Automatic boulder detection and boulder field properties: Techniques and practical applications

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The demand for surface and sub-surface detection of boulder fields is growing. Boulder fields properties acquired from satellite images help to understand the development of extraterrestrial bodies. Similar studies on Earth are useful for offshore spatial planning (e.g., wind farms, platforms, pipelines) and ecosystem research. However, most offshore areas lack high-resolution non-confidential bathymetric and acoustic imagery data to apply and evaluate boulder detection techniques. In our project, we examine a large boulder field (~2 km^2, >10 thousand a meter-size boulders) in the Altai Mountains (“Stone Garden”), which provides an ideal location to test different techniques and design robust detection/analysis workflows. Using this quantitative analysis, the study also aims to understand the origin of the Stone Garden. Two main hypotheses are now under consideration claiming either Altai mega-floods or glacier as the main transport agents. During the 2021 field campaign, we applied structure-from-motion photogrammetry to UAV photography data collected over the Stone Garden to compute a high-resolution (13 cm/px) digital surface model (DSM) and orthophoto imagery mosaic (6 cm/px). Our study involves two major parts: (i) boulder detection and outlining, and (ii) analysis of boulder population properties.

Three methods were used for boulder detection: (1) Deep learning technique to analyze high-resolution orthophoto images of the area (Prieur *et al.*, 2022a, 2022b); (2) Advanced combination of standard GIS methods and manual tuning of DSM and orthophoto images; (3) Numerical recognition of topographic singularities on DSM. The analysis of boulder sizes demonstrates identical power-law distribution (Clauset *et al.*, 2009) for all three methods with power-law exponent between 3 and 4. This dependence breaks for boulders smaller than ~2-3 m in effective diameter. This defines the completeness of the detection only for boulders of larger dimensions (2-10 m), if no additional geological mechanism exists that removes average size boulders (0.5-2.5 m) from the area.

While analyzing individual and statistical properties of detected boulders, we pay special attention to potential difference between traditional, planar (2D, obtained from images), and volumetric (3D) properties estimations. Benefiting from available high-resolution DSM, we use additional characteristics of boulders (such as height, volume, asymmetry, etc.) in the analysis of the field. This way we can illustrate potential errors of image-based (2D) analysis of boulder fields. Applied to the Stone Garden, we demonstrate differences in average boulder size depending on elevation. Orientation of elongated boulders is not well-defined statistically, but major axes tend to be orthogonal to the average topographic trend. We also develop DSM-based methods to detect boulders characterized by distinct stoss slope, which allows us to build a map of the distribution of stoss slopes orientation.

The combination and comparison of different methods increases the analysis robustness. The three methods in our study show comparable boulder detection results. We also developed routines for in-depth analysis of statistical and individual properties based on DSM. Offshore areas without acoustic imagery data can also benefit from these workflows.

References

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