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Inpainting Technique application to Rebuild Partially Detected Dark Slope Streaks

Aplicação de técnica de inpanting para reconstrução de dark slope streks parcialemtne detectados

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ABSTRACT
This paper approaches the implementation of an algorithm that automatically detects features of interest on the Martian surface known as Dark Slope Streaks (DSS), and the application of an inpainting technique to improve the results obtained by the detection. The greatest difficulty for the development of this algorithm is the false positives caused by shadows, depressions or fading of DSS, after a period. To overcome these problems, techniques such as image segmentation and custom filtering routines were used. Sometimes, the extraction algorithm obtains partially detected features, culminating in a loss of quality. However, in order to remove occlusions and restore lost features, the resulting image goes through an inpainting process proposed by Galerne et al (2017). To understand if the inpainting technique improves the quality of the extraction process, we created a reference image and compared with both the image obtained from the extraction algorithm and the resulting image of the inpainting algorithm. This process was repeated for four interest areas. Comparing the mean of pre-reconstruction SSIM and the mean of post-reconstruction SSIM, the inpainting algorithm shows an improvement of 6.13% in quality. Therefore, both algorithms may contribute greatly to the increasing quality of extraction of DSS in the area of cartography.

Keywords: Remote Sensing, Mars, Dark Slope Streaks, Cartography, Image Processing, Inpainting.

RESUMO
Este artigo aborda a implementação de um algoritmo que detecta automaticamente características de interesse na superfície marciana conhecidas como Dark Slope Streaks (DSS), e a aplicação de uma técnica de inpanting para melhorar os resultados obtidos pela detecção. A maior dificuldade para o desenvolvimento desse algoritmo são os falsos positivos causados por sombras, depressões ou o clareamento do DSS, após um período. Para superar esses problemas, técnicas como segmentação de imagem e rotinas de filtragem personalizadas foram usadas. Algumas vezes, o algoritmo de extração obtém recursos parcialmente detectados, culminando em uma perda de qualidade. Para minimizar este problema, a imagem resultante passa por um processo de inpanting proposto por Galerne et al (2017). Para entender se a técnica de inpanting melhorou a qualidade do processo de extração, foi criada uma imagem de referência e feita a comparação com a imagem obtida no algoritmo de extração e a imagem resultante do algoritmo de inpanting. Este processo foi repetido para quatro áreas de interesse. Comparando a média do SSIM pré-reconstrução e a média do SSIM pós-reconstrução, o algoritmo de inpanting mostrou uma melhoria de 6,13% na qualidade. Portanto, ambos os algoritmos podem contribuir muito para o aumento da qualidade da extração do DSS na área de cartografia.

Palavras-chave : Sensoriamento Remoto, Marte, Dark slope streaks, Cartografia, Processamento de Imagem, Inpanting.

1 INTRODUCTION

Almost all Cartography studies use remotely sensed data that has been extracted from some devices such as radars, optical sensors, lasers, etc. To help Cartography studies, several researches have been dedicated to extract features/objects more efficiently from data created by sensorial devices. Consequently, detections that are more accurate lead to better results in data analysis. One of the biggest difficulties faced in data extraction from sensorial devices along years from the same area is related to surface changes. These dynamics of changes is particular evident on Mars due to frequent and global storms that can affect the surface albedo characteristics, generating distinct images from the same area when captured years apart. To analyze this type of data, algorithms are being developed to detect unconventional patterns. These patterns, also referenced as features in this article, can be volcanoes, flow networks, dunes, and craters, among others. In addition to those patterns detected in the Martian surface, we are going to focus on Dark Slope Streak (DSS), an albedo pattern whose nature remains unknown, leading to several studies to research the formation process of DSSs, their composition, etc. (Shorghofer and King, 2011).

Therefore, this paper proposes an algorithm to improve the performance of detection of a previous approach to automatically detect DSS (Carvalho, 2016; Puga et. Al, 2015).

Although achieving good overall performances, some of the results obtained by this previous algorithm show partially detected features, culminating in a certain loss of quality of the extraction process.

These drawbacks can be improved by inpainting algorithms which operate by gathering information around the damaged area and making a subtle junction of this information to the area to be reconstructed, also called as “area of interest”. Besides restoration, inpainting techniques also aim at the removal of occlusions.

Thus, the main objective of this paper is to improve the automated detection of DSS based on the inpainting technique proposed by Galerne and Leclaire (2017), aiming to improve the quality of the extraction results.

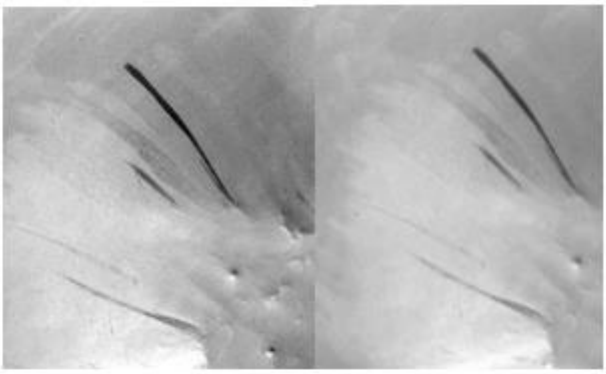
2 THEORETICAL FOUNDATION

a. Dark Slope Streaks

Accodirng Shorghofer and King, 2011 and Sullivan et al., 2001, dark Slope Streaks are defined as: "Dark, fan-shaped trails that extend down steep slopes on the surface of Mars. They are made up of dust and other substances not yet identified, but their nature still unknown."

Second Puga et al., 2016 and Soille 2004, it has been found that these features become lighter and fade over time, often making their detection more difficult, like observed in the pair of images of Fig.1, the left picture was taken in February 2000 and the right one, in February 2004. Both images were captured by the MOC camera onboard the Mars Global Surveyor probe.

Fig. 1: Dark slope streaks fading over time in images captured by MOC camera, in 02/2000 (left) and 02/2004 (right).



Slope Streaks detection requires a high level of accuracy, being mostly performed by specialized teams manually. Automated alternatives are already available in the literature but require improvements to increase their performances.

The motivation of this work is included in this context of increasing the speed and precision of the feature detection process.

b. Otsu Method

Among the several image thresholding methods available in the literature emerges the Otsu method, a very popular algorithm designed to automatically separate objects from the background into a binary image. It calculates the optimal threshold that better separates the objects from the background, (Otsu, 1979).

Briefly explaining, Otsu method is used to find a threshold that minimizes the variance within each class and also that maximizes the variance between classes. This method is suitable for image segmentation due to its simplicity and stability, based only on the distribution of gray levels arranged in a histogram. However, it should be emphasized that this method is very sensitive to image blur, noise or low contrast. The detection is normally adequate if the histogram is bimodal, but becomes worse as the difference between these sections, in which the algorithm divides the image, increases.

c. Inpainting

The pixels of a common image contain real data information and noise. Considering this fact, the inpainting concept aims at detecting relevant information in the selected area's neighborhood to restore damaged portions of the area of interest.

Some inpainting techniques intend to detect which portions of an image have missing data. This would enable a reconstruction algorithm that concentrates only in these areas and, consequently, causing reconstruction errors to be reduced, (Kokaram, 1995).

According Samuel and Kuran (2013), the approaches to this concept can be divided into three main groups: the first handles the restoration of images and videos. The second is related to texture synthesis, in which the restoration occurs through the insertion of textures by the user. Finally, the third is related to the removal of occlusions. This inpainting addressed in this paper is included in the last two groups.

d. Galerne and Leclarie inpainting algorithm

This inpainting technique is based on Gaussian conditional simulations and is considered a texture synthesis algorithm. The first step is the estimation of a Gaussian texture model on the masked area. The user manually inserts the mask that indicates the area to be reconstructed. Next, this model samples the texture in the neighborhood of the area to be inpainted. These samples are used to reconstruct the area of interest during a conditional sampling step, which essentially consists of solving a large, poorly conditioned linear system. In Galerne and Leclaire (2017), it is proposed to solve this linear system relying on the conjugate gradient method, which takes into account the Fourier-based implementation of the system matrix, computed with the Fast Fourier Transform (FFT).

3 TEST IMAGES, METHODOLOGY AND RESULTS

a. Test images

The images used in this work were captured by the sensors MOC (Mars Orbiter Camera) and *HiRISE* (High Resolution Imaging Science Experiment) onboard the NASA probes Mars Global Surveyor and Mars Reconnaissance Orbiter, respectively, with resolutions between 0.25 and 6.5 m/pixel It is worth to mention that original images cover large areas, requiring to be cropped as for containing only DSS areas and therefore to easily develop the algorithm. These cropped images have sizes ranging from about 150 x 200 pixels to 300 x 600 pixels, like shown with some examples in Figures 2 to 5

Fig. 2: image of size 159x132 pixels.

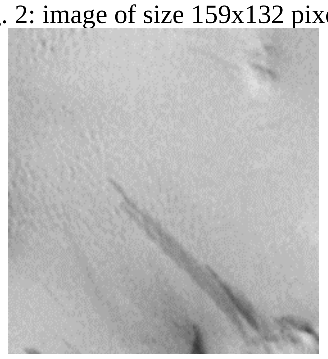


Fig. 3: image of size 539x539 pixels

Fig. 4: image of size 186x240 pixels.

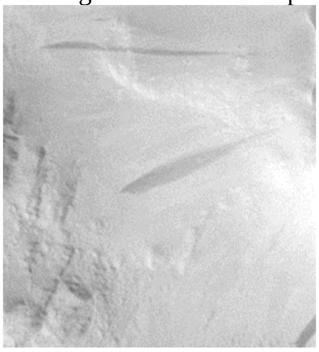
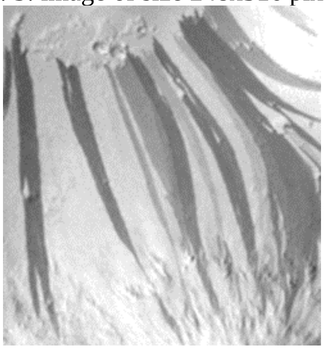


Fig. 5: image of size 248x316 pixels.



b. Methodology

The methodology of this work is divided in three processes: the application of DSS detection algorithm, the application of the inpainting algorithm, and the analysis of the results.

c. DSS Detection Algorithm

According Puga et al., 2015, the detection algorithm is organized in the following stages: pre-processing, leveling of the DSS to allow obtaining a better thresholding in the following, the detection/filtering process itself.

The pre-processing stage consists in the analysis of the image by its resolution, finding the size of the structuring element (SE), and the adjustment of contrast between features of the image. The measurement of the size of the SE is done by calculating the average size of the features in the image. To adjust the contrast, there is a step of calculating the minimum and maximum value of the pixels.

Second Soille, 2004, iIn order to emphasize the Slope Streaks, the algorithm uses a top-hat transform to level the slope streaks intensities and a mean filter to remove small scale noise. This stage is key for a good and smooth detection.

After the pre-processing phase, a custom threshold was built based of Otsu method implementation. The image was divided into several sub-areas to get a better mean of all the image pixels. With all the information gathered the algorithm can proceed to the detection itself, without deforming or shifting the position of the features within the image.

The algorithm uses two different approaches for binarizing the image. One being the most effective, but still lacking of detection in some smaller areas: a high-pass filter, alongside with the removal of small objects operator, the erosion operator and, in order to polish the detection even more, the following morphological operators: spur, removal of isolated pixels and bridging of unconnected pixels.

The second method of binarizing the image is simply using the custom threshold on the same image before the high-pass filter was applied. The method uses binarization alongside with the same operators used on high-pass filter.

For the last step of the algorithm, both binarized images are merged, one being more accurate in smaller features and the other for larger ones. At last, there is a process of removing leftover features in order to polish any abrupt difference cause by the merge.

d. Statistical analysis of the Inpainting Algorithm

In other to evaluate whether there has been an improvement in the quality of the extraction, a binary reference image is built manually and it should illustrate what the image should look like after the DSS has been extracted. The creation of this reference image is only for analytical purposes, and it is not necessary for the execution of the inpainting algorithm.

The user will then select manually the portions of the DSS extraction result that must be reconstructed, after that the inpainting algorithm will be applied, providing the reconstructed binary image.

After that, both extraction result and inpainted result must be compared, based on the reference image, in order to understand if there was an improvement in quality. To analyze statistically this comparison, quantitative metrics must be used.

The lack of quantitative metrics to evaluate the results of an inpainting process is addressed in [11, 12, 13]. The reason why this happens is that there is usually no reference image, and because the content of the area to be rebuilt is unknown. Therefore, in most cases, a visual evaluation is used, where it is verified if the result is the appropriate one. However, visually analyzed results are complex and unpredictable due to human subjectivity factors that are difficult to control. Thus, an alternative is to use known quality metrics of digital image processing area, such as Structural Similarity Index (SSIM).

SSIM is an index that predicts the quality of images and videos, by measuring the structural similarity between two images.

Therefore, the SSIM metric will be applied between the original DSS extraction image and the reference image (SSIM1), and between the inpainted result and the reference image (SSIM2), both SSIM will be compared in the quality assessment.

e. Results

The results obtained from automatic detection on the images from Figures 2 to 5 are shown in Figures 6 to 9 whose detections are outlined by red edges. The original image is overlaid by this detection.

Fig. 7: Detection result from Fig. 6.

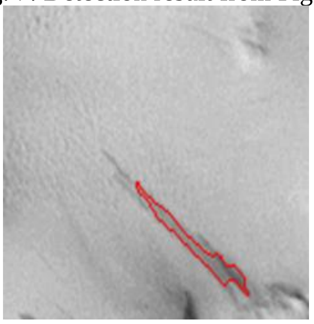


Fig. 9: Detection result from Fig. 8.

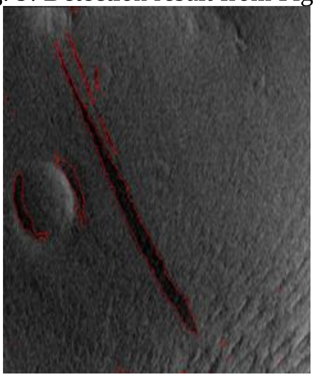


Fig. 11: Detection result from Fig. 10.

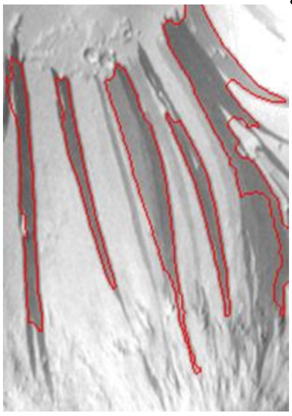
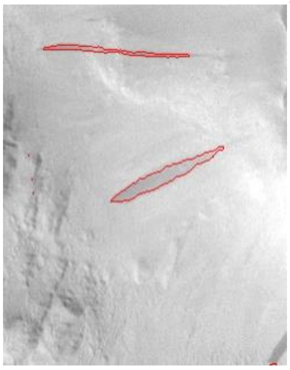


Fig. 13: Detection result from Fig. 12.



After processing the test images and analyzing them, we can state that the algorithm fulfills its role to detect DSS with high performances in different situations. One main issue on previous attempts of the algorithm happened when areas containing Dark Slope Streaks had similar color compared to the DSS itself as shown in Fig. 6, and the detection in Fig. 7, another issue occurred when DSS faded, according to Fig. 12 and the detection in Fig. 13.

Regardless the accuracy of the detections, it must be pointed out that some detected targets are not Dark Slope Streaks, that is, they correspond to false positives such as shadows, terrain reliefs or depressions. One example is the detection in Fig.9, that detected the crater, when it shouldn't.

Another important factor in image processing that directly affects the image quality thereafter the accuracy of the detection is the spatial resolution of the image used in the process [8].

Fig. 14a shows the entry image 1, Fig. 14b, the detected DSS reached from automatic detection, Fig. 14c, the reference image and Fig. 14d, the result obtained with the implementation of the inpainting algorithm.

Fig. 14a: Entry Image.

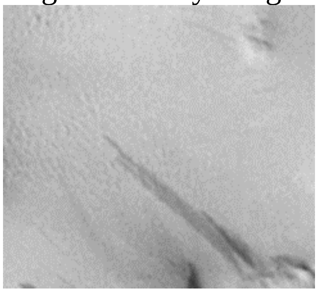
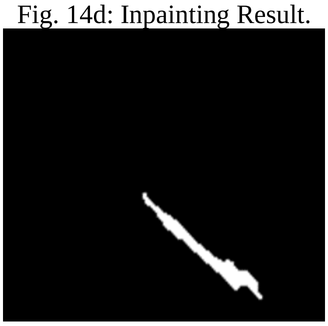


Fig. 14b: Detected DSS.

Fig. 14c: Reference Image

Fig. 14d: Inpainting Result.



The result displayed in Fig. 14a, 14b, 14c and 14d, regarding reconstruction of entry image 1, obtained SSIM in the entry image was 94.64% and the SSIM in the resulting image was 98.48%.

Fig. 15a shows the entry image 2, Fig. 15b, the detected DSS reached from automatic detection, Figure 15c, the reference image and Fig. 15d, the result obtained with the implementation of the inpainting algorithm.

Fig. 15a: Entry Image.

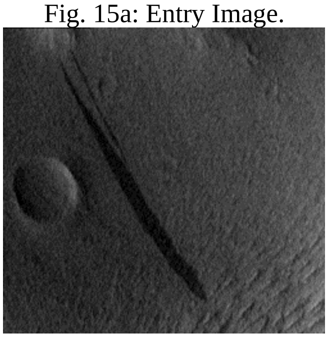


Fig. 15b: Detected DSS.

Fig. 15c: Reference Image.

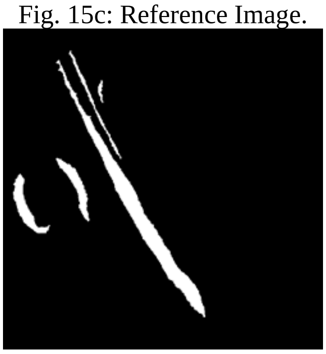


Fig. 15d: Inpainting Result.

The result obtained on image 2 was entry image SSIM with 88.80% and in the resulting image was 96.82%.

Fig. 16a shows the entry image 3, Fig. 16b, the detected DSS reached from automatic detection, Fig. 16c, the reference image and Fig. 16d, the result obtained with the implementation of the inpainting algorithm.

Fig. 16a: Entry Image.

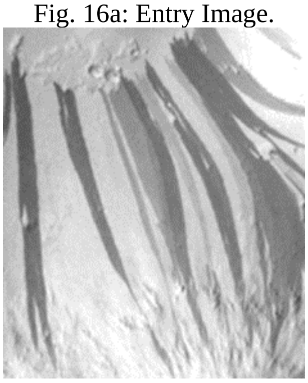


Fig. 16b: Detected DSS.

Fig. 16c: Reference Image.

Fig. 16d: Inpainting Result.

The result displayed in Fig. 16a, 16b, 16c and 16d, regarding reconstruction of image 3, obtained SSIM in the entry image was 90.63% and the SSIM in the resulting image was 97.98%.

Fig. 17a shows the entry image 4, Fig. 17b, the detected DSS reached from automatic detection, Fig. 17c, the reference image and Fig. 17d, the result obtained with the implementation of the inpainting algorithm.

Fig. 17a: Entry Image.

Fig. 17b: Detected DSS.

Fig. 17c: Reference Image.

Fig. 17d: Inpainting Result.

The last result displayed in Fig. 17a, 17b, 17c and 17d, regarding reconstruction of image 4, obtained SSIM in the entry image was 92.34% and the SSIM in the resulting image was 97.65%.

All the obtained results indicate that the applied inpainting technique contributes to the improvement of quality in the process of extracting Dark Slope Streaks, by performing the reconstruction of partially detected features.

The processing time of the algorithm varies according to the number of regions of interest, that is, the smaller the number of regions of interest, the lower the processing time. In addition, the results of the quality of the extraction process of the entry images had a mean of SSIM1 equals to 91.60%, while after the application of the inpainting technique the mean of SSIM2 was 97.73%. When comparing SSIM1 with SSIM2, there is a significant improvement.

Table 1 synthesizes the results obtained before and after the application of the technique of inpainting.

Table 1: SSIM before and after the application of the inpainting techniques.

Test Image	SSIM 1(%) (before inpainting)	SSIM 2 (%) (after inpainting)
1	94.64	98.48
2	88.80	96.82
3	90.63	97.98
4	92.34	97.65
Mean	81.503	97.353

4 CONCLUSIONS

For the automatic detection analysis, it is noticed that Dark Slope Streaks were detected in an efficient way. The methodology used for the detection process can be used for any image containing Dark Slope Streaks as interest features.

There are still improvements to be implemented for the refinement of detection, such as the incorporation of pixels density/image quality treatment.

The pixel density is the ratio of pixels/real area represented, it affects the dimensions of the structuring elements, parameters of function to clean the image, or parameters used in simpler operations such as morphological opening and closing.

Observing the final analysis of the results obtained with the inpainting technique proposed by Galerne and Leclaire (2017), in the entry images, we could understand their high relevancy.

In addition, we believe that the improvement of the quality of the process of extraction of partially detected cartographic features can be applied to other problems in the area of cartography, by supporting processes that update cartographic products.

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