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

Image Recommendations
- High-resolution images
- 60% overlap between images
- Camera parallel to object of interest

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
- Attached to robotic arm of Curiosity
- Highest resolution of 13.9 µm/pixel from range of 2.04 cm

Large-Scale SfM Terrain Models:
Navigational Cameras (Navcams)
- Two cameras 42 cm apart
- Focus is best at 1.0 m distance from rover
- Sufficient overlap for SfM model construction

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

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. Terrain models also have important uses in traverse planning and geologic mapping.

References: