Optimal Estimation of Calibration Parameters for LiDAR Data

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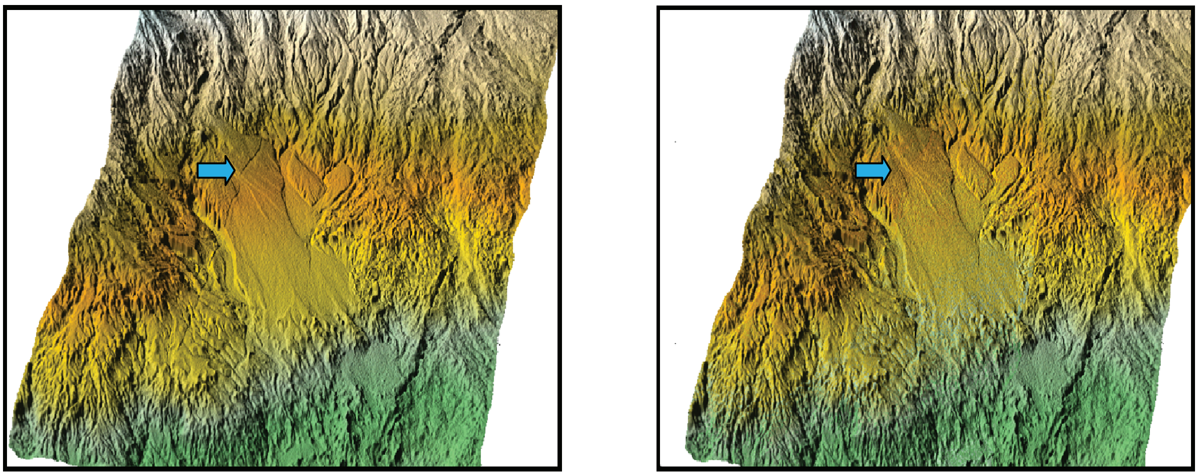
The accuracy of airborne LiDAR has been a topic of research for many years, but there remains a need for a robust and reliable calibration technique. The accuracy of LiDAR points depends on various factors including GPS/IMU position and orientation, laser range, and scan angle measurements. As a result, the adjacent overlapping swaths, or flight strips, fail to match with each other. Surface matching is a procedure used to relatively register the LiDAR data and reduce the mismatch between the overlapping strips. However, in the presence of systematic errors and varying flight dynamics classical registration algorithms render poor results. Two types of algorithm are currently used for this purpose. One requires the presence of geometric features and the other utilizes the conventional surface matching techniques. The techniques based on geometric feature matching usually fail to render results in non-urban areas. On the other hand, the surface matching algorithms (that do not require specific geometric features) are suboptimal in estimating the calibration parameters. Figure (1a) illustrates the presence of artifacts in LiDAR DEM (digital elevation model) due to the presence of unresolved systematic discrepancies in the data. We present a systematic error estimation technique based on optimal relative registration of LiDAR that does not require geometric tie features. In the proposed method, points from overlapping strips are matched using modified iteratively closest point (ICP) method and the Euclidean distances between selected closest (conjugate) point pairs in overlapping strips are minimized as a function of systematic errors. LiDAR point pairs used in minimization process are selected based on two criteria.



(a) (b)

Fig.1 (a) Artifacts in DEM due to Systematic Discrepancies (b) No Artifacts in DEM after Error Adjustment

One is their ability to constrain the relative movement in all possible directions between the overlapping laser swaths and second is their location in the swath so that it maximizes the effect of each individual error. A general LiDAR equation can be written as [12]:

$$X_L^M = X_g^M + \Delta X_g^M + R_N^M \left(R_I^N \Delta R_I^N \left[(a + \Delta a) + R_S^I R_p^S \Delta R_p^S (\rho + \Delta \rho) \right] \right) + \varepsilon \qquad (1)$$

where $X_L^M = [x \quad y \quad z]^T$ is the ground location of a laser point in the mapping frame M. X_g^M and ΔX_g^M are the location and systematic error in location of the IMU center respectively, both in mapping frame M. R_N^M is the rotation from local (navigation) reference frame to mapping frame M. R_I^N and ΔR_I^N are the rotation and rotational offset from body reference frame to local reference frame respectively. *'a'* and *Δa* are the offset vector and its systematic error between laser firing point and the IMU center. R_S^I is the rotation between laser altimeter and IMU body frame. R_ρ^S and ΔR_ρ^S are the laser scan angle (or rotation between laser beam and laser altimeter) and its systematic offset due to scanner scale. ρ is the laser range and $\Delta\rho$ is the range bias. ε are the random errors. These biases and errors are estimated by minimizing the Euclidian distances between the optimally selected point pairs. Only those points are selected in the minimization process that help constrain the motion overlapping swaths based on their covariance matrix analysis. As shown in figure (2), systematic errors like roll bias, scanner scale and range offset affect the accuracy of the data across the flight direction. In addition, it was found that 50% swath overlap maximizes the effect of errors in the conjugate point pairs in overlapping strips. This helps the reliable estimation of most of the systematic errors.

In conjunction with covariance matrix analysis, the point pairs with the best location to maximize the effect of various systematic errors are selected in estimating the calibration parameters.

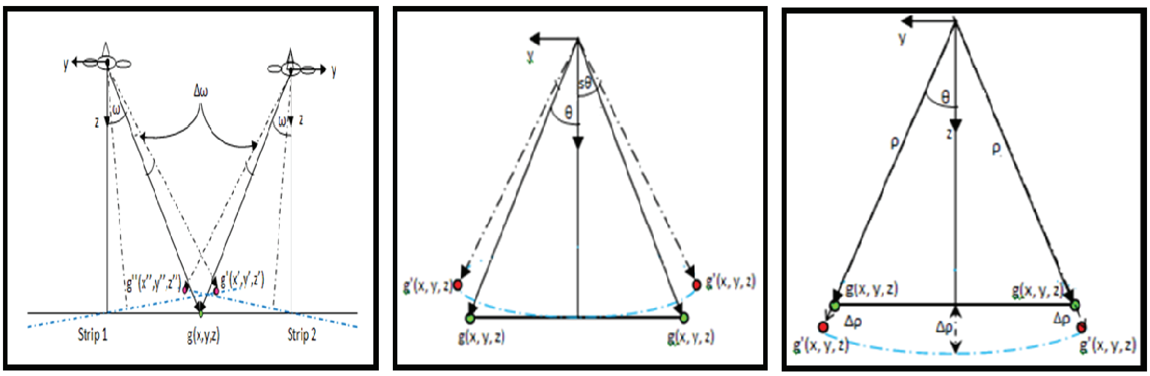


Fig. 2. Systematic Errors due to Roll, Scanner Scale and Range Offset affect Accuracy of LiDAR Points across the Flight Swath (*flight direction along X-axis*)

Results

The proposed method was tested on a LiDAR data set over a lava surface in Hawaii. Due to unfavorable weather conditions and high flight dynamics, the raw data was contaminated with systematic errors that conventional methods fail to fix. Three flight lines flown in opposite direction with an approximate 50% overlap are used to estimate systematic errors and adjust the data. Figure (1b) and Figure (3) illustrate the preliminary results obtained using proposed method. This method will be further tested on other data and detailed analysis of the results will be presented.

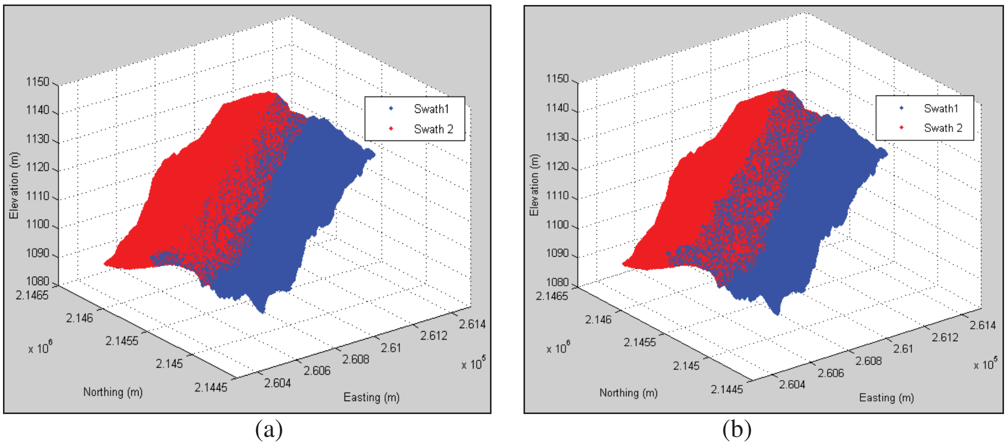


Fig.3. Effect of Systematic Errors (a) Overlapping Swaths with Systematic Errors and (b) Adjusted for Systematic Errors

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