DUST DEVILS DETECTION AND INference OF THEIR MOVEMENT DIRECTIONS. T. Statella\textsuperscript{1} and E. A. Silva\textsuperscript{2}, \textsuperscript{1}Federal Institute for Education Science and Technology, Zulmir Ca\textsuperscript{2}varros street n\textsuperscript{o} 95, Cuiab\textsuperscript{a}, Brazil, e-mail: thiago.statella@eba.ifmt.edu.br, \textsuperscript{2}S\textsuperscript{a}o Paulo State University, Roberto Simonsen street n\textsuperscript{o} 305, Presidente Prudente, Brazil, e-mail: erivaldo@fct.unesp.br.

Introduction: Dust devils are vortexes caused by unstable wind convection processes near the planetary surfaces, due to solar heat. They have been studied on Earth for centuries and were first observed on Mars in orbital images taken by the Viking (1975). These phenomena can achieve miles in width and height, and knowledge about their activity contributes to the understanding of Martian climate, geology and surface modification which is essential to plan future manned missions ([1], [2]). According to [5], air circulation is one of the currently active process which models the surface of Mars and some researches show that these vortexes are responsible for most of the linear and curvilinear surface features of the planet. Moreover, the inference of the wind direction based on dust devils tracks detection is one of the few techniques for verifying circulation models of the atmosphere. The Global Circulation Model (GCM) of the atmosphere indicates a wind behavior according to a pattern N-S and E-W, contrasting with directions inferred from dust devils tracks observation (SW-NE, NW-SE). This fact suggests that more research on aeolian processes is needed and it can be done by image analysis ([4], [5]).

In November 1996 NASA launched the mission Mars Global Surveyor (MGS) with the high resolution camera Mars Orbiter Camera (MOC) that took images of the planet between the years of 1997 to 2006 in a geometric resolution up to 1.5 m per pixel. There are hundreds of high resolution images depicting Martian surface and the amount of information on them is greater than the human capability to analyze and extract relevant data from these products to characterize the planet under study ([3]). That made room for automatic feature extraction processes. This paper is about using Mathematical Morphology to automatically detect dust devils tracks and infer their directions, which contribute to a better understanding of wind circulation on mars surface. Images acquired by the Mars Orbiter Camera onboard Mars Global Surveyor depicting the regions of Argyre Planitia (MOC2-220-A) and Southwest of Argyre (E10-04279) were used as study areas and are shown in figures 1 and 2.

Method: Involves the following steps: 1) preliminary filtering (median filter and morphological surface area open filter); 2) First automatic binarization (by Otsu method); 3) Morphological granulometric analysis (Structuring Element (SE) disk); 4) Morphological closing top-hat; 5) Second automatic binarization; 6) Skeletonization (by Zhang and Suen method); 7) Morphological granulometric analysis (Directional line SEs).

Results and Discussion: The first step was to apply a preliminary filtering to the scenes so that noise and bright features like dunes could be smoothed. Next, the images were automatically binarized using the Otsu method ([7]). The resulting images had the tracks in black and anything else in white. They were
negated \( \text{neg}(f) = 1-f \) so a granulometric analysis using morphological openings could be done. At this step disk-like SEs were used to infer the size of the biggest connected components in the study areas. The radii of the SEs which removed the biggest connected components from images MOC2-220-A and E10-04279 were 27 pixels and 11 pixels, respectively.

Then morphological closing top-hats using SEs whose sizes were defined by the granulometry were applied to the filtered images to enhance the tracks by removing scenes illumination gradients. A new binarization by the Otsu method was applied to detect the features (figures 3 and 4) and a skeletonization was carried out. The method chosen here was the one proposed by [8]. This method avoids segmentation at the corner of objects (an undesired effect generally caused by other methods) and preserves the connectivity of the skeleton. A granulometric analysis was done over the skeletonization (this could have been done over the binary images but it would have caused errors due the thickness of the objects), this time using a family of directional line SEs. For the MOC2-220-A image, the frequency of pixels removed by openings with directional SEs was the highest (785 pixels) when the SE was oriented at 90°. For E10-04279 image, the highest frequency of pixels removed (1,123 pixels) occurred when the SE was aligned with the path at 135°. Those are very good indicatives of the main direction followed by dust devils in the study areas. From binary images was also possible to determine the area covered by tracks for each scene. That resulted in 54,984 pixels for MOC2-220-A (~14% of the image) and 27,872 pixels for E10-04279 (~6% of the image).

**Conclusion:** Tracks have been detected with a fairly good precision, except for the older and too much smoothed tracks. In such cases only a few streaks could be segmented. By making a visual analysis one can see that the main orientations were well identified. They resulted in N-S direction for MOC2-220-A image, which corresponds to the predicted direction of martian GCM; and SW-NE for E10-04279 image, which agrees with [5] and [6] observations. A final conclusion about dust devils main behavior cannot be done with only two study areas. Future work will apply the method in a greater number of images. This work was concerned in developing a method to detect dust devils tracks and infer their directions. The method is automatic and can be applied to images despite their resolution or the size of the tracks. The area covered by the tracks was also calculated from binary images. This is a good indicative of the frequency, intensity and size of dust devils crossing the study areas.