a particular body.

Since the training scheme follows a supervised approach, the generation of ground truth images is fundamental for the creation of the database. In order to

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render these images and create the ground-truths needed for the masks, another module of *AstroSim* was used: *astroRender*. This module uses Blender ([2]) to render the elements of a simulation into an image that simulates what a camera mounted on-board would take.

Combining the results of the aforementioned layers, safety maps are generated following a priority-based logic, where pixels flagged as deep-space are prevalent over the ones flagged as hazard, which in turn prevail over the safe pixels. This means that, if in each of the three layers described above a pixel is labelled differently, e.g.. safe for the first layers, hazard for the second, and deep-space for the third; it will be considered as deep-space.

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