MOBILE SYSTEM ANGULAR ALIGNMENT QUAILTY ANALYSIS

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ABSTRACT

LiDAR and INS-GPS sensor integration requires exact alignment for a mobile system to provide precise data. Even the most precise mounting of multiple sensors can lead to angular misalignment. Correction programs and procedures exist in many available software packages from both manufacturers and 3rd party software solutions. Commonly, data is mutilated in a way that can lead to inaccuracy results, in order for multiple passes to align with each other and establish survey ground control. *RIEGL*'s RiPROCESS scan data alignment tool provides a semi-automatic algorithm for the calibration of misalignment angles. To verify this process, a ground control field was placed along a boat landing, and a tripod based scan was taken and registered to the ground control. Then, previously calculated boresight adjustment angles were applied to the system's 10 passes over the surveyed and scanned area, with the scanner set at different yaw angles with respect to the boat's reference frame and speeds. The mobile data was compared to the registered tripod scan data before and after adjustment to the ground control system to determine the quality. It will be shown that RiPROCESS' scan data adjustment will produce angular alignment values that minimize relative error, allowing for simple vertical adjustment within the error of kinematic GPS solutions.

Keywords: Mobile, LiDAR, Alignment, Quality Control, 3D Laser Scanning

INTRODUCTION

Mobile laser scanning requires the integration of multiple sensors in order to produce a well calibrated point cloud. A variety of standards have been written to help realign the calibrated point cloud with surveyed ground control points. A study of current literature shows this surface to ground control point method that is currently used with some deficiencies in regards to the rest of point cloud not near a control point(s). One method suggests using terrestrial static data to align airborne data (Fowler, 2011). This method focuses on using a terrestrial static scanner to scan several sites and then compare the airborne data at these sites. A major issue using this similar method with mobile data is the amount of area that would need to be cover in order to compare all of the areas scanned. This is more critical when examining mobile data since the mobile data is more susceptible to GPS outages. The surface to surface method will be used to verify the angular alignment of a mobile 3D laser scanning system.

System Description

The mobile 3D laser scanning system consists of a *RIEGL* VZ-400 and an Applanix POS MV unit. *RIEGL*'s VZ-400 is a class 1 eye safe laser, with a repeatability and accuracy better than 5mm and an effective measurement rate of 125,000 meas./sec. The V-line systems use online signal processing capable of discriminating the echo pulse shape with respect to the emitted pulse shape (Rieger, 2008). The system is mounted on a common ridged plate so that the both the Inertial Measurement Unit (IMU) and the *RIEGL* VZ-400 experience the same motion (Figure 1). The mounting of the scanner and IMU to a ridged plate with a short lever arm, the offset between measurement axes, reduces errors in measurements (Glennie, 2007) The POS MV unit utilizes a single Global Navigation Satellite System (GNSS), Trimble Zephyr Model 2 antenna, with a BD960 Trimble receiver. A GNSS reference station was setup near the project to provide a broadcasted real-time kinematic (RTK) signal for better heading accuracy during the mission.

Figure 1. Mobile VZ-400 System, mounted next to the IMU.

Boresight Alignment

In order to calculate the angular misalignment between the measurement axes of the laser scanner and the measurement axes of an internal measurement unit (IMU) a boresight must be performed. The method of calculation used is a least squares approach for reducing the error between multiples passes on the same planar surface. The *RIEGL* method of boresight alignment allows for a flexible procedure to be used in acquiring data with any 2D line scanning laser and an IMU, (Rieger, 2008). The mobile system mounted on a boat was first boresighted on land by towing the boat on a trailer passed several buildings near the waterfront. Nine passes were performed with the scanner yaw (heading) angle changed for each pass.

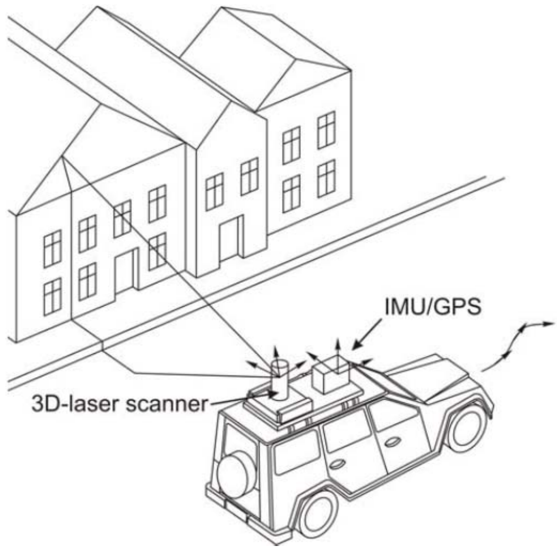

Figure 2. Typical Setup of a mobile scanning system with a 3D- Laser Scanner and an IMU/GPS system.

After the data is collected, it is combined with the smoothed best estimate trajectory (SBET) file from Applanix's POSPac MMS. The misalignments between the measurement axes appear when analyzing the point cloud. The resulting boresight values using *RIEGL*'s RiPROCESS software tool scan data adjustment, are listed in Table 1 along with the statistics supporting the quality of the boresight values.

Table 1. Boresight alignment quality and results

Roll [deg]	0.06579
Pitch [deg]	-0.16511
Yaw [deg]	0.42834

Boresight Quality	
Number of observation (Planar Surfaces)	3072
Error (Std. deviation) [m]	0.0142

The process uses auto calculated planes from each pass and with user defined matching criteria, which filters out planes that do not match planes from the other passes (Rieger, 2008). The resulting standard deviation of 0.0142m is a superior result from this least squares adjustment approach (Figure 3). Typical errors for each boresight angle are 0.001 degrees for roll and pitch, and 0.004 degrees for heading or yaw, when using a least squares adjustment methods using data from overlapping LiDAR passes (Glennie, 2007). The result seen will produce results within the system GPS error estimate for any proceeding project. A GPS error of 2cm+ 2ppm in the vertical is common rule when determining system expected accuracy (Glennie, 2007).

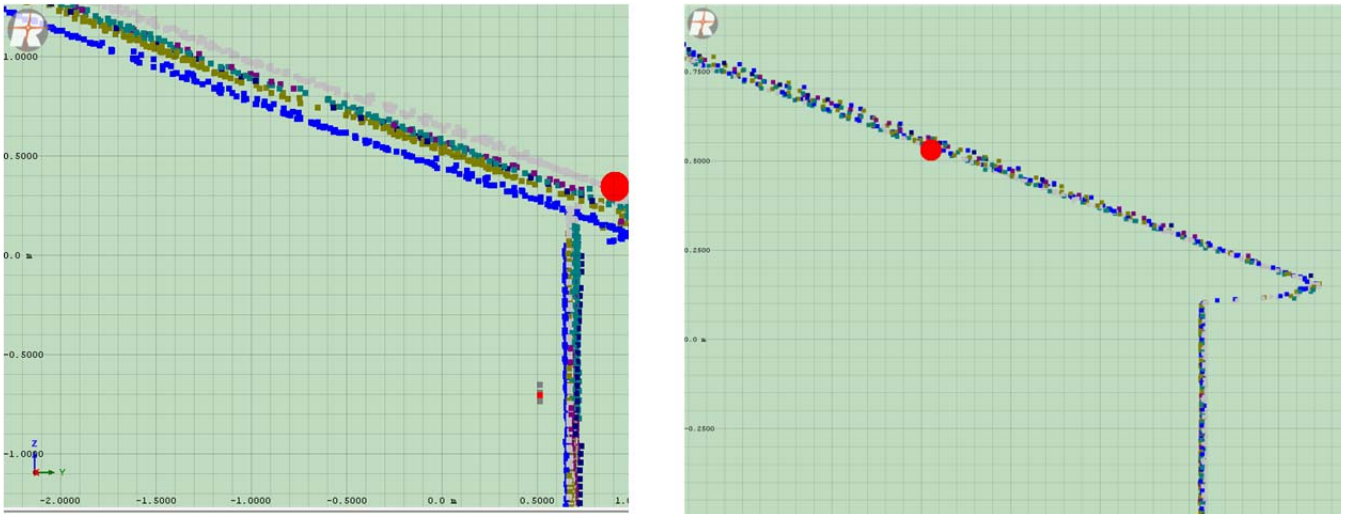

Figure 3. Detail of facade before (left) and after (right) boresight adjustment.

Quality Assessment

A second set of multiple passes was performed in the Yazoo River along the boat launch landing in Vicksburg, Mississippi. This data set will be used to first assess the quality of the boresight alignment values previously found when towing the system on a trailer. Assessing the quality of these results uses *RIEGL*'s RiPROCESS tool scan data adjustment to verify how well the boresight alignment limits the error in the system. An expected std. deviation from a matching planar surface analysis would be around 2-3cm based on errors inherent to a 3D laser scanning system. The data set will be unadjusted post processed; simply meaning a SBET matched and projected point cloud. Based on an analysis of error for kinematic scanning, a vertical error of around 0.02 to 0.04m as the range increases between 10 to 25m can be expected (Glennie, 2008). Using 4,113 planar surfaces found in eight passes over the same area an error standard deviation of 0.031m is calculated. This data set affirms the approached used by Glennie et al. in calculating error in a mobile LiDAR system. It also shows an improved overall quality, since at further distances of 175m plus errors remain within 2-4cm. This confirms the boresight values' precession, now a more rigorous analysis is needed to verily the system accuracy.

Accuracy Analysis

The same area scanned by the mobile system was then scanned by the VZ-400 using two scan positions and four targets. A current method to do absolute accuracy analysis is to use surveyed ground control points, using a triangular mesh of the data to determine offset between the control point and the data (Fowler, 2011). This is the standard practice for assessing mobile LiDAR data. Setting control points at regular intervals along the highway allows for a check at those points. An accepted mobile laser scanning standard sets control points every 150m with every 2 points used as check points (CALTRANS, 2010). This test field 96 control points were set along the inclined surface of the boat launch area. These points where then used to determine the absolute accuracy (Figure 4).

Figure 4. Detail of area used for absolute accuracy analysis.

An absolute accuracy tighter than typically seen with post processed LiDAR data, (Table 2). This method only examines the accuracy at the control points and assessing the horizontal accuracy is very difficult. These points were set on ridges and concrete cracks, but determining how close it is to the exact ground control point is very difficult even with painted targets. The process becomes more of an eye test than a reproducible analysis.

Table 2. Mobile LiDAR system, vertical comparison with ground control

LiDAR V. Ground Truth	Value [m]
Average	-0.0022
Maximum	-0.1835
Minimum	0.0003
Standard Deviation	0.0194
RMS	0.0195

Terrestrial Static Data Registration

Two scan positions were used to capture the control point field (Figure 4). Six tripod targets were setup to register the two scan positions together. This is the standard practice for acquiring terrestrial data sets (Fowler, 2011). The two data sets aligned well but an additional correction was needed to set the two scan positions together to be used as a solid baseline for analyzing the quality of the mobile data. *RIEGL*'s multi-station adjustment tool (MSA) in RiSCAN PRO was used to align the two scan positions fixing the scan position that best aligned with control as the baseline. Each position registered to control within 1.5cm std. deviation to the six targets. The second position was much closer aligned with a std. deviation of 0.92cm and is used as the baseline for adjusting the first position. The MSA tool uses common meshed surfaces similar to RiPROCESS' scan data adjustment tool to adjust point clouds. The resulting adjustments improved the two scan position's agreement (Table 3).

Table 3. Final registration of scan position 1 to scan position 2 using MSA

Adjustment of Scan Pos. 1 to Pos. 2 Results	
(Δx, Δy, Δz) [mm]	(-1,-3,-2)
Δ(roll, pitch, yaw) [deg]	(0.009,-0.005,-0.001)
Std. deviation[m]	0.005076

As this 5mm std. deviation indicates a very exact positing match was found for the two scan positions. It can now be considered more absolutely accurate than the mobile LiDAR was to the same control field (Table 2).

Mobile to Static Alignment

An absolute data location has been established with the static data and its five million plus points. This combined point cloud can be used to first analyze the quality of the mobile data and then using the MSA tool adjust the data. In order to adjust the point cloud, it must be filtered down and the points that are at further ranges must be eliminated from the filtered point cloud. These points are not as dense at 200m from the VZ-400's trajectory and are filtered out by point deviation and range (Pfennibauer, 2010). By using the MSA tool, the data quality can be assessed and corrected. MSA computes the position change needed to correct the entire scanner pass (Table 4). As shown by Figure 5 the XY planar adjustment was necessary to make the two point clouds better coincide, but it could be argued that it was not necessary based on how close the two data set are from the beginning. However, since the accuracy of the static data is much higher than the accuracy of the mobile data, it makes sense to adjust the data an additional 1.3cm and 6.2cm respectively in the horizontal direction (Table 4). The adjustment in the Z axis as shown in Figure 6, are cleaner and form a uniformed surface.

Table 4. MSA results from using the final scan data registration position to align the mobile data

MSA Quality Results	
(Δx, Δy, Δz) [cm]	(1.3, 6.2, 4.2)
Number of Planes	9569
Std. deviation [m]	0.004453

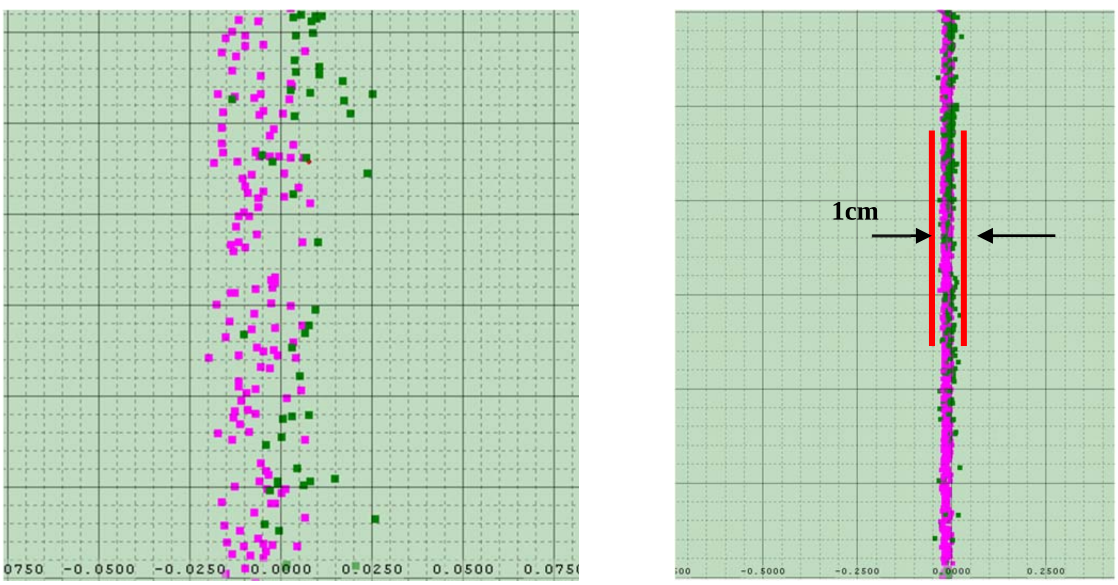

Figure 5. Mobile data (green) shown before (left) and after (right) on a wall approximately 175m from the boat.

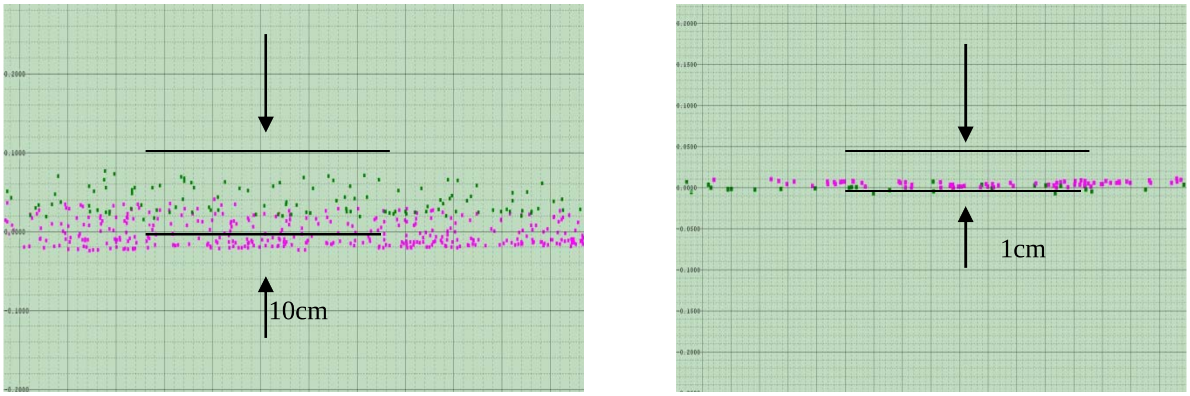

Figure 6. Vertical alignment before (right) and after (left) with the mobile data in green.

CONCLUSION

The process for bringing mobile data and terrestrial data together allows for the most complete quality analysis. This process should be used for projects to benchmark a boresight angular alignment procedure. Using a surface to surface matching does improve results as demonstrated by examining the data resulting from the final multi-station adjustment and the calculated std. deviations supports these visual results. A control point adjustment routine can adjust data within millimeters of matching control points and often does. Only a surface to surface comparison can align the complete data set within millimeters. Determining how to integrate this type of compete quality analysis into the mobile LiDAR collection process is work for the future. The use of terrestrial static data is a good supplement for scanning under bridges or in areas with poor sky view. The quality analysis demonstrated proves that the VZ-400 and the *RIEGL* boresight method produce very accurate data when examined by any method.

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