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Automated feature detection and tracking of RSLs at Valles Marineris through super-resolution restoration and deep learning using HiRISE images and 3D terrain models

Y. Tao and J.-P. Muller

Imaging group, Mullard Space Science Laboratory, University College London, Holmbury St Mary, RH5 6NT, UK

(yu.tao@ucl.ac.uk; j.muller@ucl.ac.uk)

Abstract

In this paper, we demonstrate novel computer vision and deep learning techniques on detecting and tracking of Recurring Slope Lineae (RSL) features in the Valles Marineris area using repeat-pass HiRISE images and Digital Terrain Models (DTMs).

1. Introduction

Studying the transport and formation processes on the Martian surface requires accurate measurements of dynamic features and the underlying 3D static surface. Tracking of such dynamic features has never been achieved automatically before due to the fact that detection and classification methods usually require a static reference frame and do not perform well when the feature itself is changing all the time. In this work, we propose a new approach to detect and track the dynamic features by extracting the "static part" of the Martian surface through super-resolution restoration (SRR) using repeat-pass HiRISE observations.

This study focuses on RSLs which are metre-to decametre-wide dark streaks found on steep slopes, which grow during the warmest times of the year, fade during the cooler periods and reappear again (but not necessarily in exactly the same place). The origin of these features is controversial, with some authors suggesting they are formed by water or brine and others suggesting they are completely dry processes. The implications of each of these formation mechanisms is fundamental to constraining Mars' water budget and habitability.

We selected Valles Marineris, where the highest concentration of RSLs is found on Mars. In the longer term, we aim to provide the first regional map of RSL occurrence, with associated growth rates, timings (including inter-annual variability) and topographic information (including slopes and orientation). In this report, we present the first stage of this study which is using SRR and deep learning techniques to automatically detect and track the RSL features, derive robust measurements, and their associated 3D information.

2. Method

Previously within the EU FP-7 Planetary Robotics Vision Data Exploitation (PRoViDE) project (http://provide-space.eu), we developed a novel super-resolution algorithm called GPT-SRR [3] to restore distorted features from multi-angle observations using advanced features and an area matcher, Gotcha [2] and regularization approaches, achieving a factor of up to 5x enhancement in resolution [4][6].

More recently funded by the UKSA CEOI (SuperRes-EO), we have further developed the SRR system using advanced machine learning algorithms, applied to EO data. The new SRR system is based on the Mutual shape adapted Features [1] from Accelerated Segment Test (O-FAST) [8] and Convolutional Neural Network (CNN) [9] feature matching, the Support Vector Machine (SVM) and Graph Cut (GC) based shadow modelling and removal [10], and the Generative Adversarial Network (GAN) [11] deep learning based super-resolution refinement. The new MSA-FAST-CNN-GPT-GAN (MAGiGAN) [12] system not only retrieves subpixel information from multi-angle distorted features from the original GPT algorithm, but also uses the loss calculated from feature maps of the GAN network to replace the pixel wise difference based content loss of the original GPT algorithm to retrieve high texture detail.

Due to the ability of the SRR technique to extract super-resolution for static features, we are able to restore matched (unchanged) features and meanwhile automatically track the unmatched (dynamic) pixels to characterize and measure the "change". Combining with a CNN based classifier, the detected dynamic changes can be further classified to known dynamic features, such as RSLs.

In parallel, within the completed EU FP-7 iMars project (http://www.i-mars.eu), we have developed a fully automated multi-resolution DTM processing chain for CTX and HiRISE stereo-pairs, called the Co-registration Ames Stereo Pipeline (ASP) Gotcha Optimised (CASP-GO) [5], based on the open source NASA ASP [13] [14], with Gotcha sub-pixel refinement [1] and a unique tie-point based multi-resolution image co-registration system [7]. The CASP-GO system guarantees global geo-referencing congruence with respect to the aerographic coordinate system defined by HRSC, level-4 products and thence to the MOLA, providing much higher resolution stereo derived DTMs.

At the next stage, by adding 3D information from repeat DTMs produced from multiple overlapping stereo-pairs, we are able to restore the unchanged surface also in 3D as SRR requires multiple angle views as inputs. This allows us to overlay tracked dynamic features onto the reconstructed "original" surface, providing a much more comprehensive interpretation of the surface formation processes in 3D.

3. Results

We report on detailed results from a study of one of the RSL sites (centre coordinates: 41.6°S, 202.3°E) in the Palikir Crater, with 8 repeat-pass 25cm HiRISE images from which a 5cm SRR image using GPT-SRR was produced. The SRR image shows the restored static surface without any dynamic features. By tracking the unmatched features from the original HiRISE images, we are able to initially mask out the dynamic features (i.e. RSLs) on the static surface.

Recently, supported by the UKSA-Aurora programme, we are exploiting the CASP-GO system to generate new very high resolution 3D products from HiRISE (see locations in Figure 1) over 40 locations in Valles Marineris using our in-house imaging cluster and the Amazon® AWS cloud computing resources. In this work, we show the latest results of automated RSL detection and tracking using the new MAGiGAN SRR system, a CNN based feature classification system, and CASP-GO.

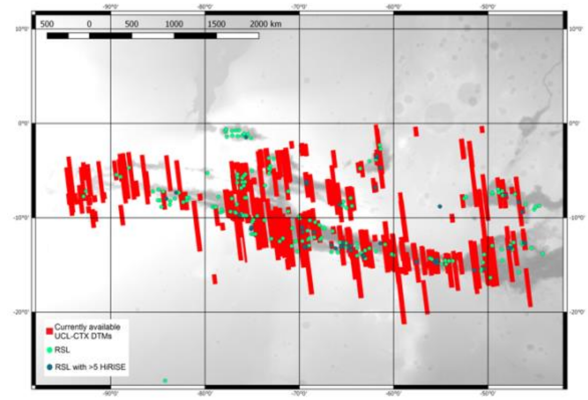

Figure 1 Map of the Valles Marineris region showing a MOLA DTM as the background image with footprints of the available CASP-GO CTX DTMs (in red), the locations of all HiRISE images (in green) and of RSLs identified by [15] and those with 5 or more HiRISE images.

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