ONBOARD SCIENCE ON THE MARS EXPLORATION ROVERS: CLOUD AND DUST DEVIL DETECTION

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Introduction:

Dynamic atmospheric phenomena observed by the Mars Exploration Rovers (MER) include dust devils and clouds. These scientifically interesting events are typically rare, especially when out of season. Traditionally, dust devil and cloud campaigns on MER have been conducted by collecting a set of images at a fixed time pre-specified in the command sequence and then downloading the image set. When few images contain events of interest, this can result in an inefficient use of downlink bandwidth. Recently, a new approach has been developed and deployed on the rovers.

We have developed algorithms that analyze images onboard the rovers to identify the presence of events of interest. In this approach onboard processing is used to screen images for the science features of interest (i.e., clouds and dust devils). By employing this screening approach, many images can be collected onboard resulting in a much greater time range for capturing the rare phenomena. Even when the images cannot be down-linked (such as when too many events are detected), compact summary statistics on the number and type of events can be still be down-linked to provide valuable information.

The code implementing these algorithms has been integrated with the MER flight software and uploaded to the MER rovers as part of the R9.2 software upgrade. Both the dust devil and cloud algorithms have successfully run on the MER rovers and have successfully passed initial checkouts. The first image collected for cloud detection is shown in Figure 1.

Cloud Detection:

In detecting clouds, a single image algorithm was used as the time frame over which the clouds may change significantly is too long to require the rover to remain motionless on a regular basis, as would be necessary for effective application of image differencing.

The approach is to assume that large variations in the intensity of the sky in the image correspond to clouds. Our approach to automating the detection of clouds is to first locate the sky (equivalently, the horizon) in an image and then determine if there are high variance regions in the sky. This algorithm, which operates on individual images, achieved over 93% accuracy in testing on 210 hand-labeled images taken by the Mars Exploration Rover Opportunity. In these tests, there were three misses (false negatives) and eleven false positives. All of the three misses were labeled as a possible cloud (low confidence) by the scientist performing the labeling. No high confidence clouds were missed. For more details on the algorithms and experimental testing see [1, 2].

Dust Devil Detection:

A second type of dynamic atmospheric phenomena of interest on Mars is dust devils. The two most common methods for detecting dust devils are the comparison of two or more spectral bands of the scene and the motion detection using a temporal sequence. We selected the latter as it has application to grayscale as well as color imagery. In theory, detecting rapid motion in the scene is not equal to detecting dust devils. In practice, changes in a sequence of images taken over a short time period of a scene on Mars are from dust devils. Dust devils are high dust opacity features on a dusty background and often have a faint signature in an image. The main challenge is to detect these often subtle features in the presence of significant image noise. The algorithm (Fig. 2) consists of a preprocessing step to reduce image noise followed by an image averaging. The difference between the average image and the input or test image is then computed. Noise effects are removed from the difference image and blob detection is performed on the remaining differences. A buffered bounding box is formed around each detection to ensure the full dust devil is captured. The dust devil algorithm was tested on 385 images divided into 25 image

sequences acquired by the MER Spirit rover. The sequence lengths varied between 6 and 20 images. The algorithm achieved an 85% accuracy rate where the average image was determined using sets of four contiguous images. For more details on the algorithms and experimental testing, including results with different window sizes for the average image (i.e. different number of images used to form the average image), see [1, 2].

References: [1] Castano, A., et al., *ICIP*, (2006). [2] Castano, A., et al, *Machine Vision and Applications*, (2007).

Figure 1. Initial image taken for automated cloud analysis. Although subtle, a potential cloud was identified. This was correct operation as there was not agreement among scientists as to whether a cloud is present or not.

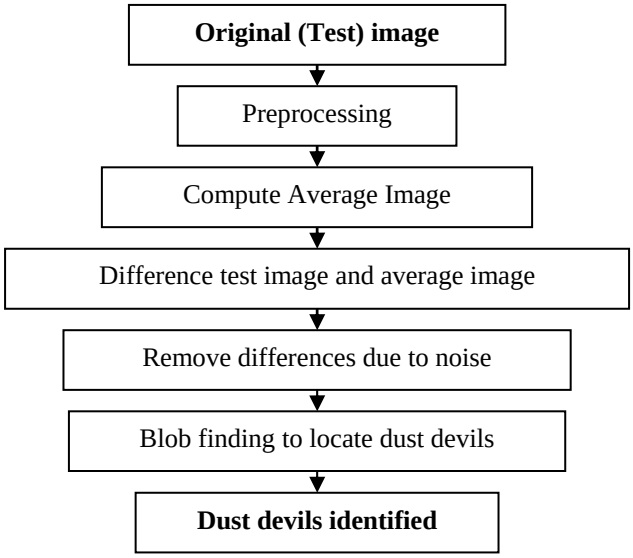

Figure 2. Dust devil detection algorithm.