Comparative Analysis of Two New Approaches for LiDAR System Calibration

Ayman Habib, Ki In Bang, and Ana Kersting

(ahabib; kibang; ana.kersting)@ucalgary.ca

Department of Geomatics Engineering, University of Calgary

Abstract:

LiDAR systems have been widely adopted for the acquisition of dense and accurate topographic data over extended areas. Although the utilization of this technology has increased in different applications, the development of standard methodologies for the calibration of LiDAR systems has not followed the same trend. Current in-flight calibration methods have the following drawbacks: (i) They are time consuming and expensive; (ii) They are generally based on complicated and sequential calibration procedures; (iii) They require some effort for surveying the control surfaces; (iv) Some of the calibration methods involve manual and empirical procedures; (v) Some of the calibration methods require the availability of the LiDAR raw measurements such as ranges, mirror angles, as well as position and orientation information for each pulse; and (vi) There is no commonly accepted methodology since the calibration techniques are usually based on a manufacturer-provided software package and the expertise of the LiDAR data provider. As a result of the non-transparent and sometimes empirical calibration procedures, collected LiDAR data might exhibit systematic discrepancies between conjugate surface elements in overlapping strips. This paper presents two new calibration procedures for the estimation of biases in the system parameters that overcome the limitation of existing calibration procedures. The first presented method – denoted as the “Simplified Calibration Procedure” – makes use of the LiDAR point cloud from parallel LiDAR strips. The system biases are estimated using identified discrepancies between conjugate primitives in overlapping LiDAR strips. The second method – denoted as the “Quasi-Rigorous Calibration Procedure” – can deal with non-parallel strips, but requires time-tagged LiDAR point cloud and navigation data (trajectory position).

Introduction:

A LiDAR system is composed of a laser ranging and scanning unit and a position and orientation system (POS), which consists of an integrated differential global positioning system (DGPS) and an inertial measurement unit (IMU). The principle of laser ranging is to measure distances from the sensor to the ground. The GPS system provides position information and the IMU provides attitude information. The coordinates of the LiDAR points are the result of combining the derived measurements from each of its system components, as well as the mounting parameters relating such components. The relationship between the system measurements and parameters is embodied in the LiDAR equation (Vaughn et al., 1996). LiDAR system calibration, which aims at the estimation of the system parameters, is usually accomplished in several steps: (i) Laboratory calibration, (ii) Platform calibration, and (iii) In-flight calibration. In the laboratory calibration, which is conducted by the system manufacturer, the individual system components are calibrated. In addition, the eccentricity and misalignment between the laser mirror and the IMU as well as the eccentricity between the IMU and the sensor reference point are determined. In the platform calibration, the eccentricity between the sensor reference point and the GPS antenna is determined. The in-flight calibration utilizes a calibration test field composed of control surfaces for the estimation of the LiDAR system parameters. The observed discrepancies between the LiDAR-derived and control surfaces are used to refine the mounting parameters and biases in the system measurements (mirror angles and ranges).

Existing approaches for dealing with calibration problems in LiDAR systems can be classified into two main categories: system driven (calibration) and data driven (strip adjustment) methods. System driven (or calibration) methods (Skaloud and Lichti, 2006), which are considered by many researchers as the ideal solution, are based on the physical sensor model relating the system measurements/parameters to the ground coordinates of the LiDAR points. These methods require the original observations (GPS, IMU, and the laser measurements) or at least the trajectory and time-tagged point cloud, which might not be directly available to the end-user. Due to that fact, several approaches relying solely on the LiDAR point cloud coordinates, categorized as data-driven methods (or strip adjustment methods), have been proposed by several authors (Pfeifer et al., 2005). In this type of approach, the effects of the errors onto the point cloud are usually modeled by straightforward transformations between the laser strip coordinate system and a reference coordinate system.

This paper presents two new calibration procedures for the determination of biases in the system parameters that overcome the limitation of existing calibration procedures in terms of requirements of raw LiDAR data. The first presented method – denoted as the "Simplified Calibration Procedure" – makes use of the LiDAR point cloud from parallel LiDAR strips. The system biases are estimated using identified discrepancies between conjugate primitives in overlapping LiDAR strips. The second method – denoted as the "Quasi-Rigorous Calibration Procedure" – can deal with non-parallel strips, but requires time-tagged LiDAR point cloud and navigation data (trajectory position). The following sections provide concise description of these procedures.

Simplified Calibration Procedure:

The "Simplified Calibration Procedure" is designed to work with parallel LiDAR strips acquired by fixed wing platform over an area with moderately varying elevation. It only requires the LiDAR point cloud and the system biases are estimated using detected discrepancies between overlapping LiDAR strips. More specifically, this calibration method consists of a two-step procedure: First, discrepancies between parallel overlapping strips are determined; Then, biases in the system parameters are estimated using the detected discrepancies between the strips. The proposed method will be explained in the paper as follows: First, the mathematical model explaining the impact of biases in the LiDAR system parameters on the derived point cloud will be explained; Second, we will introduce the relationship between the detected discrepancies among parallel overlapping strips and the biases in the system parameters will be derived; Third, a procedure for utilizing the proposed mathematical model while using appropriate primitives that can be identified in overlapping strips to estimated the biases in the system parameters will be presented; Finally, we will introduce the formulation for the adjustment of the point cloud according to the estimated biases in the system parameters.

Quasi-Rigorous Calibration Procedure:

The “Quasi-Rigorous Calibration Procedure” can deal with non-parallel strips. In addition, this method can handle heading variations and varying elevation heights since it also makes use of time-tagged point cloud and trajectory position data. In other words, this method only assumes that we are dealing with a linear scanner and that the LiDAR system unit is vertical. The paper will present the mathematical model relating conjugate points in overlapping strips in the presence of systematic biases in the system parameters. Then, appropriate primitives, which can deal with the irregular nature of the LiDAR points will be introduced. Afterwards, the similarity measure, which incorporates the primitives together with their established mathematical relationship to describe their correspondence and estimate the biases in the system parameters, will be discussed. Finally, we will present the adjustment of the point cloud according to the estimated system parameters.

Comparative Evaluation:

The performance of the proposed methodologies for LiDAR system calibration will be analyzed through the evaluation of the relative and absolute accuracy before/after the calibration process. The evaluation of the relative accuracy will be based on quantifying the degree of compatibility between conjugate surface elements in overlapping strips before and after the calibration procedure. In addition, the impact of the LiDAR system calibration on the absolute accuracy of the point cloud is evaluated by using the LiDAR data for photogrammetric geo-referencing before and after performing the proposed calibration procedure. The outcome of the photogrammetric reconstruction will be evaluated through check point analysis. Preliminary experimental results have shown that the proposed calibration procedures improve the relative and absolute accuracy of the LiDAR point cloud.

References:

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