Title:
CNN based framework capable of analysis both local and global context for precise mapping of the surface of Mars

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Name of Academic Institution: Warsaw University of Technology

Level of study or work: Research Project
(Bachelor thesis, master, PhD, research, project, etc.)

Information about you (and your team): My name is Kamil Choromański. I'm PhD candidate at Warsaw University of Technology. My main research areas are spatial data mining and spatial big data methods. My primary focus revolves around processing diverse spatial datasets such as images, point clouds and crowd-sourced data to extract valuable insights vital for scientific advancements and business innovations. I have participated in numerous research projects where I'm utilizing my knowledge to develop useful and scalable solutions based on spatial big data and artificial intelligence technologies.

Area of interest
(Identifying the problem, explain why it is important and the current relevance of the topic, up to 250 words)

In the field of automatic mapping, data from aerial or satellite observations may not always be sufficient to determine land cover accurately, while information derived directly from the terrain perspective (e.g. in the form of panoramas taken by cars or humans) and elevation models provides a rich source of additional knowledge. This problem also applies to the topic of automatic mapping of the surface of other planets - such as Mars, where both satellite imagery and elevation data (e.g. HIRISE system) and information collected by rovers such as Opportunity or Perseverance are available. Achieving high accuracy is particularly important for tasks like mapping geomorphological formations, as it is vital for understanding the planet's history and planning future exploration expeditions.

Neural networks (especially convolutional networks (CNN) and transformer-based networks) are the method with the best results in the topic of automatic mapping based on spatial imagery data. However, it is not straightforward to efficiently and effectively integrate two such diverse data sources as satellite imagery and in-situ data into a neural network-based system.

Among the main problems are the issues of preparation of both datasets, including proper selection and interpolation of in-situ information. Another issue is the network architecture itself. It must properly balance the information from satellite imagery and that from the rover, so that one data source does not dominate the other during the network training process.

Approach to the problem

(Describe your methodology or technology and how it will solve the problem you identified, up to 300 words)

The purpose of the concluded research was to develop a methodology capable of integrating multiple data sources (both from satellite and rover) to improve the capability of automatic mapping of aeolian (related to wind) formations on Mars. Data were acquired from both satellite imagery (the MRO mission's HIRISE camera) and the Opportunity rover NAVCAM camera. Image data, digital terrain model and its derived models, i.e. topographic position index and terrain ruggedness index were used in this process. The Meridiani Planum area was selected for the testing of the proposed method.

HiRISE satellite data in the form of stereo pairs were downloaded from the Planetary Data System, McEwen (2007). The data were processed into orthoimages and terrain models using NASA ASP (Beyer A. (2018)). The NAVCAM camera images were used, as they provide the most information about the terrain context.

A modified approach used in Ceo et al. (2018) was utilized to process the data acquired from the rover. In the first step, it was necessary to convert the individual images taken at each location into a panoramic image. Using additional metadata, spatially localized panoramas were produced (fig 1.), which were then used for feature extraction using Places-CNN extractor.

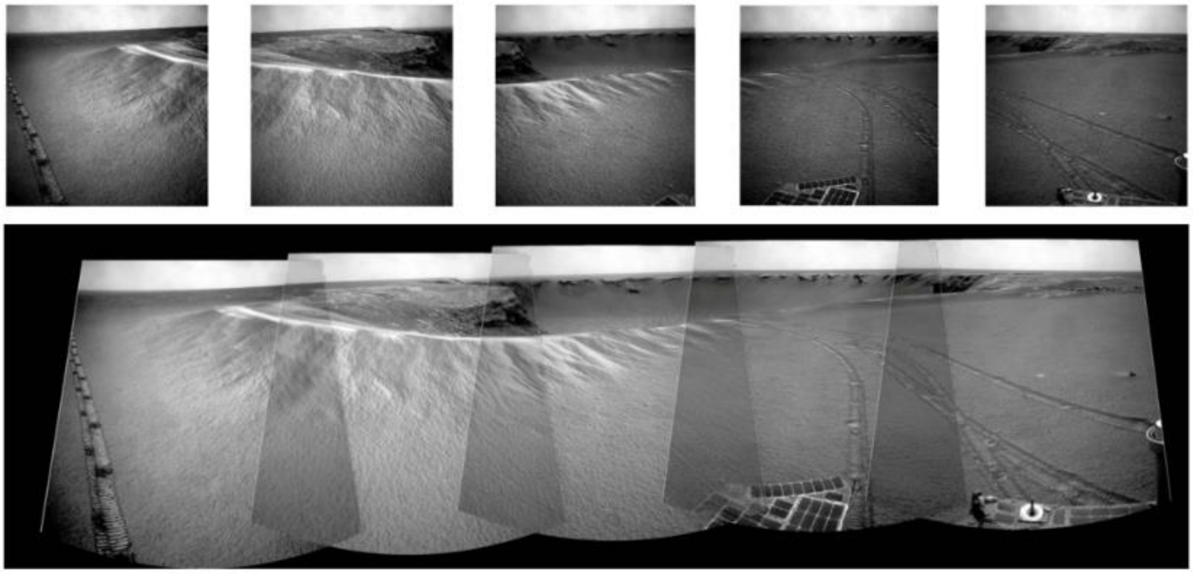

Figure 1. Panoramas creating.

Feature vector (2048-dimensional) was than reduced with use of Principal Components Analysis method to 50 dimensions. Finally, Nadaraya-Watson interpolations was utilized to spatially relate extracted (fig 2.).

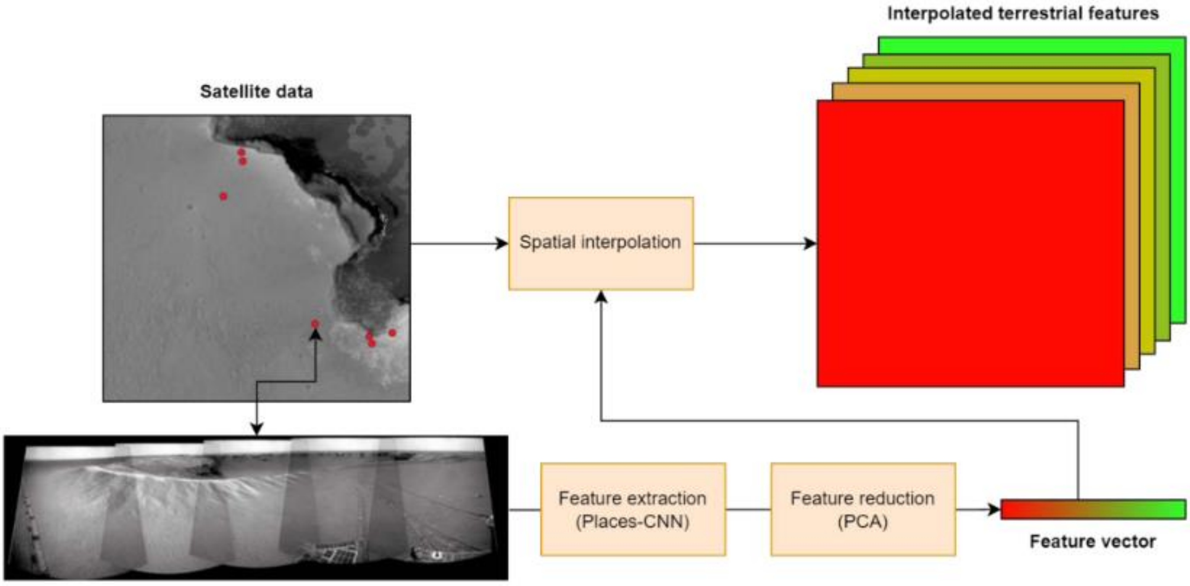

Figure 2. Features extraction.

The semantic segmentation process used an encoder - decoder neural network based on the VGG-16 architecture (Simonyan K. et al. (2015)). Two separated inputs were utilized in proposed architecture, one for satellite imagery and elevation models, second for terrestrial features (fig 3.).

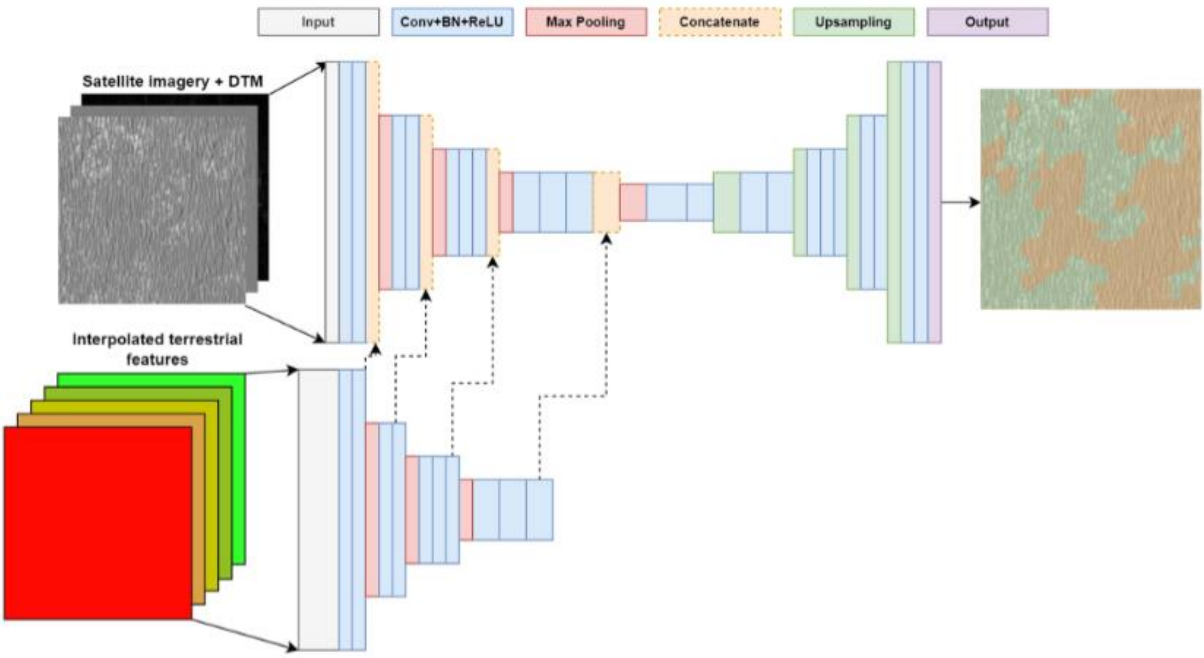

Figure 3. CNN model.

Described mapping system was developed as a part of the broader research published in Choromański K. et al. (2022).

Results, conclusions and next steps

(Present your results and conclusions of your study, up to 250 words)

The mapping system outlined above was then trained using expert-labelled learning data. Four classes where defined in training dataset: Ripple fields, Ripples on bedrock, Sand-gravel covers and others. This yielded very good semantic segmentation results both with and without using information from the rover. It achieved an overall accuracy of 94.38% on the test data using only image orbital data, 94.90% when terrain information was added, and 95.94% when all available data was used. Complete results can be seen on Figure 4 below.

Experiment	Overall accuracy
1 (orbiter only)	94.38%
2 (orbiter + TPI/TRI)	94.90%
3 (orbiter + curvatures)	94.55%
4 (orbiter and in situ fused)	94.78%
5 (orbiter and in situ fused + TPI/TRI)	**95.94%**
6 (orbiter and in situ fused + curvatures)	91.88%

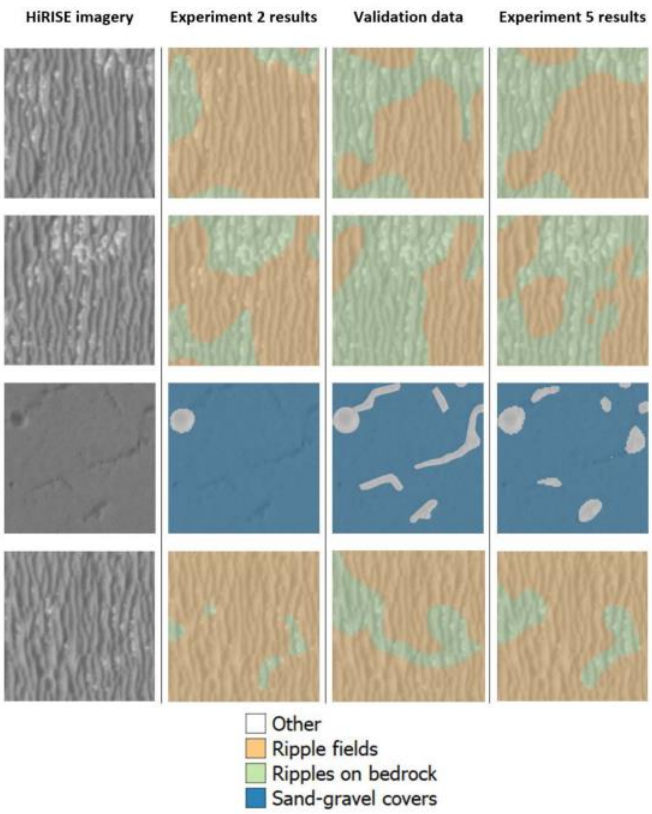

Figure 4. Results

It is noteworthy that the learning data was marked only on satellite images, which greatly accelerated the time of dataset creation. Moreover, the proposed system can work with different input data. Depending on the situation - in the case where in-situ data are available, it is possible to obtain better results using them. However, the vast majority of Martian surfaces do not have such data. In this case, mapping can be done using available orbital sources.

The developed solution, despite its high performance on test data, requires further work. In particular, more extensive research on the quality of the system's performance on areas other than the Meridiani Planum and testing the solution with other core architectures (e.g. transformer based).

Systems capable of analyzing disparate, multi-source spatial data can be used in many fields. As more and more data is acquired in an automated manner, efficient integration and interpretation can be crucial in many applications where high accuracy mapping is required.

References
(Additional information, publications, or links, up to 200 words, optional)

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