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Autonomous rock detection on mars through region contrast

Xueming Xiao, Hutao Cui *, Meibao Yao, Yang Tian

Harbin Institute of Technology, Harbin 150001, China

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Abstract

In this paper, we present a new autonomous rock detection approach through region contrast. Unlike current state-of-art pixel-level rock segmenting methods, new method deals with this issue in region level, which will significantly reduce the computational cost. Image is firstly splitted into homogeneous regions based on intensity information and spatial layout. Considering the high-water memory constraints of onboard flight processor, only low-level features, average intensity and variation of superpixel, are measured. Region contrast is derived as the integration of intensity contrast and smoothness measurement. Rocks are then segmented from the resulting contrast map by an adaptive threshold. Since the merely intensity-based method may cause false detection in background areas with different illuminations from surroundings, a more reliable method is further proposed by introducing spatial factor and background similarity to the region contrast. Spatial factor demonstrates the locality of contrast, while background similarity calculates the probability of each subregion belonging to background. Our method is efficient in dealing with large images and only few parameters are needed. Preliminary experimental results show that our algorithm outperforms edge-based methods in various grayscale rover images.

Keywords: Rock detection; Region contrast; Mars rover

1. Introduction

Hazards detection and recognition on Mars is the basis for future Mars landing missions. It plays a crucial role in route planning and geologic analysis for Mars rover. Using the images of planar surface, rocky hazards can be detected by some autonomous rock detection algorithms. Current state-of-art segmentation algorithms (Castano et al., 2005; Thompson and Castano, 2007; Pugh et al., 2010b; Burl et al., 2016) usually utilize edge-based techniques to identify closed rock contours.

However, it is difficult to extract rock boundaries from intensity images. Different from relatively regular craters, rocks are poorly suited for visual segmentation techniques. They exhibit diverse morphologies, colors, textures or other properties in characterizing them from soil of Mars (Spencer et al., 2009; Dunlop et al., 2007). Meanwhile, impact of varied illumination conditions and dust covering may lead to shadows and boundary blurring of rocks, which further exacerbated the predicament of rock detection techniques (Bonfiglio et al., 2011). Since the complexity of illumination and rock morphologies on Mars, there is unfortunately no standard detection or segmentation algorithm for rock perception. Fig. 1 shows some typical scenes that edge-based methods fail to segment obvious rocks (red[1] rectangle) or execute large portion of false detection (blue rectangle). These big rocks in Fig. 1 share a common characteristic: poor boundary with low contrast to surrounding background, resulting in a failure of edge

* Corresponding author.
E-mail addresses: alexcapshow@gmail.com (X. Xiao), cuiht@hit.edu.cn (H. Cui), meibaoyao@gmail.com (M. Yao), tianyang@hit.edu.cn (Y. Tian).

[1] For interpretation of color in Figs. 1 and 7, the reader is referred to the web version of this article.

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0273-1177/

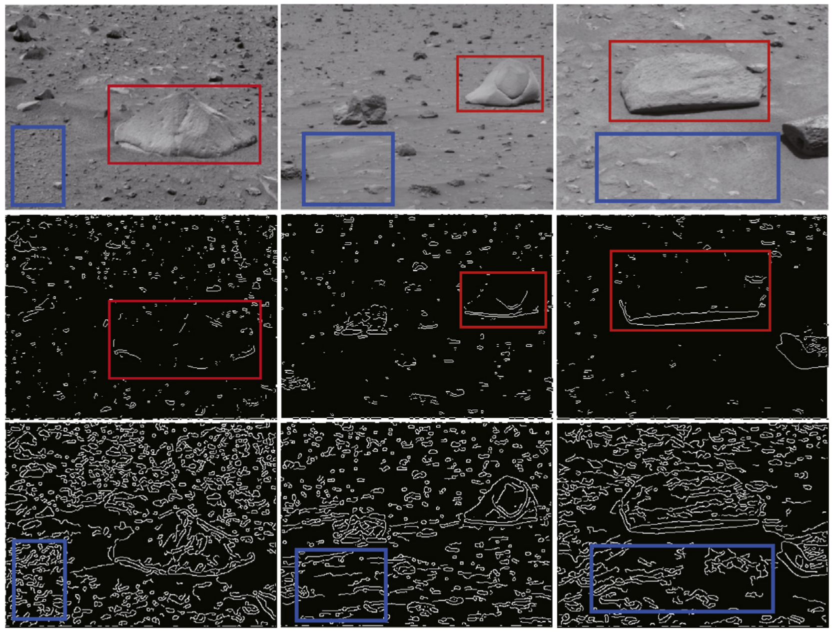

Fig. 1. Some of the notable rocks on Mars that edge detection algorithms fail to adhere contours or generate false boundaries. From top to bottom: grayscale images taken by Spirit Rover's pancam; Edge maps obtained by Sobel detector; Results from Canny operator.

detection using Sobel (Sobel and Feldman, 1968) operator (middle of Fig. 1). Although Canny (Canny, 1986) detector, to a certain extent, can achieve better performance than Sobel, it still suffers from substantially false detection (bottom of Fig. 1). In fact, the core technique of edge extraction methods is basically local gradient operator, which is sensitive to noise and cannot well identify rocks with dusty or blur boundaries. Meanwhile, such detection framework doesn't fully utilize spatial layout and intensity relationship of pixels or regions, which may be better for revealing inner discrepancy between background and foreground.

Another critically influential issue is the memory efficiency of algorithms. State-of-art well-performed visual techniques on-Earth applications are severely limited in current spaceborne computing environment, since there is not high enough processor speed and sufficient memory for complex and time-consuming computation. It plays a major hurdle for modern segmentation techniques. Take flight processor of Mars Exploration Rover (MER) RAD600 for example, the maximum RAM footprint for onboard image analysis is only 4 MB. Current mission-proved rock detection algorithm ROCKSTER (Burl et al., 2016) achieved the footprint below to 3.5 MB at the expense of removing some functional elements.

In this paper, we proposed an efficient rock detection method based on region contrast. Image is grouped into perceptually meaningful atomic regions. All the subsequent image processing is carried out in region level rather than in the rigid structure of pixel grid. Superpixel segmentation provides a convenient extraction framework of image features and will greatly reduce the complexity and memory footprint of algorithm. Only low-level features: average intensity and standard variation of each subregion are used. We measure the smoothness of each superpixel and intensity difference between them. Region contrast is then derived by integrating such intensity contrast and smoothing measurement. Further, more robust detectors are proposed by introducing spatial weight and background distance to the region contrast. Spatial weight is utilized to demonstrate the locality of contrast, while background distance calculates the probability of subregion belonging to background. Region contrast is normalized to $[0, 1]$ to produce contrast map. Rock region will take a large value close to 1 in resulting contrast map, while background is near 0. Contrast map is thresholded using an adaptive threshold to produce raw segmentation results. A morphological operation is then applied to connect the gap between all pairs of nearby rock regions. The final step is to fill holes with a flood-fill mechanism.

The remainder of the paper is constructed as follows: Section 2 presents a brief literature review of modern visual detection methods. In Section 3, we introduce the proposed rock detection method. Section 4 shows the results and evaluates the performance both on real Mars images and indoor experimental images. Section 5 concludes the paper.

2. Related work

Because the visual detection literature on object detection and segmentation is vast, we only focus on some typical papers and explore the possibility for onboard application. In addition, we also present a brief literature review of related rock detection approaches for Mars imagery.