ENHANCING IMPACT CRATER CONTOURS TO INCREASE RECOGNITION RATES

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Abstract: This paper introduces an enhancement to the edge detection procedures that are part of a general methodology which aims at increasing the robustness of the automatic recognition of impact craters on planetary surfaces. It is demonstrated that the proposed improvement is a major contribution to increase the recognition rates and to simultaneously diminish the rates of false positives. Its performance is evaluated through a comparison with other classic edge detectors, which are applied to a set of images of the surface of Mars acquired by the MOC instrument aboard Mars Global Surveyor, a probe currently orbiting the planet.

1 INTRODUCTION

The identification and counting of impact craters is an approach that has been widely used when establishing the chronology of planetary surfaces (Hartmann and Neukum, 2001). The early manual crater counts on optical images can now be aided by several semi-automatic approaches from the image processing and pattern recognition fields - Homma et al. (1997), Honda and Azuma (2000), Leroy et al. (2001), Costantini et al. (2002), Vinogradova et al. (2002), Michael (2003), Flores-Méndez (2003), Kim and Muller (2003), Brumby et al. (2003), Magee et al. (2003), Plesko et al. (2004), Barata et al. (2004), Kim et al, (2004), Earl et al. (2005) and Matsumoto et al. (2005) – but the generalization of procedures still meets with evident difficulties. Even in a recent study (Neukum et al., 2004) in which a refinement of chronology was proposed for a number of small areas of the surface of Mars, automatic recognitions were not fully trusted, and ended up being edited and manually corrected by human experts. The difficulties faced are many, and are due to several reasons: the different types of terrain, which produce different scattering behaviours; the conditions of illumination of the scene; the state of the atmosphere (when it exists); the location of the sensor; possible confusion with structures which show similar morphologies (volcanic craters, small valleys or basins, collapse structures); the existence of crater-saturated areas where overlapping structures are very frequent; and the degradation of structures by weathering agents (wind, dust, ice, water) and endogenous geological activity (faulting, eruptions).

The majority of the approaches published so far have a quite similar structure: in a first step, the image is screened for edges that correspond to the borders or rims of craters, and these are selected as candidate regions to be used as input for a second step, a matching procedure. So far, the efforts have been more focused on developing the matching phase than on the edge detection one. Thus, as we feel that any improvement that can be achieved in this complicated realm of application can have an important outcome in the final recognition result, we decided to pay more attention to the edge detection phase. Our aim is to supply better candidate regions to the subsequent matching phase, with the goal of increasing the recognition rate and at the same time substantially diminishing the recognition of false positives, i.e., structures that are not craters and that are frequently and wrongly recognized as such.

The variety of textural characteristics which occurs between the images (when they are form widely distant regions) but also within the same image (covering a smaller region) makes it hard to choose a general and single operator. The majority of available edge detectors applied to the images of the surface of Mars normally result in an excess of bad candidates that are difficult to filter out, thus producing unsatisfactory results. Hence, an edge detector based on local information is envisaged, in order to be adaptable to the common variations in the surface features. We compare its results to other classic approaches, in a non-exhaustive mode.

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2 GENERAL METHODOLOGY

We are establishing and developing a general methodology to automatically recognise impact craters on planetary surfaces. Currently, it is being tested with images from the surface of Mars acquired mainly by the instruments MOC and HRSC, the cameras aboard the Mars Global Surveyor (NASA) and Mars Express (ESA) probes, respectively.

The approach being followed is based on the following main phases:

1. Pre-processing and evaluation of the parameters of image acquisition.
2. Selection of candidate regions belonging to crater rims (edge detection).
3. Crater recognition based on template matching (several approaches are being tested and the results compared, namely, the FFT, the Hough transform and other recent template matching algorithms).

This paper addresses the problems related to the second of these phases. The difficulties presented by traditional edge detectors lead us to propose another but simple approach with important improvements in the robustness of the automatic recognition.

3 EDGE ENHANCEMENT

Impact craters are characterized by a generally circular shape, with a wide variation of contrast to the surrounding terrains, a reason why edge detection techniques can play a fundamental step in crater recognition (Fig. 1). The search for edges in a numeric image is one of the most studied problems in image processing due to the very intuitive nature of edges and their clear visual impression.

Figure 1: Image R0100925 acquired with the sensor MOC/WA. The spatial resolution is 245 meters/pixel (NASA/JPL/MSSS).

This section presents the different phases that constitute the proposed edge detection algorithm. This method is based on a local threshold approach and detects an edge whenever a local variation of grey-level is significant. The first requirement is to determine a threshold that incorporates information about the local variations in grey-levels in the original image. For this purpose, the following steps are taken:

1. A 3x3 mask M is centred over each pixel P_{ij} of the original image, in order to compute the local maxima A_{ij}, according to the equation:

$$A_{ij} = \max\left[m - \min(M), \max(M) - m\right] \qquad (1)$$

where m is the mean of the 9 pixels in the mask M.

2. The threshold t is then obtained, taking into account the global range of the matrix A, a procedure which can be translated by the following rule:

$$t = \lambda\left[\max(A) - \min(A)\right] + \min(A) \qquad (2)$$

where λ is a constant, defined by the percentage of the range that is considered. All of the results presented in this paper have λ = 0.2. This value resulted from an experimental process of fine-tuning driven by a search for the best result.

Next, this threshold t is applied to each pixel A_{ij} of matrix A, in order to compute the value (0 or 1) that will be assigned to each new pixel B_{ij} of the resulting binary image B.

This method produces binary images where only highly contrasted local edges are selected. Simultaneously this operation globally reduces the noise.

In comparison to traditional edge detection techniques (such as the first order derivative operators developed by Sobel (1970), Roberts (1965), Prewitt et al. (1966) and Canny (1986) and the second order derivative method introduced by Marr and Hildreth (1980) and designated as the Laplacian of Gaussian (LoG)), this new algorithm shows, in most situations, a better enhancement of the rims, thus allowing a sharper definition of the crater shapes and anticipating a more correct recognition. This is illustrated by the image in Fig. 1 and the images with the edges detected by all the methods mentioned in Fig. 2.

Fig. 1 illustrates the fact that, sometimes, features that can be easily identified as craters by the human eye can be extremely hard to recognize by computational methods. For instance, the rim of the larger crater that can be seen on this image does not present enough contrast to be clearly detected by any of the methods employed (Fig. 2).

From the six images presented one can gather that the different operators naturally produce differing results. It is perceivable at once that the results given by the Canny and LoG operators (Fig. 2e and Fig. 2f, respectively) are not at all suitable for crater recognition. The typical retention of major details by these two approaches becomes a drawback since they are very sensitive to low-frequency perturbations, which are a major feature of the images from the surface of Mars. It can also be noticed that, as expected, the Sobel, Roberts and Prewitt operators produce very similar results (Fig. 2b, Fig. 2d and Fig. 2e, respectively), with the Roberts operator detecting a smaller number of minor edges than the other two. Finally, our approach produces an image (Fig. 1a) where the contours with higher contrast become reinforced: the resulting edges are thicker and a merging of adjacent regions occurs, producing a smaller number of connected components (and avoiding the problem of double edges, a consequence of the long shadows produced by the topography of crater rims and the angle of the sun). Moreover, the smaller edges with low local contrast are not retained, which means that we end up with a less noisy image.

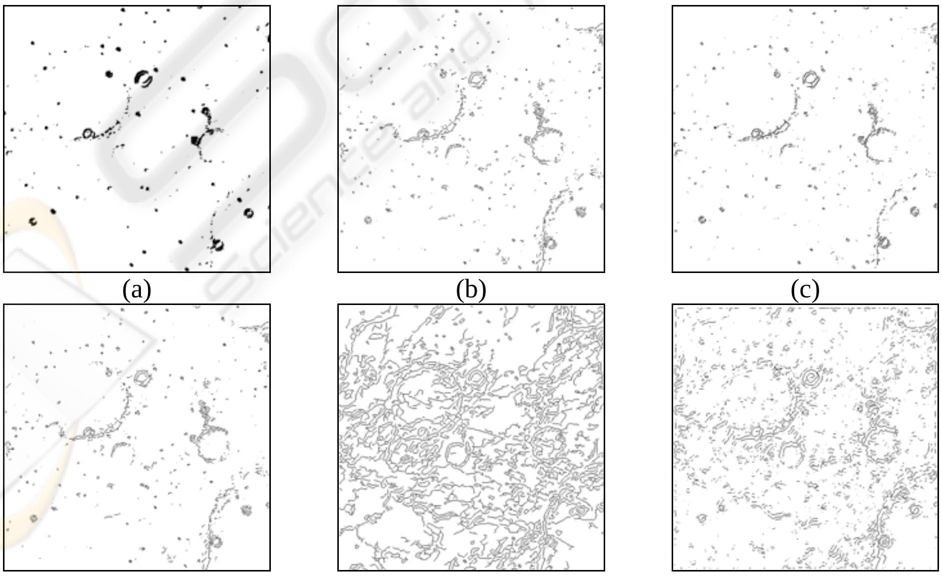
4 CRATER RECOGNITION

The results (binary images) obtained by the application of the edge detection techniques mentioned were used as input for a method for crater recognition that is still in development (phase 3 of our general methodology). Currently the best results are obtained by a procedure based on a template matching approach, through the application of the Fast Fourier Transform (FFT). The general sequence of this crater recognition method is the following:

1. Template matching with a simple circular crater model (a crown) using the FFT approach;
2. Analysis of the correlation matrix in order to find the local maxima;
3. Selection of the maxima in the correlation matrix according to a circularity index.

These steps are performed for each crater radius value within a certain predefined range (normally from 5 to 100 pixels).

This sequence was performed with our approach and with two other edge detectors (Sobel and Roberts). Since the Prewitt operator images were very similar to the ones given by the Sobel operator it was decided to work only with the latter. For illustrating purposes, the craters recognized in the image of Fig. 1 with these three operators are presented in Fig. 3. From the 14 craters that can be visually detected in Fig. 1 (craters with very small



(a) (b) (c) (d) (e) (f)

Figure 2: Edge detection results using: (a) the proposed method; (b) Sobel; (c) Roberts; (d) Prewitt; (e) Canny and (f) LoG.

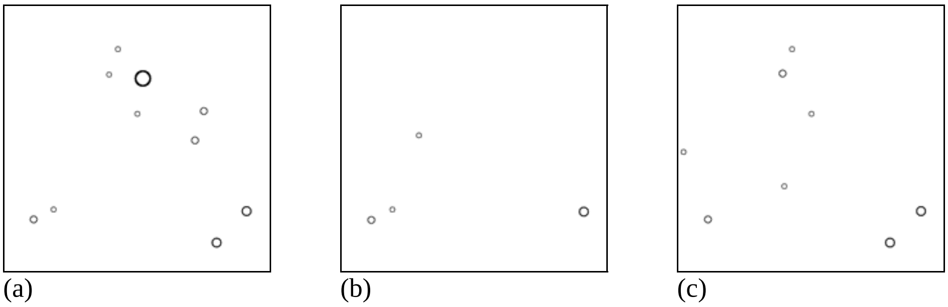


Figure 3: Crater recognition results for image of Fig. 1 using: (a) the proposed method; (b) Sobel; (c) Roberts.

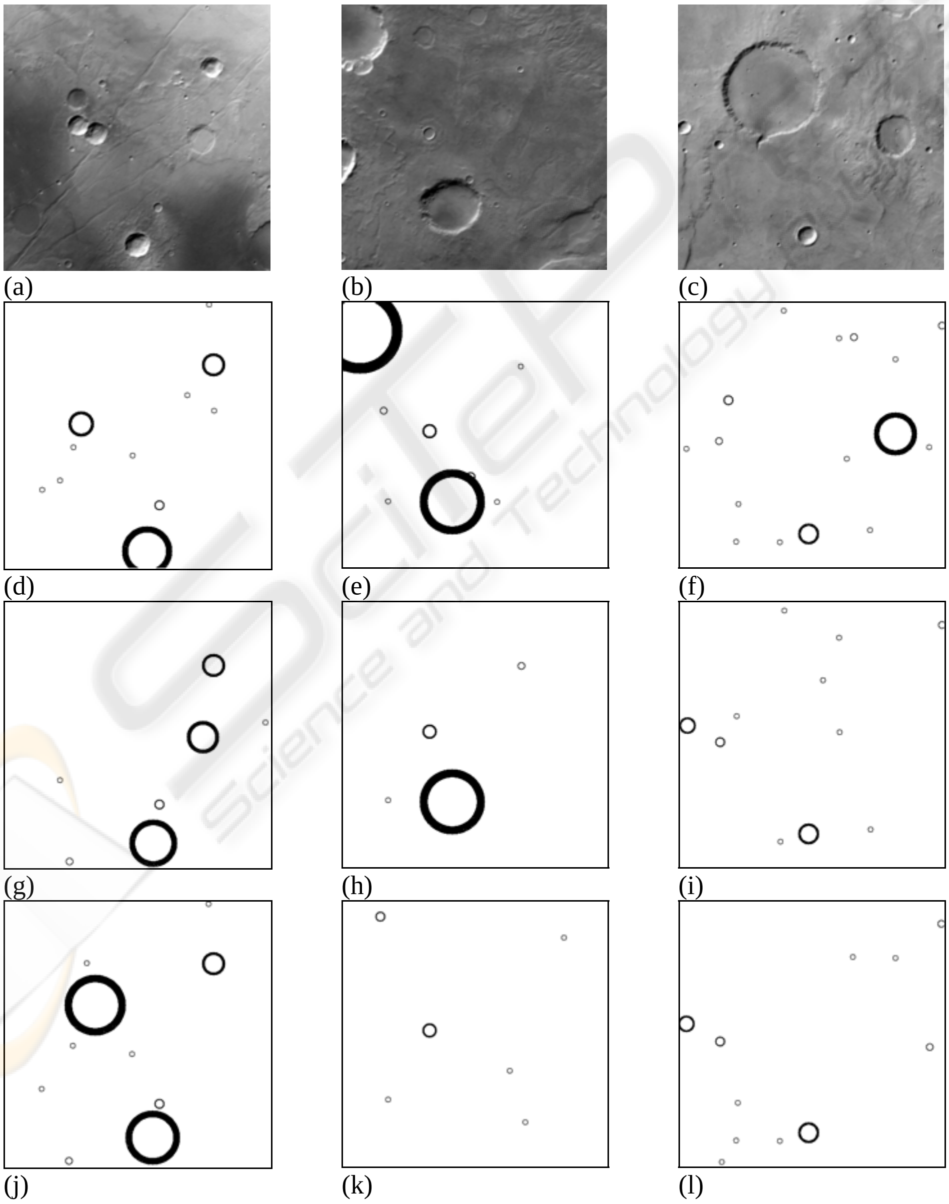


Figure 4: Crater recognition results for images (a) E1900566; (b) E1900716 and (c) R0200837 using: (d, e, f) the proposed method; (g, h, i) Sobel operator and (j, k, l) Roberts operator. [NASA/JPL/MSSS].

to detect 9 true craters (64% of success) and only one false one (Fig. 3a). The Roberts operator detected a total of 8 objects, from which 7 (50%) were true craters and 1 was false (Fig. 3b). On other hand, the Sobel operator (Fig. 3c) did not put in any false crater, but instead was only able to recognize 3 true craters (21%).

Other examples applied to quite different images are presented in Fig. 4.

Although globally our approach is the best one, with higher recognition rates among the three and lower number of false crater recognitions, there are some points that deserve to be mentioned.

For the image E1900566 (Fig. 4a), our approach and the Sobel operator are not able to detect the crater located at right centre, which the Roberts operator is able to recognize. This is sometimes the price to be paid when the detection of false craters is to be kept low: our approach and the Sobel operator add both one single false crater (Fig. 4d and Fig. 4g, respectively) while the Roberts operator includes 3 additional fake structures (Fig. 4j). The linear edges that are visible in this image do not disturb the recognition (but this is due to the matching approach followed).

The results obtained on image E1900716 (Fig. 4b) by our approach (Fig.4e) demonstrate that the craters can be recognized without being completely included in the image (see the recognition of the crater at top left corner) and also that overlap-ping structures can be recognized without any problem.

A compromise between the detection of all the craters and the inclusion of false craters is evident in image R0200837 (Fig. 4c): our approach (Fig. 4f) introduces one false crater but detects correctly 15 out of the 18 craters available; the Roberts operator (Fig. 4l) does not add up any false crater but is only able to detect 10 out 18 craters. Moreover, the detection of the larger crater would be possible but it would introduce an undesirable number of false craters.

5 RESULTS, DISCUSSION AND FUTURE WORK

We have applied three different edge detectors (our approach, Sobel and Roberts) to a set of 26 images obtained by the Mars Orbiter Camera aboard the Mars Global Surveyor probe during the mapping phase. These images, with a spatial resolution of about 245 metres/pixel, cover a total area of approximately 350000 km^2, and were selected from different regions of the planet so that the methodology could be tried on the whole range of cratered terrains present on its surface. The global results can be seen in Table 1.

Table 1: Comparison of results between the proposed approach and other edge operators.

Craters		Our approch	Sobel	Roberts
Recognised	#	157	98	147
	%	62.30	38.89	58.33
False	#	32	27	34
	%	16.93	21.60	18.78

On average, 62.30% of the 252 craters with a diameter larger than about 1.2 km (5 pixels) that are visually recognizable on the 26 images were correctly detected, a result that can be regarded as very satisfactory, considering the differing characteristics of the areas under study. This value is on the same level of crater recognition which is announced in other recent publications (Plesko et al. (2004), Barata et al. (2004), Kim at al. (2004) and Earl et al. (2005)). Our edge detector approach obtains better results than the other two methods, not only in what concerns crater recognition, but also as regards the number of false positives. This is a problem that plagues all the approaches to the issue under consideration, and the results currently presented can be considered as major improvements.

For the future we intend to fully automate the proposed method of edge detection, by making the choice of parameter λ independent from human intervention. We believe that this goal can be achieved through the use of some quality criteria, namely the ones proposed by Levine and Nazif (1985).

In what concerns the template matching phase, which is out of the scope of this paper, the corresponding methodology for crater recognition is under development, and improvements are to be expected. These should lead to higher precision in crater recognition, as well as even smaller numbers of false crater detections.

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