Automated Rock Detection from Mars Exploration Rover Images

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The Mars Exploration Rover (MER) Spirit and Opportunity have collected a large amount of surface imagery since their arrival on Mars in 2004. One of the most important tasks in route planning and geologic analysis for MER mission is the identification of observed rocks. Route planning requires generating maps to show the locations of rocks around the landing site. To do so, rocks must be detected before producing maps using photogrammetric techniques. Also in terms of geology and planetary science, rocks are very important because they might hold the clues to past water activity. In addition, rock shape, weathering, and dispersion carry important information about environmental characteristics and processes.

Rock segmentation is essential for characterizing these attributes. Currently, rock segmentation in MER imagery is mostly accomplished by manual labeling. It is extreme time consuming, tedious and thus becomes impractical with increasing amount of data being collected by the rovers. Automated rock detection is desired. In addition to this demand for post-processing, , rock segmentation is also needed as part of on-board processing. Improvement in rover mobility and lifespan allows future rovers to collect more images. However, the outer space communication bandwidth can not transmit the data volume the payloads can produce. This fact highlights a crucial need for effective data compress schemes and it can be performed by prioritizing regions in an image based on their scientific values. Therefore detection and segmentation of rocks in an image are crucial prerequisites for designing data compress

schemes. This study presents a framework for automated rock segmentation consisting of two steps: texture-based image segmentation as initials and active contours based boundary refinement.

For the texture-based image segmentation step, three texture analysis approaches are used: multi-channel approach, multi-resolution histogram, and inter-scale decision fusion. These three approaches are integrated and embedded into a framework of rock detection using discrete wavelet transforms. The multi-channel approach is based on the information packing property of local transform that most classification related information is condensed into a relatively small number of features compared with the original input image. When a series of local transforms are applied to the input image, output images containing different texture properties, namely multi-channels are produced. In this study, four coefficient channels produced by Harr wavelet transforms such as approximation, horizontal, vertical and diagonal detail coefficients are used. To extract the texture feature vectors from channels, multi-resolution histogram method is applied to each channel. The multi-resolution histograms are formed by generating a histogram for each of the lower resolution images obtained through wavelet transform. The change of histogram is then examined with respect to the image resolution. Such histogram change reflects the variation of spatial information and is measured by the generalized Fisher information content. As the result of the texture feature extraction, texture feature maps at each resolution are achieved. These feature maps provide the information necessary for image segmentation by inter-scale decision fusion. Finally, the hierarchical and interactive k-means algorithm is used for the inter-scale decision fusion.

This texture-based image segmentation can roughly segment rocks in the MER image but can not yield satisfactory rock boundaries. To compensate this problem, the boundaries are refined by means of active contours based on the level set method. Traditional active contours based on the level set method are sensitive to noise and cause the edge-leaking problem. Also, they have difficulty in handling concavities in the boundary due to weighted curve length minimization. We solve this problem by adopting the “edge flow” concept. The edge flow is defined by the flow direction determined by the first directional derivatives of the Gaussian kernel and by the edge energy represented as a flow vector by assigning probabilities to its flow direction. Once this vector field is produced, the edge flow vectors are propagated towards the edges. The propagation ends when the two flows from two opposite directions meet and those locations indicate the boundary edges. Segmentation result based on this edge flows is achieved by linking pixels with high probability of boundary edges and is further pruned by means of level set method. After this boundary refinement using active contour, we achieved not only finer boundaries but also topologically more accurate rock segmentation results than the initial results obtained from the texture-based image segmentation.

To examine its performance, the suggested framework for automated rock detection is applied into Mars surface images collected from MER PANCAM. Each image consists of 1024 by 1024 pixels with 256 gray levels, taken with a focal length 43 millimeters using R1 filter (436nm). The images are achieved by rover Spirit around the Gusev Crater landing site. Experiments present satisfactory outcome and give several worthy notes. The rock segmentation result is yielded by a fully automated process. The proposed framework can account for rock size variations without tuning parameters such as window size due to the use of the multi-scale approach. In addition, the results are robust to shadows or sand covering the rocks since the initial segmentation is performed using texture. The proposed rock segmentation framework can be applied to path determination to ovoid obstacle, rock detection for scientific studies, and surface data training of satellite image on Mars.