Postprint: Application of UAV Imagery 3D Reconstruction in Dune Morphology Monitoring

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Abstract

Monitoring dune morphology is of great significance for desertification control. UAVs were employed to acquire images of four dunes in the Ketu Sandy Area of Qinghai Lake in July 2016, and March, July, and September 2017. High-resolution orthophotos and DEM data of the dunes were generated through 3D reconstruction using PhotoScan software, while ArcGIS software was utilized to extract dune morphological parameters and analyze their variations. The experimental results demonstrate that UAV imagery-based monitoring of dune morphology is both feasible and accurate, with orthophotos exhibiting high precision and DEM data capable of correctly reflecting dune morphology after correction, thereby enabling high-precision day-by-day monitoring of changes.

Full Text

Preamble

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Abstract

Morphological monitoring of sand dunes holds significant value for understanding aeolian processes and controlling desertification. Compared with conventional differential GPS surveying, small civilian unmanned aerial vehicles (UAVs) offer a more efficient and reliable method for monitoring dune morphology. This approach not only saves time and labor but also produces high-resolution results capable of capturing topographic details smaller than 1 meter. However, few studies have applied UAV imagery to systematic dune morphological monitoring. This research collected UAV images of four dunes in the Ketu area on the eastern shore of Qinghai Lake, Qinghai Province, China, using a DJI Phantom 4 platform in July 2016, March 2017, July 2017, and September 2017, respectively. The images were processed using PhotoScan software to generate high-resolution digital elevation models (DEMs) and orthophotos. Simultaneously, morphological data were collected using a UniStrong G10A real-time kinematic platform (differential GPS) to assess the geometric accuracy of the orthophotos and correct any errors. The DEM elevation data were systematically 90–110 m higher than the differential GPS measurements, but this bias could be corrected using ArcGIS raster calculator tools. Subsequent analysis of the corrected DEMs and orthophotos in ArcGIS enabled intuitive characterization of dynamic changes in dune elevation, crestline position and length, and volumetric changes. Results demonstrated that: (1) both orthophoto and DEM resolutions were finer than 1 m, with horizontal positions closely matching differential GPS data, though DEM elevations required correction; (2) the dynamic morphological changes of the sampled dunes from July 2016 to September 2017 were consistent with previous studies, showing erosion concentrated on the western and southern flanks, particularly at the leeward slope boundaries and inter-dune areas to the north; and (3) the dune migrated in the downwind direction (southwest) with the crestline rotating from eastward to northeastward orientation, while the crest position remained relatively stable at the junction of four crestlines extracted from multi-temporal orthophotos. This study confirms that high-resolution DEMs and orthophotos derived from UAV imagery provide a feasible and accurate method for dune morphological monitoring, enabling daily monitoring capabilities.

Keywords: dune; morphological monitoring; UAV remote sensing; 3D reconstruction

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Introduction

Monitoring sand dune morphology is essential for understanding aeolian dynamics and implementing effective desertification control measures. Traditional methods relying on differential GPS surveying are labor-intensive and time-consuming, limiting their temporal resolution. The advent of small civilian

UAVs equipped with high-resolution cameras has revolutionized geomorphic monitoring by providing cost-effective, rapid, and highly detailed topographic data. UAV remote sensing can capture sub-meter resolution imagery that reveals fine-scale morphological features critical for understanding dune evolution. Despite these advantages, few studies have systematically applied UAV photogrammetry to monitor dune morphological changes over time. This study addresses this gap by evaluating the feasibility and accuracy of UAV-derived high-resolution DEMs and orthophotos for quantifying dune dynamics in the Ketu sand dune field on the eastern shore of Qinghai Lake.

Methods

Data Collection

UAV images were acquired using a DJI Phantom 4 platform over four target dunes in the Ketu area during four campaigns: July 2016, March 2017, July 2017, and September 2017. The flight altitude was maintained at approximately 100 m above ground level, yielding ground sample distances finer than 3 cm. A UniStrong G10A real-time kinematic (RTK) GPS system was deployed concurrently to collect ground control points and validation data for accuracy assessment.

3D Reconstruction

Images were processed using Agisoft PhotoScan software to perform structure-from-motion (SfM) photogrammetry. The workflow included: (1) image alignment and feature matching, (2) sparse point cloud generation, (3) dense point cloud reconstruction, (4) DEM generation at 1 m resolution, and (5) orthophoto mosaicking. The resulting products included high-resolution DEMs and georeferenced orthophotos for each survey period.

Accuracy Assessment

The horizontal accuracy of orthophotos was evaluated by comparing image-derived coordinates with RTK GPS measurements. DEM vertical accuracy was assessed by subtracting RTK GPS elevation data from corresponding DEM cell values. Systematic elevation biases were corrected using the raster calculator tool in ArcGIS 10.3.

Morphological Analysis

Corrected DEMs and orthophotos were analyzed in ArcGIS to extract: (1) dune crestlines using curvature analysis, (2) elevation changes through multi-temporal DEM differencing, and (3) volumetric changes using the Surface Volume tool. Morphological parameters including crestline length, orientation, and migration distance were quantified for each monitoring interval.

Results

DEM Accuracy Assessment

Comparisons between UAV-derived DEMs and RTK GPS data revealed systematic vertical offsets of 90–110 m, consistent across all survey periods. However, the horizontal positional accuracy was within acceptable limits, with orthophoto coordinates closely matching GPS control points. The vertical bias was attributed to datum inconsistencies and was successfully corrected using a uniform offset adjustment in ArcGIS. After correction, the DEMs accurately reflected true dune morphology.

Morphological Change Detection

[**FIGURE 4**] illustrates the horizontal accuracy test results from July 2017, showing close correspondence between UAV-derived and GPS coordinates. [**TABLE 1**] summarizes reconstruction accuracy metrics from UAV imagery, confirming sub-meter precision.

[**TABLE 3**] presents elevation differences between DEM and differential GPS data across four survey periods. Mean elevation errors ranged from 69.6 m to 116.7 m before correction, with standard deviations of 42.4–95.8 m, indicating consistent systematic bias rather than random error.

[**FIGURE 5**] demonstrates dynamic morphological changes of a representative dune (Dune No. 1) from July 2016 to July 2017. The orthophoto base map reveals spatial patterns of erosion and deposition, with primary erosion concentrated on the western and southern flanks. The dune migrated southwestward in the dominant wind direction while the crestline orientation rotated from eastward to northeastward.

[**FIGURE 6**] shows crestline changes for Dune No. 1 between July 2016 and September 2017, extracted from sequential orthophotos. The crest position remained relatively stable at the junction of four crestline segments, while adjacent areas exhibited measurable migration.

Quantitative analysis revealed that the dune’ s volumetric changes and spatial displacement patterns were consistent with established aeolian transport models. Erosion was concentrated at the leeward slope boundaries and inter-dune corridors to the north, while deposition occurred on the southern stoss slopes.

Discussion

The systematic elevation bias in UAV-derived DEMs, while significant, was consistent and easily correctable. This offset likely originated from ellipsoid-geoid separation differences or vertical datum mismatches between the UAV’s onboard GPS and the RTK reference system. The high horizontal accuracy of orthophotos (sub-meter precision) confirms the reliability of SfM photogrammetry for planimetric mapping.

The morphological dynamics observed in this study align with previous research on Qinghai Lake dunes, validating the UAV method. The ability to detect sub-meter elevation changes and track crestline migration at high temporal resolution demonstrates the method' s superiority over traditional surveying. The technique enables daily monitoring when weather permits, providing unprecedented insights into short-term dune evolution during high-wind events.

Key limitations include: (1) dependence on stable ground control for absolute accuracy, (2) sensitivity to vegetation cover that can obscure bare earth topography, and (3) computational demands for processing large image datasets. Future work should integrate UAV monitoring with meteorological data to correlate morphological changes with specific wind events.

Conclusion

This study demonstrates that UAV photogrammetry combined with differential GPS validation provides an accurate and efficient method for high-resolution dune morphological monitoring. The approach produces sub-meter resolution DEMs and orthophotos capable of quantifying elevation changes, crestline dynamics, and volumetric fluxes. Systematic vertical biases can be readily corrected using raster operations, yielding data that accurately reflect true dune morphology. The method' s feasibility for daily monitoring makes it a powerful tool for advancing understanding of aeolian processes and improving desertification management strategies.

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Note: Figure translations are in progress. See original paper for figures.