3D MODELS FROM STRUCTURE-FROM-MOTION PHOTOGRAMMETRY USING MARS SCIENCE LABORATORY IMAGES: METHODS AND IMPLICATIONS.

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Introduction:

Structure-from-Motion (SfM) photogrammetry is a low-cost method for constructing 3-dimensional (3D), geolocated terrain and object models from multiple photographs taken from cameras with arbitrary (or unknown) poses and with or without ground control points [1]. This study explores planetary applications for the SfM method using the Agisoft Photoscan Professional software package applied to imagery obtained by the Mars Science Laboratory rover (Curiosity). We reconstruct object models at the millimeter scale using Mars Hand Lens Imager (MAHLI) data and build decimeter-scale terrain models using the navigational cameras. In addition, we note that camera position and pose information is a by-product of the SfM model creation. We use this feature to demonstrate reconstruction of the traverse path of Curiosity from photographs alone, and make recommendations for applications of SfM for this purpose in current and future planetary exploration missions.

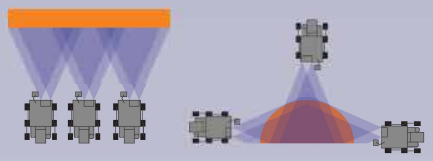
Structure-from-Motion Photogrammetry:

Method

- Structure-from-Motion (SfM) photogrammetry creates 3D models from photographs
- Camera pose is reconstructed without a priori information
- Keypoints established by textural similarities between images [1]

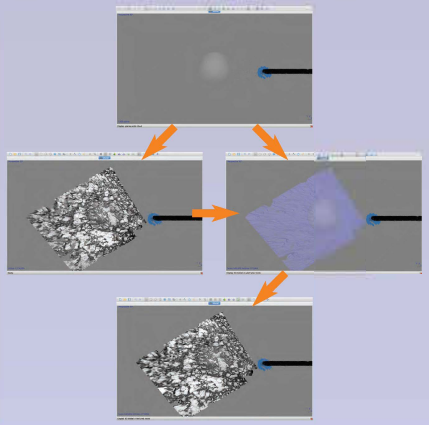
Image Recommendations

- High-resolution images [1]
- 60% overlap between images [1]
- Camera parallel to object of interest [1]



Workflow

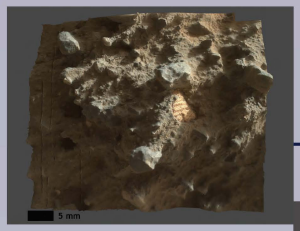
- Sparse point cloud links keypoints across photoset
- Dense point cloud constructed from photogrammetric model obtained in sparse point cloud
- Triangular irregular network (TIN), or mesh, constructed
- Images mapped onto TIN, resulting in model of target



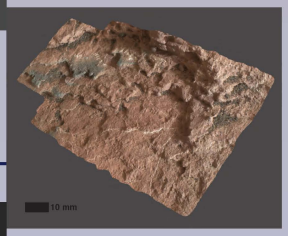
Small-Scale SfM Object Models:

Mars Hand Lens Imager (MAHLI)

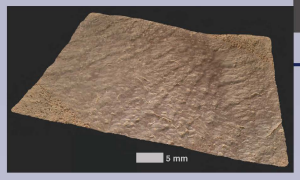
- 1600 x 1200 pixel color camera [3]
- Attached to robotic arm of Curiosity
- Highest resolution of 13.9 µm/pixel from range of 2.04 cm [3]



Bimbe conglomerate reconstructed using Agisoft Photoscan Professional from nine Curiosity MAHLI images taken on sol 1409.



Mars surface reconstructed using Agisoft Photoscan Professional from nine Curiosity MAHLI images taken on sol 1581.

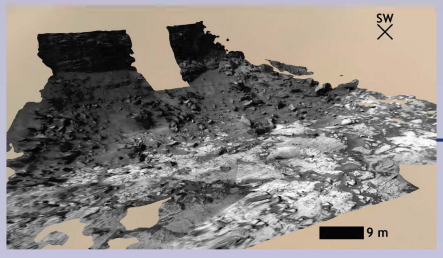


Ripple marks on Mars surface reconstructed using Agisoft Photoscan Professional from twelve Curiosity MAHLI images takenon sol 1416

Large-Scale SfM Terrain Models:

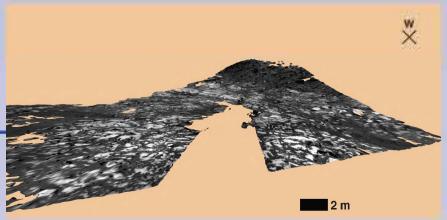
Navigational Cameras (Navcams)

- Two cameras 42 cm apart [4]
- Focus is best at 1.0 m distance from rover [4]
- Sufficient overlap for SfM model construction



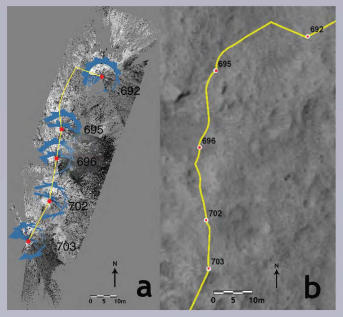
Murray Buttes reconstructed using Agisoft Photoscan Professional from 25 Curiosity Navcam images takenon sol 1455

Base of Ireson Hill reconstructed using Agisoft Photoscan Professional from 67 Curiosity Navcam images taken on sols 1605-1610



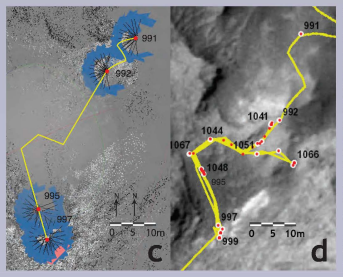
Traverse Reconstruction:

- Original camera position calculated from keypoint connections
- Projected camera positions above model reconstruct traverse of rover
- Low-cost positioning redundancy in addition to, or in place of, inertial measurements



(a) Reconstructed traverse path (yellow) of Curiosity as determined using Agisoft Photoscan Professional and Navcam images from sols 692, 695, 696,702, and 703. Red points show estimated rover position on these sols and blue polygons denote estimated camera poses.

(b) Actual traverse map for Curiosity for sols 692-703 [5].



(c) Reconstructed traverse path (yellow) of Curiosity as determined using Agisoft Photoscan Professional and Navcam images from sols 991, 992, 995, and 997. Red points show estimated rover position on these sols and blue polygons denote estimated camera poses.

(d) Actual traverse map for Curiosity for sols 991-997 [5].

Implications for Planetary Exploration:

SfM, and its capabilities for reconstructing object and terrain models as well as traverse paths, has broader implications with regards to future planetary exploration. The camera pose reconstruction capability of SfM may serve as a method to track the position of a rover throughout its traverse, in addition to inertial measurements. This ability could extend the lifespan of any robotic mission in the event of navigation instrument failure. For example, the 2020 Mars rover will rely on inertial measurements for positioning. SfM could be used as a supplement for rover positioning or as a primary navigation tool for proposed payloads such as a drone. SfM photogrammetry is a low-cost method for constructing both small-scale object models and large-scale terrain models using existing rover capabilities. Object models are useful tools for habitability studies [3]. Terrain models also have important uses in traverse planning and geologic mapping [4].

References:

[1] Westoby M.J. et al. (2012) Geomorphology, 179, 300-314

[2] Rychov I. et al. (2012) Computers & Geosciences, 42, 64-70.

[3] Edgett, K. S. et al. (2015) MSL MAHLI Technical Report 0001, Version 2

[4] Alexander, D., Deen, R. (2015) Mars Science Laboratory Project Software Interface Specification, Version 3.5

[5] Images from MSL Curiosity Analyst's Handbook, maps of Sols 692, 695, 702, 703; 991, 992, 995, 997.