Automated Crater Detection and Classification with Machine Learning

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A widely used and essential tool in planetary science to estimate the age of a planetary surface is to count and measure its impact craters. The traditional approach to this is manual counting, and several databases of craters with diameter larger than 1 km have been developed in this way for the Moon and Mars (e.g., Robbins and Hynek, 2012; Robbins, 2019). However, counting craters by hand becomes intractable with decreasing crater size because the number of craters obeys an inverse power law with size. For example, for each 1-km crater on Mars, there are more than ten thousand 10-m craters. Furthermore, manual counting can be time consuming and subjective (Robbins et al., 2014). Automated crater detection using Machine Learning provides an efficient, objective alternative to manual crater identification (Benedix et al., 2020), which can be used to count, map and analyse the millions of small craters on planetary surfaces.

In addition to providing information about the age of a planetary surface, the shape (morphology) of craters and their ejecta blankets can also provide clues to subsurface properties. For example, the presence of a strong rocky layer buried beneath weak near surface regolith can be inferred from observations of concentric craters and/or rocky ejecta blankets (Warner et al., 2017). In a given region, the size of craters that display such features can be further used to infer the depth to the strong rocky layer. One complication to this approach is that crater morphology can change with time owing to erosion and infilling—known as crater degradation (Fig. 2). For this reason, craters are often categorised by their degradation state (Robbins and Hynek, 2012; Sweeney et al., 2018). An automated method of both detecting impact craters and classifying them based on their degradation state or internal morphology would provide a powerful tool for remotely probing the shallow subsurface of another planet, with potential applications from landing site selection to *in-situ* resource utilisation.

Figure 1 Example crater detections in THEMIS images with YOLO. Number indicates detection confidence.

The aim of this project is to develop and extend an existing Crater Detection Algorithm (CDA) based on the YOLO (You Only Look Once) object detection algorithm (Redmon et al., 2016; Redmon and Farhadi, 2018; Jocher et al., 2021). This approach has proved very successful in detecting craters in Themis data from Mars (Benedix et al., 2020; Lagain et al., 2021). The project will refine and validate the CDA for this dataset (e.g., Fig. 1) before applying the same approach to other similar datasets (CTX and HiRise) from Mars and (LRO) the Moon. A key aspect of the project will be designing and testing protocols to optimally extract and classify craters at a wide range of length scales from the same image and to demonstrate the generality of the method across disparate datasets. The project will then extend the approach to develop a two-stage automated crater detection and classification (ACDC) algorithm. This will provide a fully automated method to detect craters and then classify or score them based on their morphology and appearance (e.g., Fig. 2).

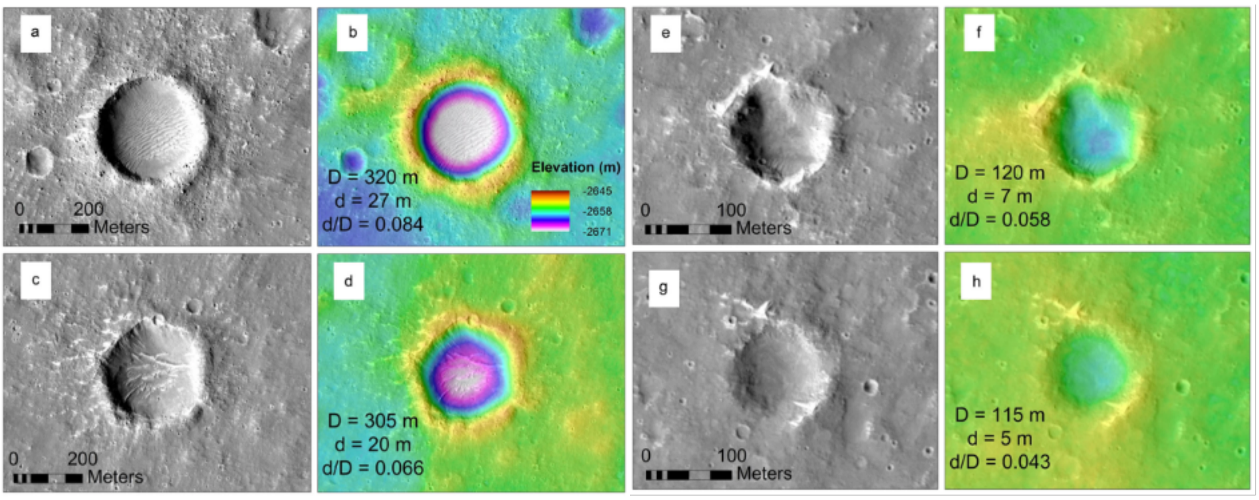

Figure 2 Craters on Mars (HiRise image and Digital Elevation Model) with different degradation states (Warner et al., 2017). (a), (b) Class 2 crater exhibits little degradation with sharp rim and block ejecta visible; (c), (d) Class 3 crater; (e), (f) Class 4 crater; (g), (h) Class 5 crater exhibits strong degradation, with smoothed rim and almost entirely infilled interior.

The successful candidate will join, and be supported by, a vibrant and dynamic research group with world-class expertise in modelling impact processes. They will be trained in state-of-the-art object detection methods using machine learning, planetary image analysis, impact physics and high-performance computing. The candidate will have the opportunity to develop their career and profile by presenting at international conferences and publishing in high impact journals. Candidates for PhD positions should have a good mathematical background and a good degree in an appropriate field, such as earth science, physics, mathematics or computer science.

Supervision

Professor Gareth Collins is an expert in impact physics and numerical modelling of geophysical processes. Dr. Navjot Kukreja is an expert in computational imaging and machine learning. Associate Professor Nicholas Warner is a planetary geologist and an expert on surface processes on Mars.

Research Environment & Training

The Department of Earth Science and Engineering (ESE) is an STFC-accredited PhD training program. The Department is well-equipped with modern laboratories, offices and high-performance computing facilities. It also benefits from a formal collaboration (facilities and staff access; joint symposia) with colleagues in the Department of Mineralogy at the Natural History Museum (NHM). Project-specific research training will be provided by the supervisors through weekly one-to-one meetings, group meetings and a mixture of supervised and online tutorials. In addition, students have access to high-quality transferable skills training provided by the Graduate School of Engineering and Physical Sciences (GSEPS). All students in ESE are automatically members of GSEPS. The Postgraduate programme involves regular report writing and presentation events in addition to research section and research group presentations. Students are strongly encouraged and enabled to attend international conferences and publish their work in respected journals.

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