BORESIGHT AND LEVER ARM CALIBRATION OF LIDAR SYSTEM USING CORRESPONDING POINTS FOR GROUND CONTROL POINTS

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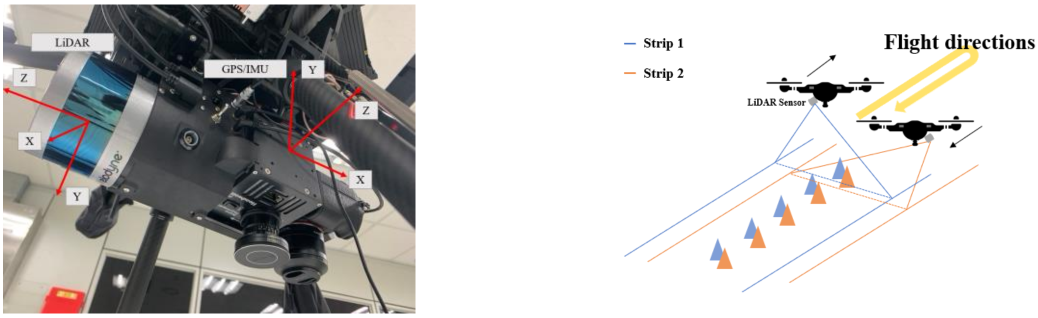
ABSTRACT: This paper describes a calibration method for the boresight and lever arm of lidar system, generated to an UAV (Unmanned Aerial Vehicle) system. The UAV used has multiple sensors, such as a frame camera, hyperspectral sensor, and lidar sensor. Multiple sensor fusion must maintain a high level of mapping accuracy. In particular, boresight and lever arm calibration in the lidar system are essential because each point cloud strip has misalignment. In this study, we developed a calibration method that estimates the boresight angle and lever arm of the a lidar sensor, using GCPs (Ground Control Points). The proposed calibration method has 3 steps. Firstly, the sensor model equation was established to transfer the coordinate from the sensor frame to the ground frame, and through this equation, we generated initial point cloud. Secondly, the corresponding points had been extracted from each strip of non-adjusted point cloud and GCPs. Finally, an observation equation, which is based on the sensor model equation was established to estimate the calibration parameter. In conclusion, misalignment between the strips can be adjusted through estimated boresight and lever arm. It is expected that direct-georeferencing for lidar systems can be applied to any of other lidar survey dataset.

1. INTRODUCTION

The use of UAVs (Unmanned Aerial Vehicles) is essential to study unknown areas, such as polar exploration. Along with the development of UAVs, various studies are being actively conducted based on data acquired from multiple sensors such as frame cameras, hyperspectral images, and lidar sensors. For this, the precise position of the acquired data between sensors is required and essential. However, it is not easy to obtain data for correction because the polar environment is quite limited for terrain, or insufficient for artificial features that are easy to recognize. Therefore, it is necessary to apply direct-georeferencing along with data acquisition without any process. Generally, a GPS/IMU sensor is mounted together on the UAV platform to obtain continuous position and rotation angle of the platform. The data acquired by the GPS/IMU sensor is used as an important parameter for converting the position of x, y, and z from the sensor frame to the ground frame. Here, there is a physical offset about rotation angle and distance between the GPS/IMU and the sensor for data acquisition (see Figure 1 (a)). we called these a boresight angle, lever-arm respectively. We can observe various cases of errors because of boresight angle, lever-arm offset. In particular in lidar system, poor precision for points, or a phenomenon in which features look like two objects along the flight direction (see Figure 1 (b)), is the most common errors. Parameter estimation of lidar systems mainly uses a method for detecting a roof-like plane of a building that is easy to recognize and establish a plane equation (Rabine Keyetieu et al., 2019), or uses ICP Algorithm to find corresponding points between the strips (Zhen LI et al., 2019). But in this paper, we aim to estimate boresight angle, lever-arm parameters using the GCPs (Ground Control points), and to apply direct-georeferencing for any other datasets, different regions through the correction parameters



(a) (b)

Figure 1. (a) rotation angle and distance offset between LiDAR Sensor and GPS/IMU (b) an error of point cloud along flight directions

2. MATERIALS AND METHODS

The two datasets were used for the study to estimate boresight angle, lever-arm and to apply its parameters. Figure 2(a)(b) shows the areas surveyed for study. In Figure 2 (a), we have attempted to estimate the boresight angle and lever-arm of the lidar sensor in UAV. In Figure 2 (b), we have also tried to apply estimated-parameter, and verified that its parameter was corrected. Velodyne VLP-16 Puck HI-RES was used to obtain data for topography in this study. In the lidar system, target features are generally installed in the survey area, as shown Figure 2 (a)(b). LiDAR systems acquire only x, y, and z values for the actual terrain without acquiring a direct image, unlike frame cameras, hyperspectral sensors. Therefore, we installed target features in the survey area to evaluate the acquiring accuracy of lidar sensors. Next, we acquired 10 GCPs through RTK surveying, to correct the precise position of the acquired data.

(a) (b)

Figure 2. (a) the survey area to estimate boresight and lever-arm (National Institute of Agricultural Sciences), (b) the survey area to apply boresight and lever-arm (Korea Polar Research Institute)

In this study, the proposed calibration methods to estimate boresight angle, and lever-arm parameter consist of 3 steps. Firstly, the sensor model equation was established to transfer the coordinate from sensor frame to ground frame. The sensor model equation is expressed as a rotation matrix, and through its equation, we can generate an initial point cloud. Secondly, corresponding points for each strip are extracted according to the flight direction of the UAV. Lastly, an unknown parameter for boresight angle and lever-arm was estimated, using the corresponding points and GCPs. The estimated boresight and lever-arm values are substituted into the sensor model equation to generate a corrected point cloud. The corrected point cloud was visually inspected whether the recognized target features were spaced apart, and the relative distance error was analyzed, compared to the GCPs.

Figure 3. Workflow of proposed estimation method

2.1 Sensor model equation

Equation (1) shows the sensor model equation that we propose in this paper. The point cloud for the ground frame can be acquired through its sensor model equation.

$$(P_L^M) = (R_N^M)*(R_B^N)*(R_{I_0}^B)*\left(R_I^{I_0} * R_L^I * P_L + T_L^B\right) + T_B^M \qquad (1)$$

Where :
P_L^M is the geo-referenced points coordinated in the ground frame.
P_L is the position vectors of x, y, and z in the lidar sensor frame.
$R_I^{I_0}$,T_L^B are unknown parameter vector for boresight angle and lever-arm.
R_L^I is the rotation matrix of axis from the Laser sensor frame to The frame camera sensor frame.
$R_{I_0}^B$ is the rotation matrix of axis from IMU Sensor frame to Body frame(platform).
R_B^N is the rotation matrix of the coordinate from Body frame to Navigation frame (Roll, Pitch, Yaw).
R_N^M is the rotation matrix of the coordinate from Navigation frame to Map frame.
T_B^M is the translation vectors of UAV Platform (Easting, Northing, Altitude).

2.2 Extract corresponding points

The general frame camera calibration method also uses a method for extracting corresponding points between continuous images, using recognizable GCP in the images. Unlike this, lidar surveying is not easy to find corresponding points because it acquires continuously countless points for the terrain. However, in this study, we recognized GCP marks using the intensity value to indicate the strength of laser pulses at the survey moment. Therefore, we acquired corresponding points for 10 of GCPs, and then extract exterior orientation parameters for each corresponding points. Figure 4 describes the concept of acquiring corresponding points for each strip. For this work, we used the Cloud Compare Software.

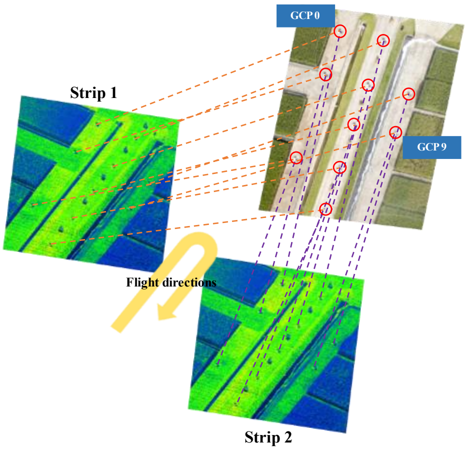


Figure 4. the concept of acquiring corresponding points for each strip

2.3 Estimate calibration parameter

Calibration parameters are estimated using the corresponding points obtained in **2.2** and Equation (1). In equation (1), unknown parameters that we want to estimate are $\Delta\omega, \Delta\rho, \Delta\kappa$, T_x, T_y, T_z, elements of a rotation matrix $R_I^{I_0}, T_L^B$. Therefore, after transfer of all elements except these two matrices, least square estimation was performed in the observation equation. Table 1 shows result of estimated parameters for boresight angle and lever-arm using strip 1-2, along with the flight direction.

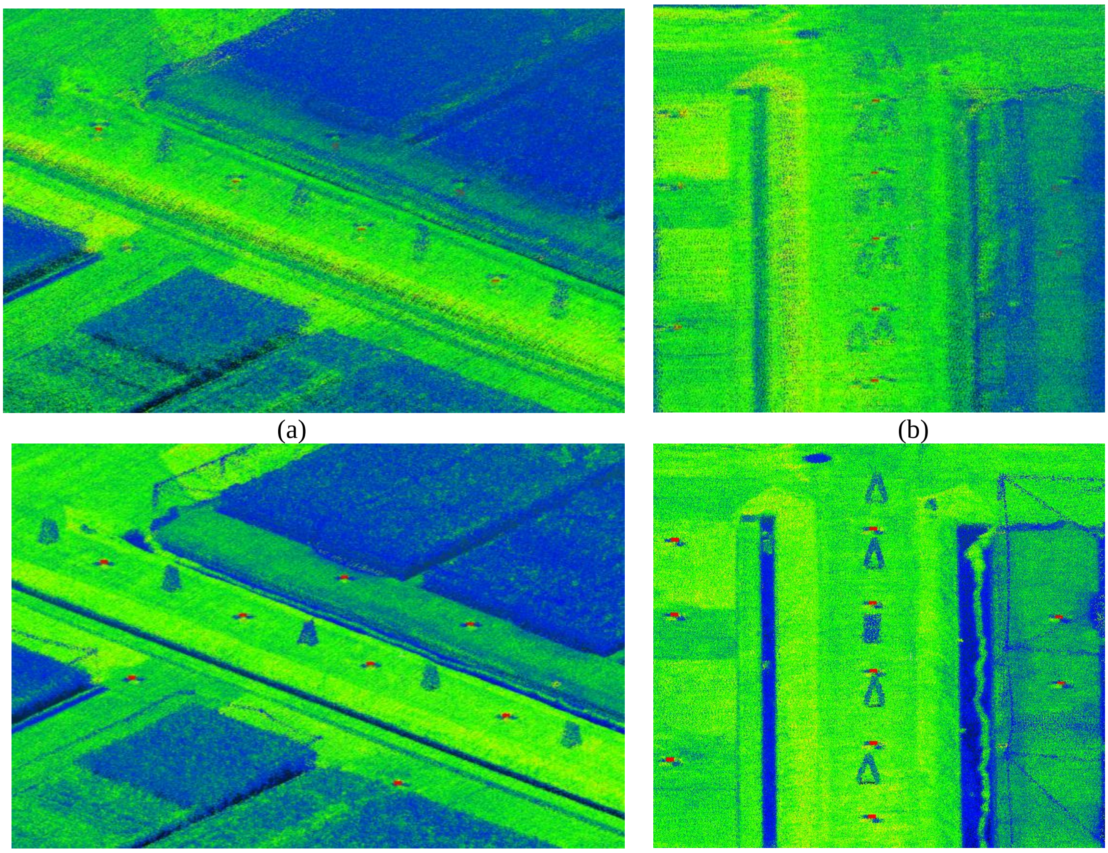
	Estimated boresight angle			Estimated lever-arm		
	Omega(deg)	Phi(deg)	Kappa(deg)	Tx(m)	Ty(m)	Tz(m)
Strips (1-2)	0.0981762	1.00089	-0.822759	-0.018217	-0.254136	-0.0636411

Table 1. estimated parameters for boresight angle and lever-arm

3. RESULTS AND CONCLUSIONS

Before applying the boresight angle and lever-arm parameters, the misalignment for each point cloud strip has been confirmed, as shown figure 5 (a)(b) and figure 6 (a)(b). It can be seen as if there are two objects. On the other hand, after applying the boresight angle and lever-arm parameters, we have confirmed that the misalignment for each point cloud strip has been completely removed in Figure 5(c)(d) and Figure 6(c)(d). In figure 5 area, we confirmed RMSE 0.056915, 0.039504, 0.028464 for x, y, and z, compared to GCPs, and in figure 6 area, 0.118935, 0.127862, 0.042454, respectively. It is quite a reasonable value for estimation, and we decided the point cloud is corrected quite well.

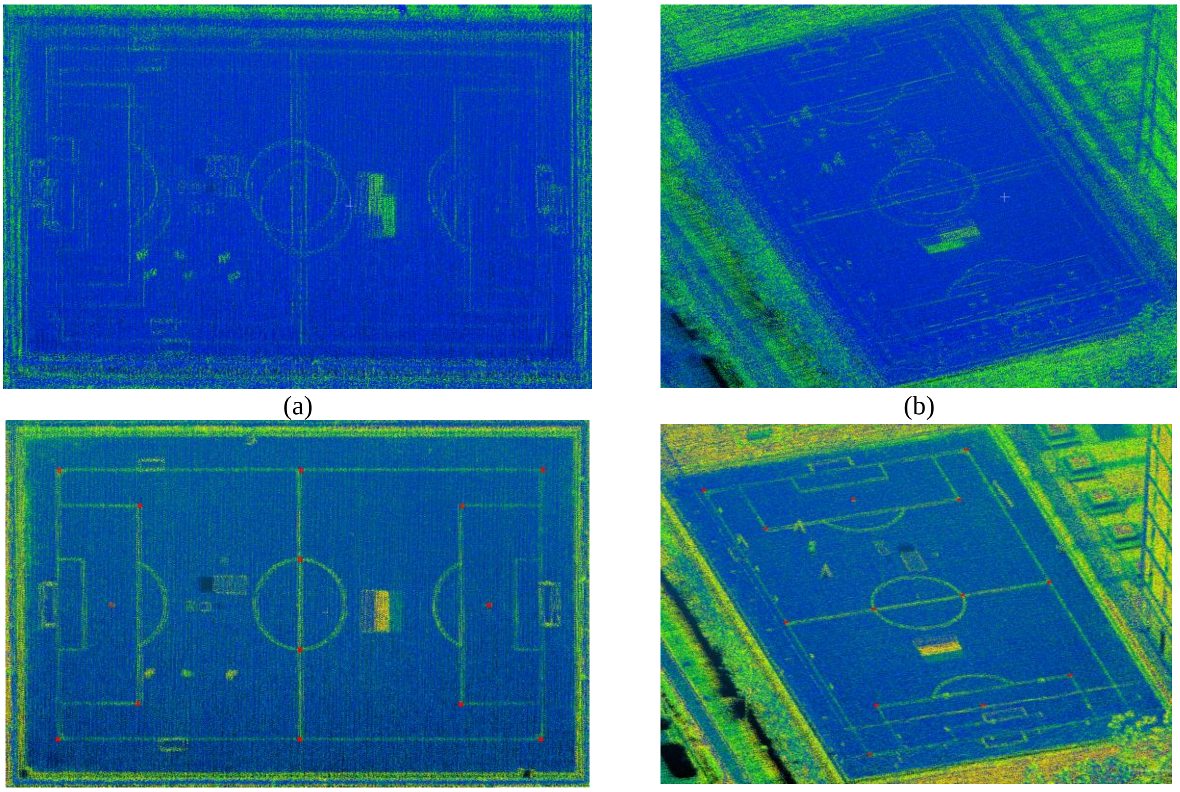
In this study, we have confirmed that the estimation of boresight and lever-arm was able to be used for the simple estimation method. And the necessity of estimation for boresight and lever-arm also are confirmed through the result of figure 5, 6 in the lidar system. The estimated parameters were applied to two of datasets. In figure 5 area to estimate parameters, it has been calibrated, but in figure 6 area to apply parameters, we have confirmed a slight error although it has been corrected, compared to before. This is predicted to be an error caused by the GC angle occurring between true north and magnetic north, and it is necessary to confirm it through follow-up studies. Nevertheless, we confirmed that both the boresight and lever-arm are crucial parameters for direct-georeferencing, guaranteeing a high speed of processing and maintaining high precision.



(a) (b)

(c) (d)

Figure 5. Multi strip point cloud before and after calibration in dataset 1. (a),(b) before boresight and lever-arm calibration, (c)(d) after boresight and lever-arm calibration. Red point means ground control points



(a) (b)

(c) (d)

Figure 6. Multi strip point cloud before and after calibration in dataset 2. (a),(b) before boresight and lever-arm calibration, (c)(d) after boresight and lever-arm calibration. Red point means ground control points

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