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Classification of objects consisting of multiple segments with application to crater detection

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1. Introduction

Connected filters and operators using structuring elements (S.E.) are common techniques in mathematical morphology to filter or analyze images for the removal, detection, or classification of individual objects present in those images. Much work has also been done on pattern-based classification or segmentation of objects and texture [3] in images. This is often done by computing and analyzing the distributions of pattern elements (size or shape pattern spectra) present in the image. We will refer to a pattern element as a grain, which is a connected component in the binary or a peak component in the gray-scale case. Any connected component derived from a gray-scale image f by thresholding it at any level is a peak component of f.

These problems are solved using one of the following cases: i) object to be detected consists of one grain, or ii) object or texture is characterized by the distribution of its grains, in which case no precise or complete detection of all the grains is needed as long as some characteristic statistic measure can be derived from these patterns.

Here, the problem is studied where objects consisting of more than one grain but for which a precise and complete detection of all of its components is required. Therefore, our proposed method will consider size, shape, and spatial relations between the individual parts. The two major morphological techniques for doing this are connected filters and operators using S.E.s. Although using the latter detecting objects consisting of more than one grain is straightforward, it (and other methods like Gabor wavelets) has a very high computational cost as the variability in size and shape of the grains and the distance between them would require filtering the image with a huge number of S.E.s. Algorithms using connected filters exist that allow the detection of objects of different sizes and shapes in one iteration. Our main application is the ongoing effort to detect craters in photographs of Mars.

2. Multiple grain objects

Partial solutions to the problem described above using connected operators exist but they all have serious drawbacks. The simplest would be to perform a closing with such a S.E. that the individual parts of the object are merged together, which can then be detected in the usual way. However, this looses too much information about the object. A suitable solution for several applications would be to use operators based on second order connectivities [1] as these do not change the shape of the grains. However, if different objects or textures are located close to one another w.r.t. the distances between the components within each object or texture, detecting or segmenting all those objects or textures correctly will be impossible.

The proposed method uses attribute filters which can be implemented efficiently using Salembier's Max-tree algorithm [2]. The filter uses vector attributes to distinguish the grains based on their shape. For each node N_h^k of the Max-tree the following is computed:

- The area (i.e., the number of pixels) of the corresponding peak component P_h^k.
- A vector containing the moment invariants by Hu, which is used to describe the shape of P_h^k.
- Hu's first moment invariant can be normalized such that it has a minimum value of 1 for a perfect circle and high values for elongated grains, we will refer to this as the elongation measure.
- The mean X and Y coordinates of P_h^k.
- The bounding box of P_h^k by computing its minimum and maximum X and Y coordinates.
- A power attribute $p = A \times (h - h_p)^2$, where A is the area and h and h_p are the gray levels of this node and its parent. This attribute is used to remove grains that are (almost) invisible.

3. Crater detection

A huge interest exists in the identification and characterization of impact craters on Mars. A detailed catalog of craters with their properties (such as size, shape, and depth) is of great importance as it can

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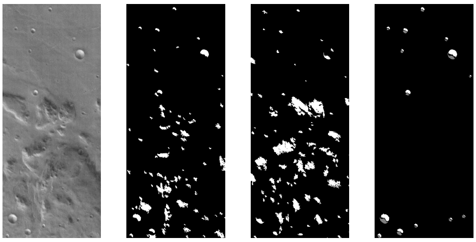

Figure 1. Crater detection. Left to right: input image f, bright crater parts, crater shadow parts, detected craters by pairing the bright and shadow crater parts.

give planetary scientists information of the Martian surface such as its age, and the presence and depth of water. A successful way for automatic detection of craters on Mars is using the elevation maps produced by MOLA [4]. However, these elevation maps have a low resolution compared with the photographic footprints made by the THEMIS instrument of the Odyssey spacecraft. These footprints are narrow but long scans of the surface of Mars. Since the images used are daytime infrared images, the amount and the direction of the sunlight influences strongly the visual appearance of the craters. To be useful for the planetary scientists, an automatically produced catalog should contain significantly more craters than the existing ones and avoid the presence of false positives, i.e., non-crater features classified as craters.

The approach used here to detect craters from the image shown in Figure 1 consists of three steps: i) preprocessing, ii) classification of possible crater parts, and iii) pairing possible crater parts to identify the complete craters. Preprocessing consists of the following steps:

1. Compute the median filter and subtract the filtered image from the original image to remove the background.
2. Remove all peak components that are (almost) invisible using the power attribute.
3. Use an area filter to remove all peak components that are too small or too large.

Detecting the crater parts is done by applying a vector-attribute filter with a few reference vectors describing possible crater part shapes and thresholding the result at a very low (dark) gray level (such as 2), such that all flat zones present become white. It is possible to include a learning algorithm here to eventually improve results if necessary.

The possible crater parts (the bright parts and the dark (shadow) parts) are matched by comparing each bright part with each dark part. If all of the following criteria are met, the two parts are considered to belong to one crater:

- Both parts should have a similar area.
- They should be adjacent to one another.
- The shape of the combined object should be more round than its individual two parts. This is determined using the elongation measure.
- The Euclidean distance is used to compare the similarity of a vector of Hu's moment invariants of the combined object with a few reference vectors.
- The ratio of pixels between the outside and the inside of the largest circle that can be drawn inside the bounding box of the combined object.

A test image, the detected bright and dark possible crater parts, and the final image with the detected craters are shown in Figure 1. In the final image, each matched pair of crater parts is visualized by a white segment representing the bright part and a gray segment representing the shadow part of the crater.

4. Conclusions

A method for classification of objects consisting of multiple segments was proposed and was used for the detection of craters in images of Mars and could also be used for detecting craters on other planets. The technique of pairing image segments works reliably. Work on this and on improving the preprocessing for a more robust detection of craters over the whole Martian surface is still ongoing.

References

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