

OpenCV-based Craters Detection on Mars

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Abstract — The following report provides an overview of the research being conducted within the Mars Craters Research as part of the Remote Earth Observation Sensing class, held at ETI Faculty of Gdańsk University of Technology. This report covers an overview of the craters phenomena, their origins and creation process. The primary goal of the project was to identify satellite photos of Mars surface and identify craters on them. This report provides description of the methods used. A discussion about strong and weak points of various approaches applied conclude this paper.

Keywords —mars, craters, satellite, observation, opencv.

I. INTRODUCTION

Mars is the most similar planet to Earth in our Solar System. Its sidereal day is 24h 37min, which is roughly 40 minutes longer than Earth's. Mars gravity is weaker and equals to 37% of Earth's gravity. Its atmosphere is probably the most distinct feature that sets Mars and Earth apart. Its average density (11.55 hPa) is around 0.6% of Earth's (101.3 hPa). The atmosphere consists of 96% of carbon dioxide, 1.93% of argon and 1.89% of nitrogen. Oxygen is present only in trace amounts (0.174%). For more details, see [2].

Asteroids occupy various orbits throughout the whole Solar System, but the area behind Mars orbit has the highest concentration. Therefore it often nicknamed "an asteroid belt". As of Nov. 2019 there are over 851.000 minor bodies known in the Solar System [3]. Earth is naturally protected from incoming minor bodies by its thick atmosphere and a large Moon that can alter the trajectory of incoming objects. Neither of those mechanisms as present on Mars. Also, the close proximity to main asteroid belt contributes significantly to the amount of surface impacts. As such, Mars is a very attractive place for meteorite research.

The goal of the research conducted was to study evidence of incoming bodies. Since the Mars' atmosphere is so thin, most of the incoming meteors end up hitting the surface and becoming a meteorite. The primary goal of this research was to study the data available, experiment with various techniques and come up with the most reliable method for detecting craters.

II. METHODOLOGY

There are currently 6 orbiters providing orbital photos from Mars: 2001 Mars Odyssey (2001), Mars Express (2003), Mars Reconnaissance Orbiter (2006), Mars Orbiter Mission (2014), MAVEN (2014) and ExoMars orbiter (2016). Year of reaching Mars orbit specified in parentheses.

III. RESULTS

A. Initial data selection

During our research we noticed that some impact craters have very bright edges on images from infrared sensor at night from THEMIS mission. NASA provide the global mosaic from these images in with a resolution of 100m. Several experiments proved that it's a good source data for craters recognition. Using this data has one limitation, however. Not every crater has a bright edge. Crater must to have a specific minimal depth (at least 0.4-0.5 km) and the radius cannot be too big (< 15 km).

Another difficulty was introduced with an observation that craters are not the only objects that have a bright edges. Other terrain forms, such as hills, may show similar behavior. Fortunately, we came up with a way to filter them out.

B. Early experiments

Initial experiments were conducted with GIMP [4], a general purpose image editing software with powerful plugins collection. The image selected for this experiment was coming from THEMIS instrument and had a resolution of 100m. Two methods were investigated. The first method uses subtle Gauss blur, thresholding (with pixels within range 160-170 treated as white), dilate filter [5] that widened and enlarged the detected areas. Finally, the resulting white pixels were used as a mask. An example result of this method has been presented in Fig. 1, denoted red.

The second, alternative approach assumed somewhat similar approach, albeit the details were different. The first step used aggressive Gaussian blur, thresholding at the value 160, detecting edges using Gaussian differences and the second thresholding. The resulting white pixels were used as a mask. An example result of this technique is depicted in Fig. 1, denoted in green.

Several conclusions emerged from those experiments. Initial blur is necessary to remove minor noise distributed throughout the whole image. The blur parameters must be adjusted to the size of the craters being searched. This implies that to find craters of any sizes, several passes of the algorithm are necessary. Too aggressive blur performs poorly, even for large craters. They're being merged with smaller craters in the area, resulting in unusable blobs of pixels. Small hills can distort the results. With increasing latitude, craters' circumference become less pronounced and hills becoming more visible, thus making detection more difficult.

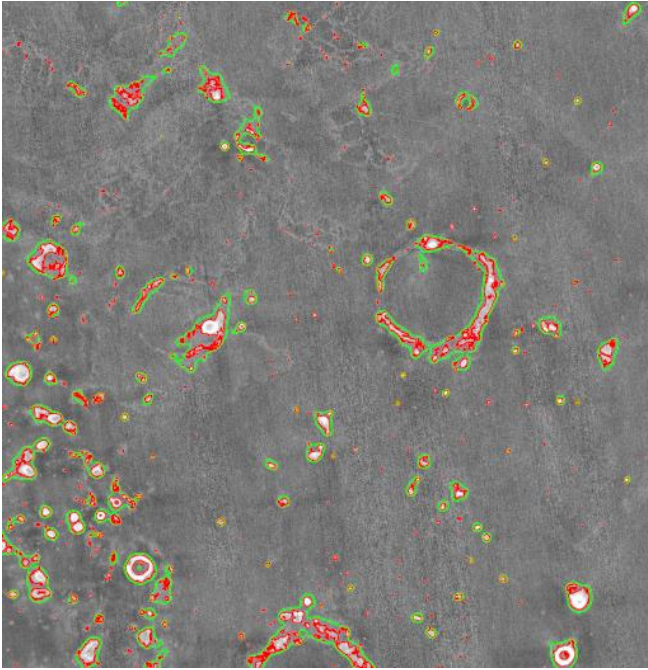


Fig. 1: GIMP experiment

IV. PATTERN RECOGNITION USING OPENCV

The next step in our research was to use OpenCV library [6]. OpenCV is an open source computer vision and machine learning software library. To ease the development, we used the basic python bindings for OpenCV [7] as well as extra wrapper for it [8]. Several experiments were conducted.

Every OpenCV based experiment had some common characteristic. First, it used the cv2 wrapper, loaded the input image file, processed the image with the results both being displayed on the screen and written to file. JPEG format was used. In some cases the detected craters could be saved as a .CSV file and the detected shapes exported to .SHP file.

In all cases the primary mechanism for detecting craters was circle Hough transform (CHT) algorithm [9] with Hough Gradient detection method, available in OpenCV [10].

A. OpenCV experiment 1

In this experiment, an image acquired by THEMIS was used. It was a night-time IR mosaic with 100m resolution. See [13] and [14] for details. Exact photo identifier was THEMIS Night IR 100m Global Mosaic (v14.0)JM137.184-15.195_256_2048ppd.jpg.

The algorithm used is as follows. First, the image is converted to grayscale. Second, a median blur is applied with the following parameters: Radius 12, Percentile 66, High precision. Then an edge detection mechanism is used with the following parameters: algorithm used: gradient, amount 1. The final step was to use Sobel edge detection algorithm.

The result of this experiment is presented in Fig. 2.

B. OpenCV experiment 2

This experiment is an extension of the previous one. It Used the same approach as before, but the parameters of the circles being looked for are different. The parameters were (150, 10, 50) and (550, 50, 500), where the first parameter denotes minimal distance between the nearest detected circle, the second denotes minimal radius and the third one denotes maximal radius. All parameters expressed in pixels. Results of this experiment are presented in Fig. 3 below.

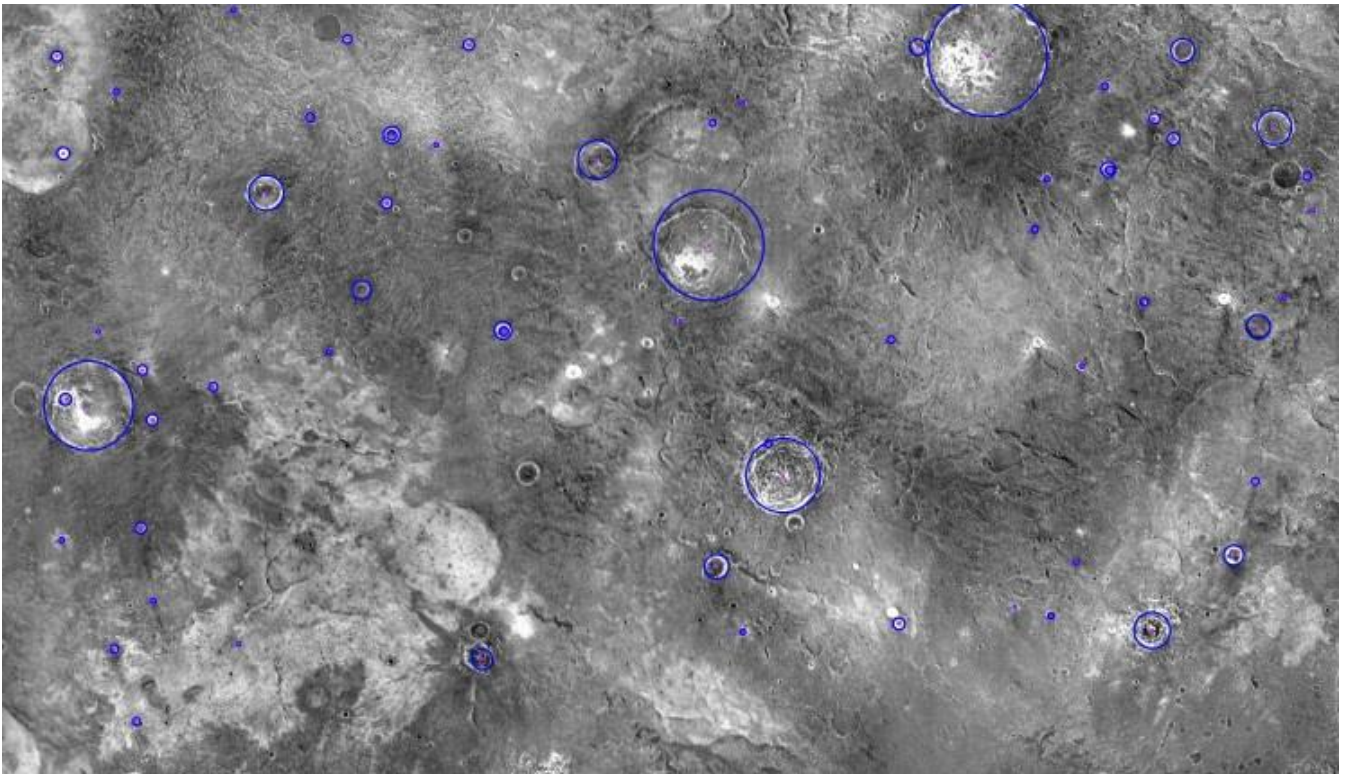


Fig. 2: OpenCV experiment 1

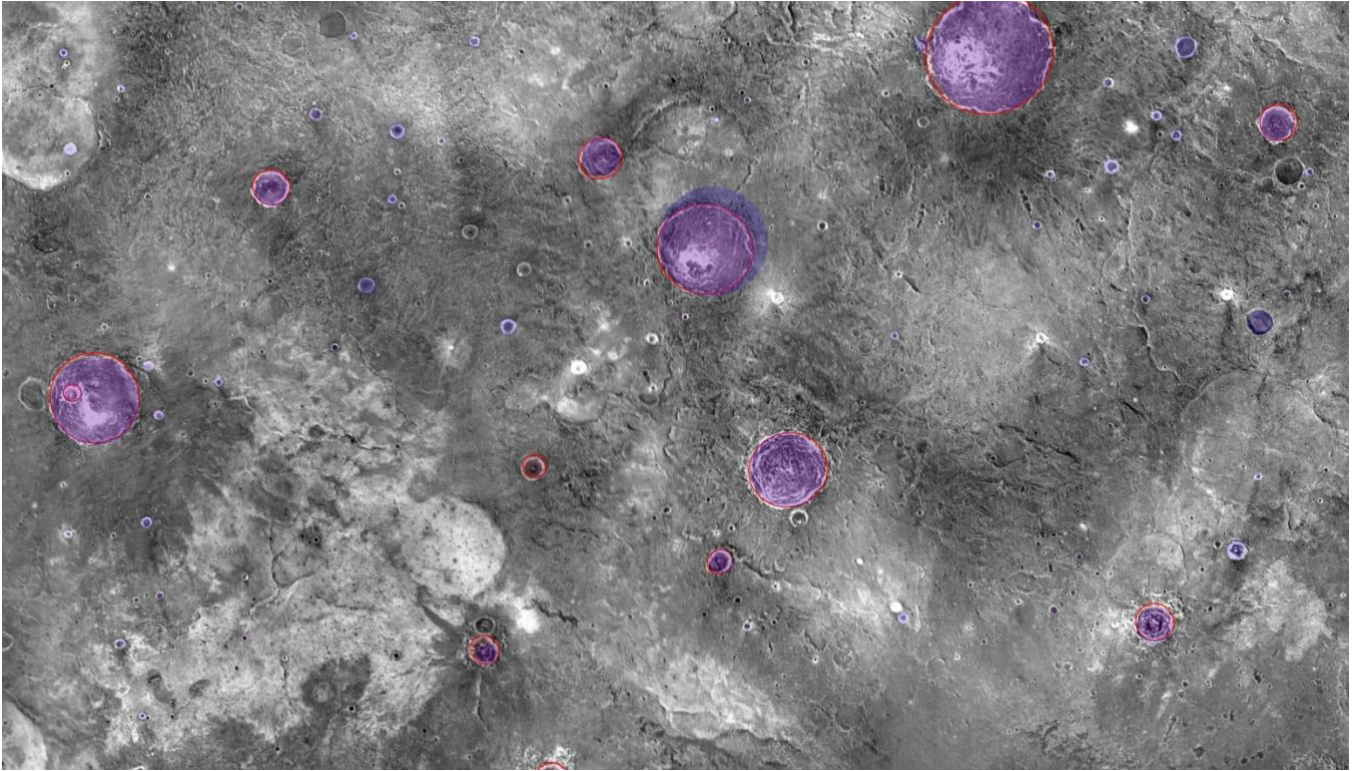


Fig. 3: OpenCV experiment 2

V. ALGORITHM PERFORMANCE

The following section attempts to assess the performance of the developed algorithms.

The data provided by JMars [11] was used as a benchmark reference. For the image analyzed in OpenCV experiment 2, we got the results as presented in Table 1.

Radius [km]	Actual	Recognized	Accuracy
> 30	3	0	0
25-30	0	0	0
20-25	1	0	0
15-20	1	0	0
10-15	9	3	0.33
5-10	6	1	0.16
4-5	5	4	0.8
3-4	10	2	0.2
2-3	17	4	0.24
1-2	55	20	0.36
< 1	240	30	0.13

Table 1: Unbound evaluation

This table compares detected craters (Recognized column) with information provided by JMars project. Accuracy denotes overall number of detected craters over all craters known.

Assuming general, unrestricted search, the algorithm is able to reliably detect only certain class of craters: diameter between 2 and 15km and depth at least 500 meters.

Different craters have different characteristics. The good performance within those ranges and poor in others can be explained by the properties of the images being analyzed. We used data acquired by THEMIS Infrared Night sensor. On those photos, some craters have a very bright edge. This phenomena, however, is only observed in craters with

specific diameter and depth. If radius was too large then the edge of crater has too low height and the edge was too damaged or otherwise not pronounced well enough. Also, if the crater was too shallow, the edge wasn't distinctive enough and thus difficult to detect. This can be explained by the characteristics of the craters. Large craters, caused by impacts of bolides (large meteorites) or small asteroids are very uncommon and most large craters are millions years old. Even though erosion on Mars is much slower than on Earth due to lack of vegetation and almost complete absence of water, with sufficient time the erosion process can be almost as destructive as on Earth.

Therefore this method is best for recognize craters with radius lower than 15 km and depth higher than 0.5 km. Assuming the crater detection problem is limited to those criteria, the algorithm performs much better. The results for specific ranges has been presented in Table 2.

Radius [km]	Actual	Recognized	Accuracy
15-10	3	3	1
5-10	1	1	1
4-5	4	4	1
3-4	2	1	0.5
2-3	3	2	0.66

Table 2: Parametrized evaluation

VI. CONCLUSIONS

It was somewhat surprising how much satellite data is already widely available for Mars. It is equally surprising how much processing went into the datasets before they have been made available. The Mars data is available from multiple sources. For example, Arizona State University

provides JMars software that aggregates most of the available information. NASA even provides WMTS and WMS services with Mars data. Those can be imported and explored using regular Earth-focused GIS software, such as QGIS. However, it has one major problem. There is much worse standardization regarding coordinate systems on Mars than there is on Earth. Also, QGIC has poor support for Mars coordinate systems.

JMars software provides a better alternative. It allows to explore data from many missions and sensors, easy search and data visualization, with exports to high resolution raster and vector formats available.

During our research we noticed that some impact craters has very bright edges on images taken with THEMIS infrared sensor. NASA provide the global mosaic from these images in resolution 100m. This specific dataset was particularly well suited for craters recognition. However, it had one limitation: not all craters had bright edges. Craters must have a specific depth (at least 0.4-0.5 km). The radius cannot be too large ($< 15\text{km}$).

Craters are not the only objects with bright areas. However, with proper filtering, we were able to remove most of unwanted (non-craters) areas.

The Circle Hough Transform is a nice algorithm that is well suited for the task of crater detection. We assumed that impact crater have rounded shape. This has the side effect of not being able to detect impacts of bodies entering the atmosphere at very shallow angles, as those impacts result in very elongated, asymmetric craters.

During filtration sometimes parts of the crater's edge will have a different brightness than others. For old craters, the edges may be incomplete or have different structure.

The algorithm developed seems 100% reliable with regards to false positives. There were no false positives. Every detection was an actual crater.

Assuming the parameters of radius less than 15km and crater depth at least 500m, the algorithm achieved a very good accuracy of **85%**.

The research project as scoped has been limited in time and scope. The workload during this semester is particularly high and this is one of eight projects being carried out. Nevertheless, we managed to achieve reasonably good results.

The source code along with the high resolution experiment results are available at [1].

A. The next steps

There is a number of new directions this research could follow. Here are several ideas:

Compare with Machine learning. There are papers available [12] that present results of machine learning based automatic crater detection.

Automate image selection. We spent considerable amount of time to select the location for analysis. The image retrieval and the whole analysis process should be automated. That way the whole belt around equator could be evaluated.

Improve robustness of the code. The Circle Hough Transform performs well, but it's very dependent on the parameters used, in particular the minimum and maximum diameters of the circles being looked for. We could improve the algorithm by doing multiple passes (small, medium, large craters).

Make the solution user friendly. Currently the solution is a set of python scripts that need to be run manually. Furthermore, it requires some configuration (such as setting PYTHONPATH variable and possibly other paths). We could make it more convenient to use, document it and turn it into a software usable by average user, without any python knowledge required. One possible way to achieve that would be to turn the code into a QGIS plug-in.

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