MEASUREMENT OF AEOLIAN DUNE MIGRATION OVER MARTIAN SURFACE BY HIGH PRECISION PHOTOGRAMMETRIC TECHNIQUES

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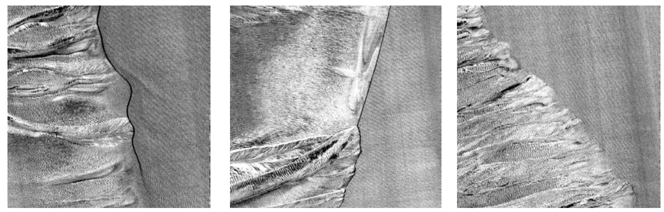
Introduction: Martian dune migrations were reported by visual interpretations (Bourke et al., 2008)**[1]** or the machine vision method (Bridges et al. 2012)**[2]**. At the present time, arguments continue regarding the migration speeds of Martian dune fields and their correlation with atmospheric circulation. However, a precise measurement of the spatial translation of Martian dunes is not feasible due to technical difficulties induced by the relatively small migration of target objects and the large error in radiometric/geometric image controls on the contrary. Therefore, we developed a generic procedure to precisely measure the dune migration with the recently introduced 25cm resolution High Resolution Imaging Science Experiment (HIRISE) employing a high-accuracy photogrammetric processor and subpixel image correlator. The processor was designed to trace the estimated dune migration, albeit slight, over the Martian surface by: 1) the introduction of very high-resolution ortho images and stereo analysis based on hierarchical geodetic control for better initial point settings; 2) positioning error removal throughout the sensor model refinement with a non-rigorous bundle-block adjustment, which makes possible the co-alignment of all images in a time series; and 3) improved subpixel coregistration algorithms with a refinement stage conducted on a pyramidal grid processor and a blunder classifier. The established algorithms were tested using high resolution HIRISE images over three dune fields.

Data Processing and technical background: The main technical issue for dune migration measurement is the photogrammetric control of the image sequence. The sensor orientation parameters of HIRISE images based on the NAIF SPICE kernel (https://naif.jpl.nasa.gov/naif/index.html) should be improved to attain precise co-registration. However, the available rigorous photogrammetric adjustment in public domain S/W packages, such as Integrated Software for Imagers and Spectrometers (ISIS), doesn't properly manipulate with the ideal sensor model of HiRISE mosaics. Therefore, we developed a conversion routine from the geometry of individual HIRISE images to the non-rigorous sensor representation and the space resection by high-order polynomial adjustment. On the other hand, ground control points were taken from the established stereo Digital Terrain Model (DTM) in order to achieve a co-aligned image sequence over the base DTM. Since conventional pixel-tracking methods using 2D image wrapping do not produce reliable measurements over the target images due to the absence of high-precision sub-pixel registration capability and the algorithm failures over dark and monotonous image textures, an in-house algorithm was established on the technical bases as follows: 1) Coarse-to-Fine pyramidal registration scheme employing polynomial transformation; 2) Scale-invariant feature transform (SIFT) to define the target points for tracing; 3) Adaptive Least Squares correlator to refine registration and to calculate registration cost. Based on the previous studies and the availability of overlapping image coverage, the target areas and images are chosen over: 1) Kaiser crater, including active bed form, dune, and gullies which is covered bythe best HiRISE time series for the dune migration measurements; 2) Proctor crater, described as a partially active dune with a wind regime consisting of three opposing directions by Fenton et al. (2005)**[3]**; 3) The "wedge dune" over Wirtz crater.



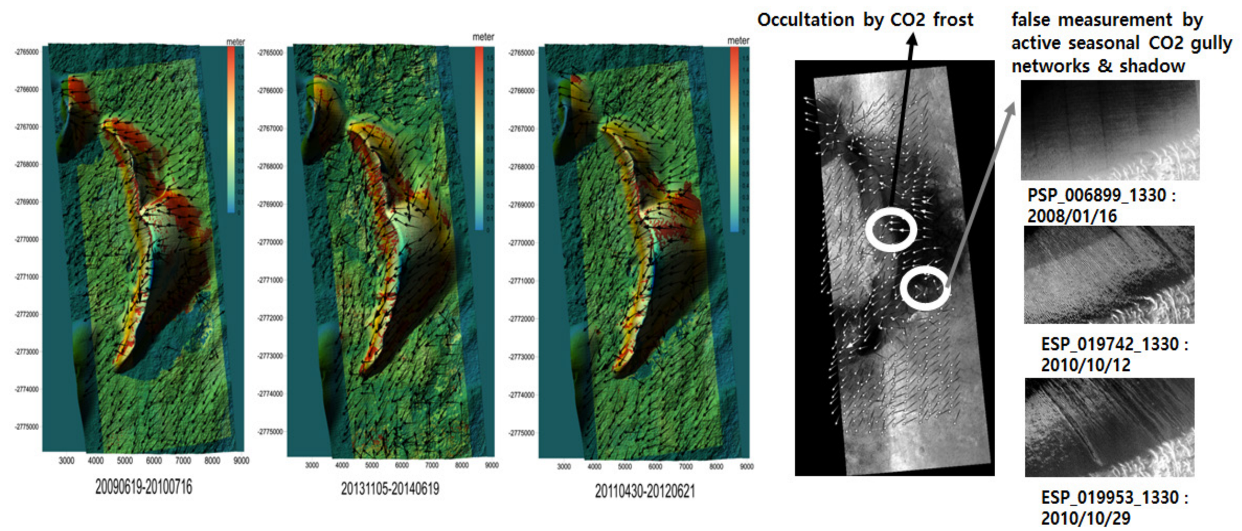
1.8m> crest line change/2 years	1.2m > crest line change/2 years	No obvious crest line change

Figure 1. Estimated dune crest line change using PCA analysis , Kaiser crater

Results & discussion: To estimate the migration range at first, the crest line change was investigated using a time series image stack produced by our photogrammetric control strategy and Principle Component Analysis (PCA). The high order PCA component produced by 12 images over Kaiser crater demonstrated the max 1.8m crest line change as shown in Figure 1. In spite of residual photogrammetric error, though it was minimized by our photogrammetric control strategy, it appeared that the estimated dune migration speed is within 1m/year. Based on this observation, we applied our processing scheme over three target areas. According to the outcomes of those measurements, only the barchan dune in Kaiser crater showed the marginal migration speed following the morphological shape of the dune and maintained consistent migration trends (Figure 2). However, some false or unreliable measurements resulting from radiometric effects, such as seasonal frost, shadows, and undergoing Co2 gully, were detected, though the blunder detection of the established algorithms removed most erroneous measurements. The traced dune migration over Proctor is not very clear, but consistent migration trends were observed, as shown in Figure 3. In the case of the dune field over Wirtz crater (Figure 4), it seems that the undergoing migration trend is not a genuine aeolian process. Once, after the offset value compensating position errors induced by "jitter effects" was applied, the migration became highly random as shown in Figure 4. Thus, the measured migration over Wirtz may be the influence of image distortions by high-speed, image-pointing vector oscillation.

Conclusion: We developed a procedure to measure the Martian migration over geodetically controlled images and applied it over a few target areas. Only the dune over Kaiser crater showed meaningful migration speeds (<1m/year), although it still includes the residual photogrammetric error. After all, the well-known crater dune fields appeared to be quite static for considerable temporal periods, although parts of their migrations were correlated with the dune morphology and possibly with the wind directions estimated by the

Mars Climate Database (Millour et al. 2015)**[4]**. Currently, a technically improved processor to compensate for residual error using time series observation is under development and expected to produce long-term migration speeds over the Martian dune fields where constant HiRISE image acquisitions are available. Moreover, the volumetric changes of Martian dunes will be further traced by means of stereo analysis and photoclinometry.



(a) Measurements of temporal change of migrations (b) Yearly migration/false measurement cases

Figure 2. Traced dune migrations over a barchan dune in Kaiser crater.

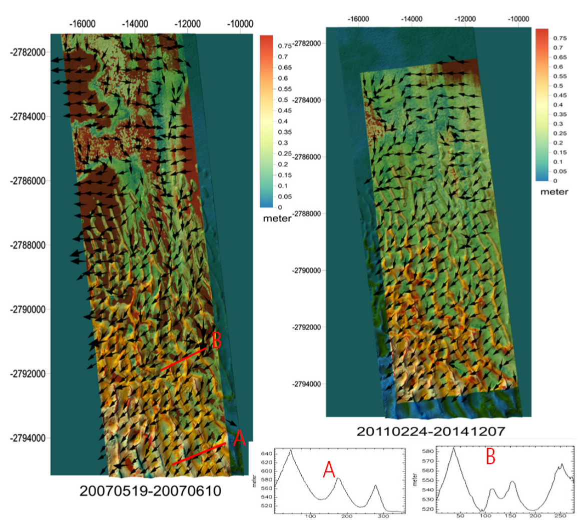
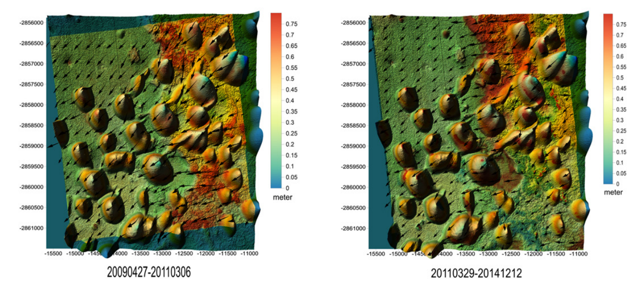
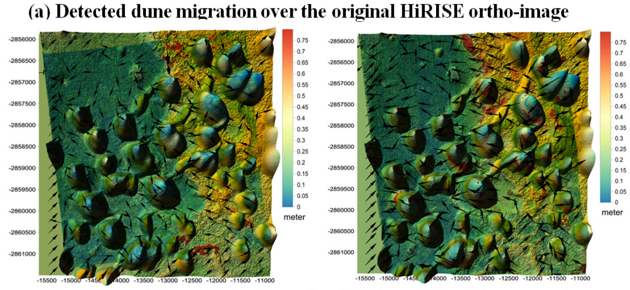


Figure 3. Traced dune migrations over linear dune field in Proctor crater. Note the slip faces of dunes are not well defined in this case.



(a) Detected dune migration over the original HiRISE ortho-image



(b) After applying offset value estimated from jittered image part.

Figure 3. Traced dune migrations over dune field in Wirtz crater.

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References: **[1]** Bourke, M. C. et al. (2008). *Geomorphology*, *94*(1), 247-255. **[2]** Bridges, N. T. et al. (2012). *Nature*, *485*(7398), 339-342. **[3]** Fenton, L. K.et al. (2003). , J. Geophys. Res*: Planets (1991–2012)*, *108*(E12) **[4]** Millour, E. al. (2012). Mars climate database version 5.