COMPARATIVE ANALYSIS OF REGISTRATION BETWEEN IMAGES AND LIDAR USING DIFFERENT PRIMITIVES

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1. INTRODUCTION

The complementary characteristics of LiDAR and photogrammetric data continuously motivate the integration of both systems and the benefits of integrating them have already been proven by many researchers [1], [2]. To fully utilize the synergic characteristics of these data, they should be georeferenced to the same reference frame; hence, the importance of a proper co-registration methodology is obvious and cannot be ignored [3]. To register any two datasets, common features have to be identified and extracted from both datasets. The decision of primitives influences the subsequent registration steps; therefore, it is crucial to decide upon the primitives to be used for establishing the transformation between the datasets in question. In traditional photogrammetric applications, point primitives are commonly used. However, since the LiDAR footprints are irregularly distributed, identifying distinct conjugate points in overlapping photogrammetric and LiDAR data is almost impossible. Consequently, alternative features should be considered. Habib et. al. [4] introduced the incorporation of straight lines in photogrammetric and LiDAR registration. Habib and Aldelgawy [5] proposed a method for geo-referencing photogrammetric data using LiDAR linear and areal features as control information. In this paper, straight-lines and planar patches are used as the registration features to register Photogrammetric and LiDAR dataset to the desired ground coordinate system. The objective of this paper is to present a comparative analysis of registration between Photogrammetric and LiDAR using real data to evaluate the use of three alternatives, linear feature, areal feature, and both of them. In addition, this paper compares the registration accuracy depending on the image resolution and laser scanning data density. The next section describes the suggested methodologies by discussing how to represent and extract the planar and linear features from the photogrammetric data and LiDAR data, respectively. The mathematical models and similarity measures in the suggested registration methodologies will be addressed next. To demonstrate the comparison between the registration results using the different primitives and different datasets, quantitative and qualitative analysis will be performed.

2. METHODOLOGY

The co-registration of photogrammetric and LiDAR datasets using planar patches and straight lines can be implemented as a 2-step procedure. The utilization of both primitives is based on preliminary and independent processing of the LiDAR and photogrammetric data, where a photogrammetric model is built relative to a coordinate system defined by the EOP information or GCPs. The photogrammetric model incoporates straight line features during bundle adjustment based on coplanarity condition [6]. Then, conjugate LiDAR and photogrammetric features are utilized in an absolute orientation between the photogrammetric model and the LiDAR reference frame. The registration parameters will be determined relative to the image reference frame, then, transformed LiDAR points will be determined through Equation 1 where ($X'_{LiDAR}, Y'_{LiDAR}, Z'_{LiDAR}$) refers to the transformed LiDAR point cloud to the image reference frame.

$$\begin{bmatrix} X'_{LiDAR} \\ Y'_{LiDAR} \\ Z'_{LiDAR} \end{bmatrix} = \frac{R^T}{S} \left(\begin{bmatrix} X_{LiDAR} \\ Y_{LiDAR} \\ Z_{LiDAR} \end{bmatrix} - \begin{bmatrix} X_T \\ Y_T \\ Z_T \end{bmatrix} \right) \tag{1}$$

2.1 Representation and extraction of Photogrammetric features

The photogrammetric planar surface is identified and represented by three or more 2D points in the image space. Three points are the minimum number of points required to explicitly define a plane. The vertices should be measured on all overlapping images the points appear in to define a photogrammetric 3D surface. Straight lines appearing in a group of overlapping images are represented by two end points which are used to define the corresponding 3D model space line through the collinearity model, and a series of intermediate points. The extraction of image lines starts by identifying two points in one or two images along the line under consideration. The advantage of using linear feature is that these points need not be identifiable in other images. Intermediate points along the line are measured in all the overlapping images. Similar to the end points, the intermediate points need not be conjugate.

2.2 Representation and extraction of LiDAR features

LiDAR patches are represented by the set of 3D points that comprise the patch under consideration. LiDAR_QC program developed by Digital Photogrammetry Research Group enables planar patches to be extracted from LiDAR point clouds semi-automatically. The detail process for the extraction of planar patches can be found in [7]. The outcome is an aggregated set of points representing planar patches in the selected area. LiDAR lines will be represented by two 3D points and they are extracted automatically by intersecting neighbouring segmented planar patches [7].

2.3 Mathematical Model: Point based method

Once linear and planar features from the 3D photogrammetric model and LiDAR datasets are obtained, the relationship between conjugate features must be established. To define the relationship between 3D features from different datasets, 3D conformal transformation parameters, which use three rotations, three translations, and a scale factor, are estimated. In the traditional registration based on corresponding points, least square solution ensures the minimization of the Euclidian distance between two corresponding points after applying the estimated transformation parameters. However, we should consider that the points selected in the imagery and in LiDAR features need not be conjugate. During the absolute orientation procedure, the centroids of the patches were used to define these patches. The advantage of using the centroid is that the centroid passes through the fitted plane through the segmented points. In order to compensate for the non-correspondence between the centroid of vertices defined in the imagery and the centroid of vertices in the LiDAR patch and also the endpoints of lines in the respective datasets, we will restrict the weight of the selected points from both datasets along the plane direction and along the line direction. This weight matrix is manipulated so that the points can freely move along the plane direction or along the line direction respectively. For more detail about the manipulation of restricted weight, please refer to [8].

3. EXPERIMENTAL RESUT

To verify the applicability of the proposed approach and to compare the performance of each method, 2 Photogrammetric datasets with different resolution, panchromatic and RGB images, and 2 LiDAR datasets with different point densities that have been captured by two different systems, Leica and Optech, are used. The four datasets cover the same test area. The performance of the proposed methodologies will be analyzed through quantitative and qualitative analysis.

3.1 Quantitative analysis

Before discussing the final registration quality, to ensure the quality of reconstructed photogrammetric model, the outcome of the bundle adjustment should be evaluated. Two parameters, the square root of the a posteriori reference variance ($\sigma 0$) and the root mean square error (RMSE) resulting from check point analysis, will be analyzed. The RMSEs are compared with the expected accuracies (σX , σY ,and σZ) of the reconstructed points computed based on assumed image measurement accuracy, the elevation height, the camera's focal length, and height-base ratio.

The final registration quality will be compared using sigma value which represents the normal distance between conjugate elements after applying the transformation parameters.

3.2 Qualitative analysis

To prove the compatibility between the LiDAR and images qualitatively, true orthophotos will be generated using the angle-based true orthophoto generation methodology [9]. RGB and PAN true orthophotos with respective to Leica and Optech DSM respectively can be compared to evaluate the compatibility between transformed LiDAR and images.

Another analysis to show the quality of the registration parameters is the projection of features on to imagery. Extracted patches and lines from LiDAR can be transformed with respective to the image reference frame by applying the estimated seven registration parameters. Then, transformed patches and lines are projected onto imagery using the given EOP and IOP information. By examining the discrepancy between the projected features and the original features in the images, the performance of the introduced methodologies can be evaluated and compared.

4. REFERENCES

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