MULTIVIEW STEREO PHOTOGRAMMETRY OF MARS AEOLIAN ANALOGUES. S. P. Scheidt[1], J. R. Zimbleman[1] and M.B. Johnson[1], [1]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, PO Box 37012, MRC 315, Washington, DC 20013-7012. (sscheidt77@gmail.com).

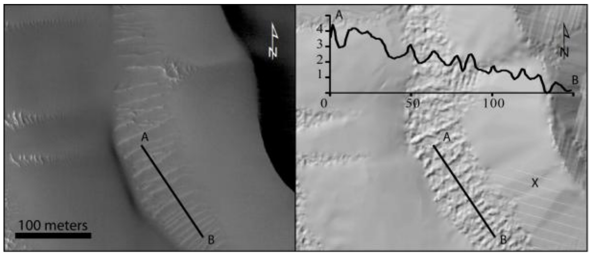

Figure 1: Subset of HiRISE image ESP_018925_2520, centered at 71.89N, 344.65E (left) and corresponding DEM DTEPC_018938_2520_018925_2520_U01 (right). Transect A-B shows a TAR topographic profile, where "X" shows the location of sparse interpolated data of a dune surface.

Introduction: Three-dimensional (3D) information of the Martian land surface is constructed from satellite and rover optical images utilizing stereo photogrammetry [1]. Both Spirit and Opportunity utilize computer vision-based processing of rover images to assist navigation [2]. The High Resolution Imaging Science Experiment (HiRISE) camera acquires very high spatial resolution image stereo pairs from obit (25 cm/pixel) [3], allowing calculation of digital elevation models (DEMs) using ISIS and SOCET SET software systems (Fig. 1). For several surface types, 3D positional information is resolved at comparable scales and accuracy between orbital and rover data [4].

Aeolian processes and geomorphology are dominant on Mars, and therefore are critical to understanding the planet's stratigraphy, natural history and active surface processes. All feature-matching based stereo photogrammetry methods have difficulty retrieving 3D information because of varying degrees of smooth surfaces, subtle features, or contiguous ripple textures. Much to the chagrin of aeolian geomorphologists, aeolian bedforms on Earth and Mars fit this bill, including sand ripples, sand dunes and Transverse Aeolian Ridges (TARs). Problems with terrestrial dunes are similar [5], where accurate 3D data are not retrieved using photogrammetry alone. Retrieval of TAR dimensions has been successful using photoclinometry on Mars [6], but this and other methods used to measure the height of aeolian bedforms have varying degrees of success and accuracy [7]. HiRISE images and DEMs are useful for capturing the topography of TARs and dunes [8,9], but smooth areas are inaccurate (Fig. 1). Active sand transport was observed from ripple migration using image feature correlations [10,11].

In the field on Earth, the dimensions of aeolian features were measured using a precise differential global positioning system (DGPS) and provided a concrete basis for comparison of Martian TARs [12]. However, these data are relatively sparse and may not have a data density ideal for an analysis of fine features. Orbital and airborne data of terrestrial aeolian systems often lack the 3D spatial resolution needed to resolve small scale features. In the case of Martian TAR analogs, there are few locations on Earth where this type of feature are seen from space [13]. Because smaller granule ripples are similar when scaled, they are useful as Mars analogs [14]. Although LiDAR is an effective means of quantifying the topography of smooth textured dunes [14], we explore the use of field-scale images and multiview stereo photogrammetry (MVSP) for the purpose of obtaining dense 3D models of terrestrial aeolian features at multiple scales, including dunes, ripples and terrestrial TARs.

3D Modeling: An MVSP processing pipeline uses only 2D images acquired from several 10s to 1000s of view points for a target, 3D points are reconstructed from the occurrence and correlation of features. A modern MVSP simultaneously computes projection matrices of the camera for each image, including interior (focal length, principle point and lens distortion coefficients) and exterior camera orientation (positional x, y and z and rotations κ, φ and ω) parameters for each image and a set of 3D points of the target, common in all images [15]. In general, unique features are detected and matched from multiple overlapping images [16], resulting in a singular unique solution of tie points making up a sparse 3D point cloud. Following, a dense reconstruction of the scene is processed [17] a number of different postprocessing steps can be completed to create color-textured, to-scale, georeferenced 3D surfaces. We have selected and tested several MVSP systems for the application to aeolian geomorphology, such as the open source VisualSFM package [18] installed on a highly-capable multi-core CPU Linux workstation with Cuda-enabled GPU. Other 3D reconstructions were created using similar online systems, including CMPSfM [19] and Autodesk [20]. Our goal is to produce accurate CAD-like 3D models comparable to HiRISE DEMs that can be analyzed in a geographic information system (GIS).

Results of Terrestrial Field Work: The success of a 3D model reconstruction using MVSP increases dramatically if imaged surfaces have significant texture, contrast and physical structure. The homogeneity of dune surfaces are highly problematic for 3D reconstruction because the resulting count of key feature matches between images is too low. To test and develop the MVSP pipeline, we have collected image sets of several types of landforms, specifically dunes and ripples with variable shape, scale, sand grain size and composition at Cape Henlopen, DE; Grand Falls, AZ; Bruneau Dunes, ID; Great Sand Dunes, CO; Kau Desert, HI; Puna desert, Argentina; and central Iceland.

Bruneau Dunes, Idaho. Because of previous DGPS surveys of this Martian TAR analog site, a kite aerial photography (KAP) platform was used to capture images from a range of altitudes and positions of the dune. The 3D model was constructed using [18] and [19] from a selection of 686 images. A high resolution DEM of the area was produced, but only some 3D data of the dune was generated, excluding smooth textureless dune areas. A small unmanned aerial vehicle and a higher resolution camera are obvious next steps. A 3D view of this project can be viewed online at http://photosynth.net/view.aspx?cid=67c92721-73c6-4af9-b81d-955fef9d2ed7.

Great Sand Dunes, Colorado. MVSP [20] was used to successfully generate 3D models and DEMs of a granule-coated megaripple that migrated 75 cm eastward compared to placed ground markers (Figure 2).

Cape Henlopen, Delaware. Testing MVSP reconstructions [18,19] of these sand surfaces led to a novel approach that overcomes previous limitations. By combining a few DGPS points with a 3D reconstruction from images collected in a linear pattern, small-scale features were integrated with larger bedform geomorphology along a 150 meter transect in a sandy blowout. The full 3D profile was produced because the unique pattern of sand grain distribution and microtopography allowed feature matching. Gaps were overcome by acquiring 900 high resolution (16 MP) sequential overlapping images (75%) at low altitude (1.5 m), yielding 2.8 x 10^7 3D points, equal to 30 points/cm^2. This "ground stare", essentially high resolution optical flow, could have implications for the use of rover imagery to navigate and study "featureless" aeolian terrain on Mars. This also shows that problems retrieving topography at Brunea can be overcome.

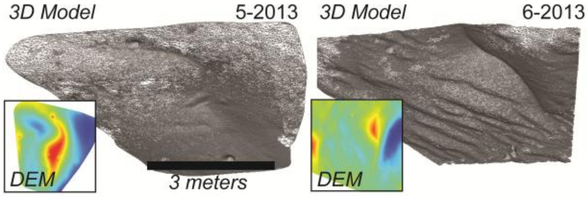

Figure 2: An untextured 3D mesh model and associated DEM of an active granule ripple, photocaptured at two different timse, one month apart. Metal nails placed in the ground were used as reference points for migration.

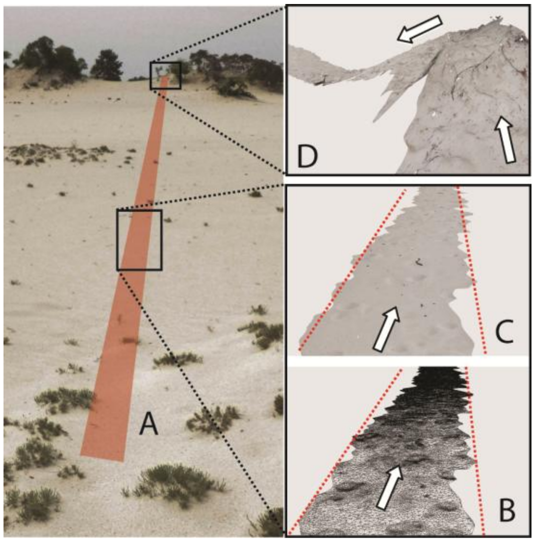

Figure 3: The left image shows a simulated rover or UAV path (arrows indicate direction) used to create a 3D transect from MVSP results (A, red path on photo). Mesh points (B) and photo-textured surfaces (C, D)are shown at right.

Conclusion: These data form the basis of a potentially new field method technique describing fusion of DGPS, DEMs and topographic profiles. The success of MVSP to retrieve accurate 3D structure of granular surfaces has important implications for the use of past and future rover images, although MVSP would ideally be performed by field geologists during manned exploration on planetary surfaces.

References: [1] Olson C.F. and Abi-Rached H. (2007) *Comput. Vis. Image Und., 105, 73-85.* [2] Li R. et al. (2004) *Photogramm. Eng. Remote Sens., 70(1), 77-90.* [3] McEwen A. S. et al. (2007), *JGR, 112, E05S02.* [4] Li R. et al. (2011) *JGR, 116, E00F16.* [5] Medina R.A. et al. (2011), *GSA Abs., 43, 5, 433.* [6] Shockey K.M. and Zimbelman J.R. (2012) *Earth Surf. Proc. Land., 38(2), 179-182.* [6] Bourke M. et al. (2006), *Geomorphology, 81, 440-552.* [7] Berman D.C. et al. (2013), *LPS XLIV*, Abstract #2359. [8] Bridges N.T. et al. (2013), *Aeolian Res., 9, 133-151.* [9] Bridges N.T. et al. (2012) *Nature, 485(7398, 339-342.* [10] Silvestro S. et al. (2010) *GRL 37(20), doi:10.1029/2010GL044743.* [11] Zimbelman J.R. and Scheidt S.P. (2013), *Icarus (in press).* [12] deSilva et al. (2012), *LPS XLIII*, Abstract #7035. [13] deSilva S. et al. (2013), *Geol. Soc. Am. Bull., 125(11-12), 1912-1929.* [14] Ewing R.C. et al. (2008), *LPS XXXIX*, Abstract #7031. [15] Snavely N. et al. (2006), *TOG, 25, 3, 835-846.* [16] Lowe R. (2004), *Int. J. Comput. Vision, 60, 2, 91-110.* [17] Furukawa Y. and Ponce J. (2010), *IEEE Trans. Pattern Anal. Mach. Intell., 32, 8, 1362-1376.* [18] Wu C. (2013), *Int. Conf. 3DV, doi:10.1109/3DV.2013.25*. [19] Heller J. et al. (2010), *CMPSfM Web Service v1.0*. [20] Autodesk 123D Catch (2014), *URL (Jan. 2014), 123dapp.com/catch.*