Joint KSGPC-UNSW Seminar on Geomatics

Robust Recovery of Systematic Biases for LIDAR Calibration

Introduction ⇨ Proposed approach ⇨ Experimental results ⇨ Conclusions

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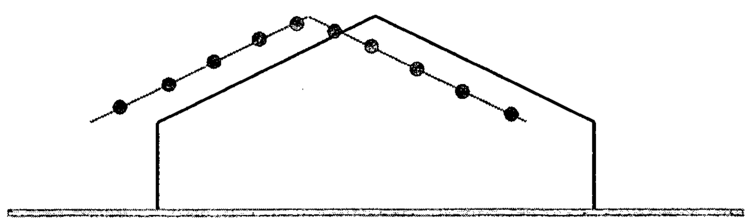
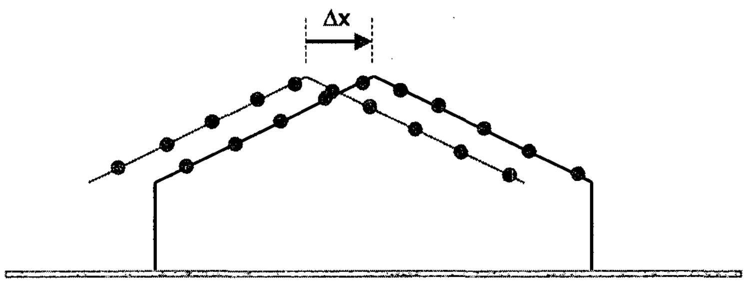
Systematic Errors in LIDAR Data

- LIDAR data often include systematic errors.
  - LIDAR mainly consists of GPS, INS, and Laser ranging modules.
  - Systematic errors occurs due to the systematic biases inherent in each module, or the imperfect integration of the modules.



Calibration of LIDAR Data

- Calibration aims to removing systematic errors.
  - Analyze the error sources and model the systematic errors by introducing some bias parameters.
  - Estimate the parameters by comparing the points with given reference data. → called parameter recovery



Reference Data for Parameter Recovery

- Use of planar patches
  - Extracted from large man-made structures
  - Ex: roofs of large buildings, or surfaces of parking lots
- Problems
  - It often fails to estimate a number of parameters with reasonable accuracy,
    - since the parameters are usually highly correlated and
    - it is difficult to find sufficient number of independent patches.
- Natural surfaces as alternative
  - since they includes implicitly planar patches of various slopes.

Purpose

- To develop a robust method for parameter recovery using natural surface as reference data.
- For the parameter recovery, we'd better not use entire points but a portion of points that may produce better results.
- We attempted to develop a sophisticated selection process.

Laser Equations

- Used to compute the coordinates of laser points by combining information from GPS, INS, laser ranging module.
- $p' = P' + R' * u * r'$
  - p: the coordinates of a laser point
  - P: the coordinates of the platform position, getting from GPS.
  - $R' * u$: the laser pointing vector, getting from INS
  - r: the range between a LIDAR and a target
  - apostrophe?
    - indicates that the values are not true but measured.

Modeling Systematic Errors

- 7 bias parameters introduced
  - 3 parameters for GPS bias: ΔX, ΔY, ΔZ
    - $P' \rightarrow P' + \Delta P$
  - 3 parameters for INS bias: $\Delta\omega$, $\Delta\phi$, $\Delta\kappa$
    - $R' \rightarrow (I + \Delta R)\, R'$
  - 1 parameter for range bias: Δr
    - $r' \rightarrow r' + \Delta r$

- $p = P' + \Delta P + (\, I + \Delta R\,)\, R' * u * (\, r' + \Delta r\,)$
  $\equiv p' + \Delta p$

- Δp is a function of the unknown systematic biases.

Constraint and Observation Equations

- Constraint: a fully calibrated point should be on a physical surface.

- Reference data can be given by a surface function (ex. DEM)
  - $z = f\,(x, y)$

- The calibrated coordinates should satisfy the function.

$$z' + \Delta z = f(x' + \Delta x, y' + \Delta y) \quad \Rightarrow \quad z' + \Delta z = f(x', y') + \frac{\partial f}{\partial x}\Delta x + \frac{\partial f}{\partial y}\Delta y$$

- This constraint provides an observation equation. If we have *n* points, we establish *n* observation equations.

Recursive Parameter Estimation

- Based on the observation equations, the parameters can be estimated using a recursive process.
- Main concerns
  - dependency on the initial values
  - the accuracy of the converged values and
  - the convergence rate
- All of these are closely related to the linearization errors.
  - The smaller the error, the better results are promised.

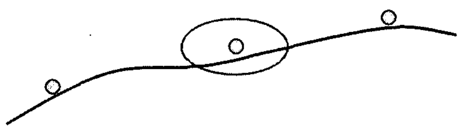
Reducing Linearization Errors

- Comment on linearization errors
  - If the reference surface is perfectly planar, then the linearization errors are clearly eliminated.
- Properties of natural surfaces
  - They never be represented by an infinitely large plane.
  - But represented as a set of bounded planar patches retaining different roughness.
- To reduce linearization errors,
  - The sub-areas from given reference patches that can be represented as smooth large patches are preferred.

Reason to Selection

- We should NOT use every points overlapping with reference data.
- Otherwise, we may get lots of outlying observation equations that we should avoid to achieve accurate estimates.
- Rather use only a portion of points involving less linearization errors to achieve more accurate estimates.

Selection Process

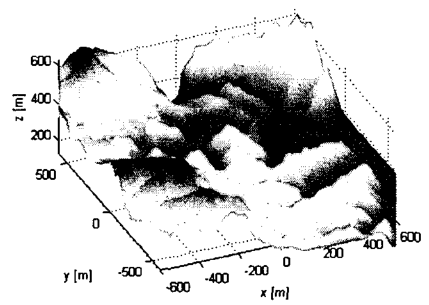


- Define a region with the point as its center.
- Fit a plane and get the roughness.
- If the regions retains small roughness, then we select the corresponding points.
- With each pair of the point and region, we can establish an observation equation.
- For this equation, the roughness can be used as weight.
- In every iteration, this selection process is performed.

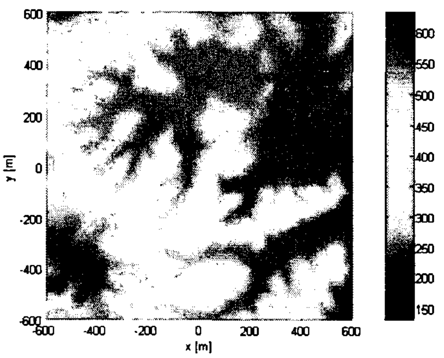
Experiment

- We applied the proposed method to various sets of simulated data.
- To assess the accuracy of the recovered parameters, we used simulated data instead of real data.
- A representative experiment and the result are shown here

DEM for Simulation

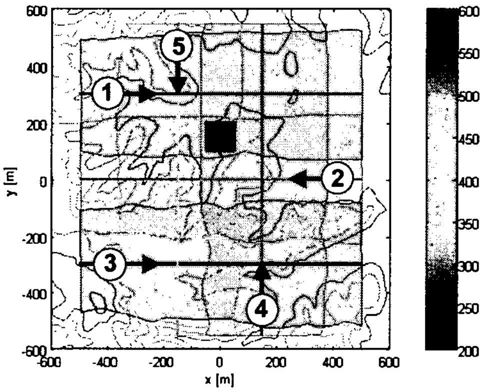


3D view



2D view

Simulated Test Data



Set	Duration [s]	No. points
1	33.34	1000200
2	33.34	1000200
3	33.34	1000200
4	36.68	1100400
5	36.68	1100400
Total	173.38	5201400

Test Results: Parameter Estimation

- In every iteration, we selected only the points in the regions retaining the roughness < ±0.4 m.

Iteration	ΔX	ΔY	$\Delta\omega$	$\Delta\phi$
Initial	0	0	0	0
1	2.1791	0.7295	0.1032	0.2109
2	1.9827	0.9711	0.1015	0.1989
3	1.9886	0.9668	0.1010	0.1991
4	1.9886	0.9671	0.1010	0.1991
True	2.0000	1.0000	0.1000	0.2000

Test Results: RMS Errors

- RMS errors were computed with respect to the true coordinates of laser points.

Set	Before calibration			After calibration		
	dx	dy	dz	dx	dy	dz
1	2.346	3.171	0.219	0.007	0.010	0.010
2	2.252	3.123	0.213	0.007	0.011	0.010
3	2.027	3.004	0.203	0.006	0.012	0.009
4	2.296	3.146	0.437	0.007	0.011	0.010
5	2.141	3.066	0.418	0.006	0.011	0.010

Conclusions

- With the proposed method, we can recover the bias parameters with acceptable errors within a few iteration steps.
- The calibration results show the superior quality with respect to RMS errors.
- The calibration process was developed to calibrate ICESat GLAS (a spaceborne LIDAR system) data with airborne LIDAR data
- The selection principle can be also applied to registering images with LIDAR data.