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3-D uncertainty-based change detection in point clouds derived from structure-from-motion photogrammetry

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The recent advances in structure-from-motion (SfM) software have driven a strong resurgence in the use of photogrammetric approaches across the geosciences. Although results can be unprecedented in their detail, rigorous analyses are limited by a poor understanding of the complex and spatially varying uncertainties involved. Here, we describe a novel method for full 3-D change detection between SfM surveys that is based on cutting-edge point cloud comparison algorithms, but incorporates SfM-specific uncertainty estimates. In our method, we 1) characterise the spatially variable 3-D point measurement precision across individual SfM-photogrammetry surveys, and 2) quantify change between the resulting point clouds, identifying where 3-D differences exceed a locally derived confidence-bounded detection limit. We illustrate the value of the results using an aerial survey case study on erosion monitoring.

To estimate 3-D coordinate precision for surface points, we develop a Monte Carlo approach because SfM-photogrammetry software does not yet provide all the detailed error metrics that are characteristic of rigorous photogrammetry. Our solution is implemented in PhotoScan, and provides individual estimates of coordinate precision in X, Y and Z for all sparse points. These estimates are then interpolated over the dense point clouds in CloudCompare software. The resulting 2-D or 3-D 'precision maps' can be used to identify weak areas in surveys and to assess survey-limiting factors such as georeferencing. For confidence-bounded 3-D change detection, we adapted the state-of-the-art point-cloud comparator, M3C2, of Lague, et al. (2013), to include the point precision estimates provided in the precision maps. Consequently, the resulting M3C2-PM variant enables confidence-bounded change detection that appropriately considers the photogrammetric and georeferencing considerations that are specific to photogrammetric surveys (James et al., 2017).

Applying the method to annual aerial SfM surveys of an eroding badland showed that M3C2-PM identified more probable erosion patterns than conventional DEM-based analyses or M3C2 alone, with sub-decimetre changes detected within the $\sim$4700 m^2 catchment area. Consequently, and particularly for 3-D forms or steep topography, M3C2-PM should provide a valuable tool for rigorous analysis of SfM surveys. Furthermore, the 'PM' implementation in the M3C2 CloudCompare plugin enables any externally-derived point precision estimates to be used, thus opening M3C2 to wider additional applications.

References

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