Probabilistic change mapping from airborne LiDAR for post-disaster damage assessment

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Introduction

Summary

Change detection using remote sensing has become increasingly important for characterization of natural disasters. Pre- and post-event LiDAR data can be used to identify and quantify changes. The main challenge consists of producing reliable change maps that are robust to differences in collection conditions, free of processing artifacts, and that take into account various sources of uncertainty such as different point densities, different acquisition geometries, georeferencing errors and geometric discrepancies.

We present a novel technique that accounts for these sources of uncertainty, and enables the creation of statistically significant change detection maps. The technique makes use of Bayesian inference to estimate uncertainty maps from LiDAR point clouds. Incorporation of uncertainties enables a change detection that is robust to noise due to ranging, position and attitude errors, as well as “roughness” in vegetation scans.

The validation of the method was done by use of small-scale models scanned with a terrestrial LiDAR in a laboratory setting. The method was then applied to two airborne collects of the Monterey Peninsula, California acquired in 2011 and 2012. The data have significantly different point densities (4 vs. 40 pts/m2) and some misregistration errors. A new point cloud registration technique was developed to correct systematic shifts due to GPS and INS errors.Spanned changes were detected and interpreted mostly as construction and natural landscape evolution.

Dataset description

WSI

- WSI for Naval Postgraduate School (Monterey, CA)
- Collection date: 2011/10-2011/11
- Scanner used: Leica ALS50 (co-located sensor)
- Flight parameters: 450 m AGL, 100% overlap, 60° side look
- Scanning geometry: 90 kHz PRF, 1° deg F.O.V., sawtooth
- Point density: 40-80 pts/m2 average
- Posted accuracy: 7 cm vertical, 20 cm horizontal

NOAA

- Fugro EarthData, Inc. for the NOAA CA Coastal Conservancy Coastal Lidar Project
- Collection date: 2009/10-2011/10
- Scanner used: Leica ALS50 (co-located sensor)
- Flight parameters: 1300 m AGL, 100% overlap
- Scanning geometry: 100 kHz PRF, 6° F.O.V. sawtooth
- Point density: 5-8 pts/m2 average
- Posted accuracy: 18 cm vertical, 50 cm horizontal

AMBAG

- Digital Mapping Inc. for the Association of Monterey County Area Governments (AMBAG)
- Collection date: before 2010/08
- Scanner used: Optech ALTM Gemini (co-located sensor)
- Flight parameters: 1300 m AGL, 50% overlap
- Scanning geometry: 100 kHz PRF, 40° F.O.V. sawtooth
- Point density: 8 pts/m2 average
- Posted accuracy: 23 cm vertical, 35 cm horizontal (underestimated)

Context: Remote Sensing for Improved Earthquake Response

Change detection ingredients

- Bayesian Inference for parameter and error estimation
- Gridding: compare DSM generated from point clouds (indep.)
- Local polynomial surface model (linear in current imprints.)
- Kernel regression to infer model parameters
- Empirical errors from local residuals
- Heavy-tailed Student t distributions for low point densities
- Probabilistic comparison of local height distributions
- Approximations to allow fast comparisons
- Simple model to account for geometric errors
- Present significance levels for change detection
- Intuitive visualization method

Automatic dataset registration

- Bayesian Inference for 3D shift estimation
- Simultaneous gridding of both datasets into the same DSM
- Approximation 1 - Distr. marginalization
- Approximation 2 - Density-weighted log variances
- Approximation 3 - Piecewise constant shift
- Nonlinear Conjugate Gradient optimization

Test: automatic registration

- Manual point cloud registration experiment: synthetic point cloud data
- With synthetic point cloud with smooth surface, realistic and imagined
- Right, non-quadratic behavior of the energy function to be minimized for two different areas of interest

Validation: terrestrial scans

- Automatic point cloud registration experiment: synthetic point cloud data
- With synthetic point cloud with smooth surface, realistic and imagined
- Right, non-quadratic behavior of the energy function to be minimized for two different areas of interest

Issues, Solutions, Future work

- Explicitly accounting for overlapping surfaces
- Full 3D non-parametric modeling?
- Preliminary surface filtering to avoid overlaps
- Strip adjustment for IMU error reduction
- Use of predictive uncertainty and handling missing data

Conclusions & Recommendations

- Point density > 3 pts/cell (depends on target GSD)
- Swath overlap > 60% sidleap (=3 swaths in area of interest)
- Sampling pattern: sampling distance should match footprint size (reduce aliasing)
- Geometric quality: minimal inter-strip discrepancy, good IMU data
- Raw discrete return data, if available
- Approx. predictive uncertainties (instead of empirical)
- Raw waveform data, if available
- Rigorous predictive uncertainties (instead of empirical)