Case Study

LiDAR QC
Mobile Mapping Town Center

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Overview

Applanix LiDAR QC Tools comprise a set of POSPac™ software tools designed to attain the utmost level of georeferencing accuracy with LiDAR sensors.

These tools facilitate *boresight calibration* between the Inertial Measurement Unit (IMU) and LiDAR sensor, *trajectory adjustment*, and the generation of *LAS file* point clouds. Primarily employed in the uncrewed airborne (UAV), land mobile mapping, and indoor survey industry, this software is hardware-agnostic, functioning seamlessly with any LiDAR system. Ground reference data, such as Ground Control Points (GCP), is unnecessary. The primary objective is to generate a consistent and homogeneous point cloud and refine the vehicle trajectory using LiDAR data.

The LiDAR QC Tools leverage Applanix® Point Cloud Data Adjustment (PCDA) technology. Applanix PCDA™ technology represents an advanced iteration of LiDAR Simultaneous Location and Mapping (SLAM), founded on a robust global Voxel iterative least squares adjustment (LSQ). In this context, the LiDAR serves as an aiding sensor, contributing to trajectory optimization. This optimization is generated in POSPac, utilizing data collected from Trimble® Inertial hardware, such as the Trimble Applanix POS or Trimble AP+ solutions.

Figure 1: Trimble MX50 I Mobile Mapping

Background

This case study specifically focuses on Mobile Mapping data in GNSS critical terrain (town center). The Trimble MX50 product (refer to Figure 1) is employed for this investigation. The MX50 utilized in this case study is equipped with two LiDAR sensors (left/right), a spherical camera, and an AP20 GNSS-INS system from Trimble Applanix. The primary objective of this exercise is to showcase the absolute accuracy in the 3D point cloud both before and after the utilization of LiDAR QC Tools. To achieve this, the latest **IN-Fusion+ Single Base** processing mode is applied to generate the reference trajectory (SBET). This mode leverages a nearby base station, ensuring optimal elimination of GNSS error budget. Consequently, it creates a highly accurate trajectory for the direct georeferencing of LiDAR sensor data.

Test Area

The test area is situated in Biberach, Germany. Data collection took place in the town center through two runs in the same direction, essentially forming loops with overlapping point cloud scenes. Each individual run or loop covers an approximate distance of 1 km.

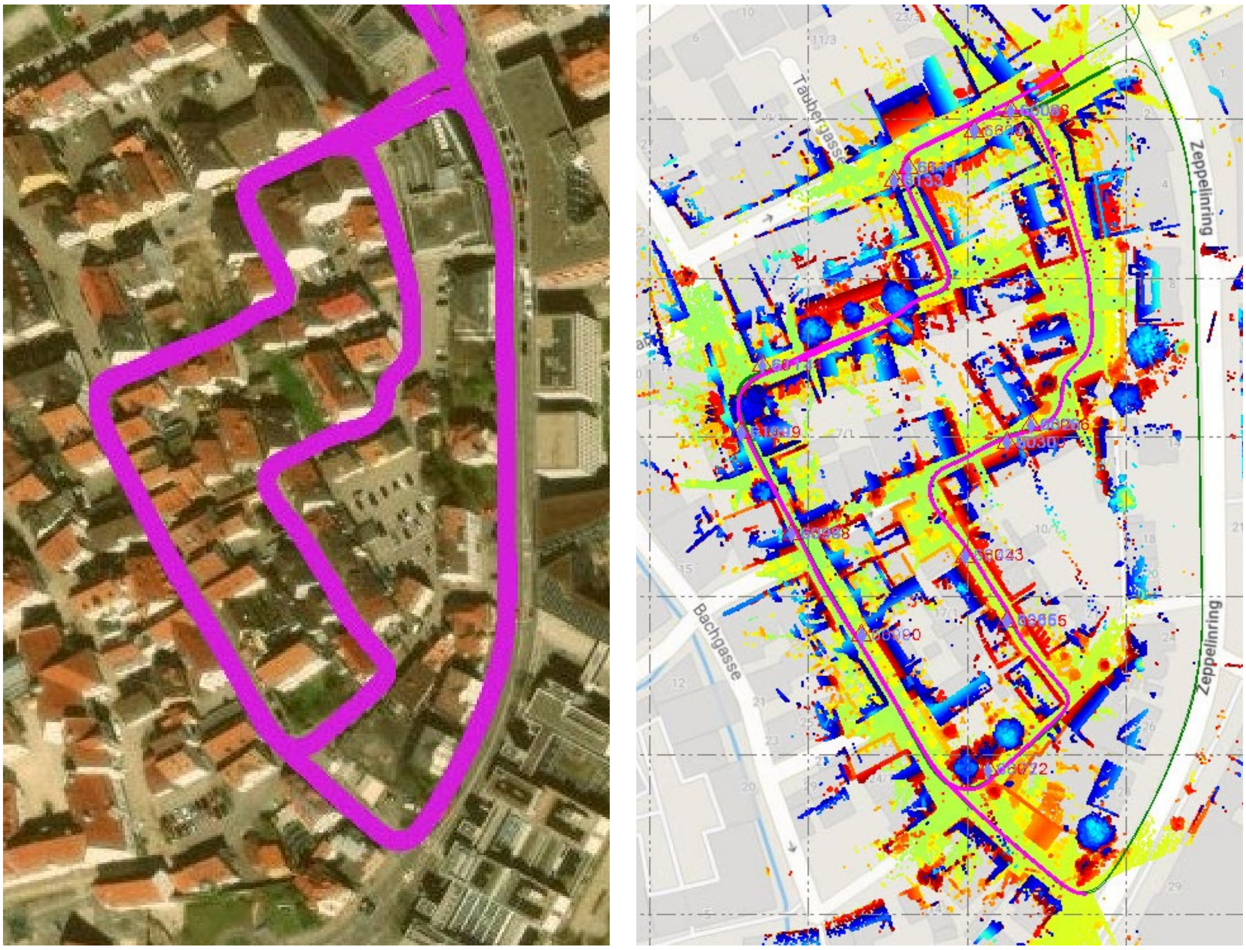

Figure 2: Left - Entire GNSS-INS Trajectory, Right - LiDAR recorded loops

The terrain proves challenging for GNSS due to the narrow roads measuring only 4–8 meters in width, with buildings reaching heights of up to 12 meters. During a segment of the journey, the vehicle traversed a “canyon” for approximately 8–9 minutes. Please refer to Figure 3 for the limited GNSS satellite coverage in the town center area (highlighted in red).

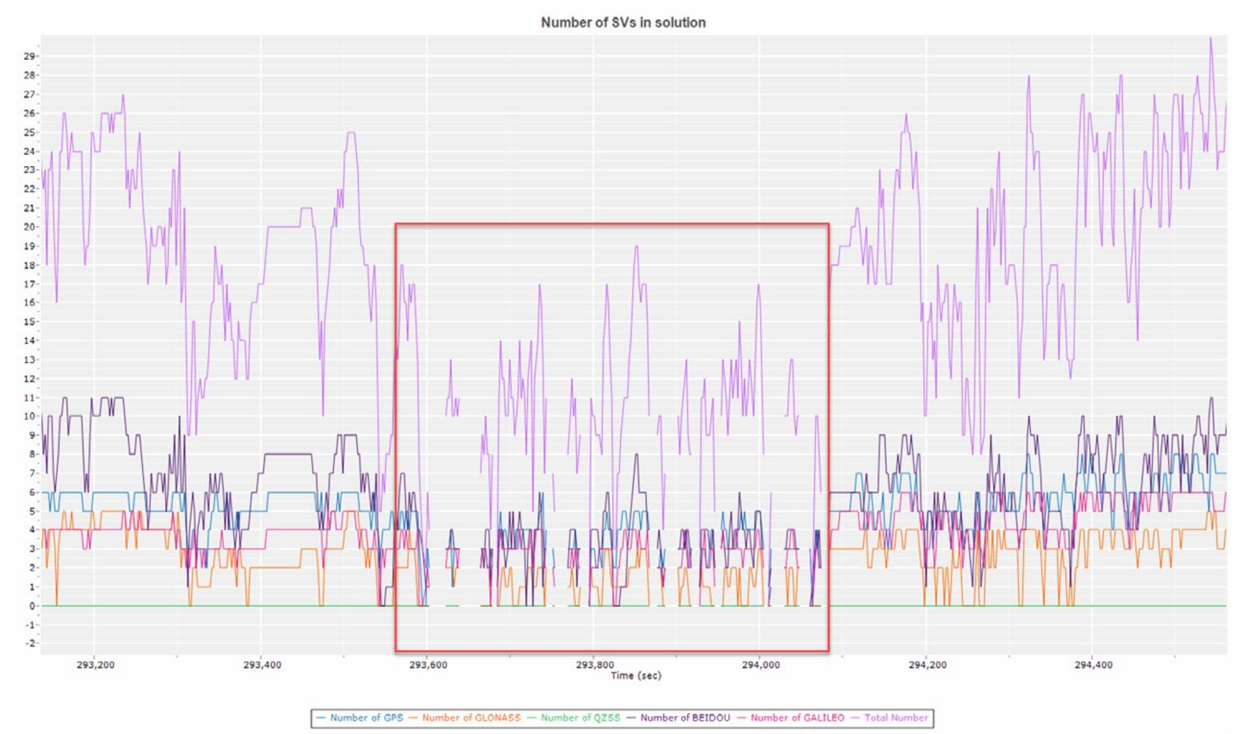

Figure 3: GNSS Satellite Visibility - red frame represents town center

In terms of ground control points (GCPs), both 3D and vertical points were strategically positioned. These points underwent surveying through the establishment of a dense reference point network using GNSS technology and Trimble terrestrial 3D Laser. All surveyed points (GCPs) are referenced in the ETRS89 frame. To mitigate potential datum defects, the same base station (same coordinates!) was utilized for GCP surveys and GNSS-INS trajectory post-processing (Single Base mode). Additionally, the baseline length was kept < 5 km. This approach ensures that any datum-related issues are excluded from the error budget. The vertical GCPs were positioned along the road without any explicit identification marks. In contrast, the 3D points are discerned as road paintings within the point cloud. The accuracy for the GCPs are a few millimeters.

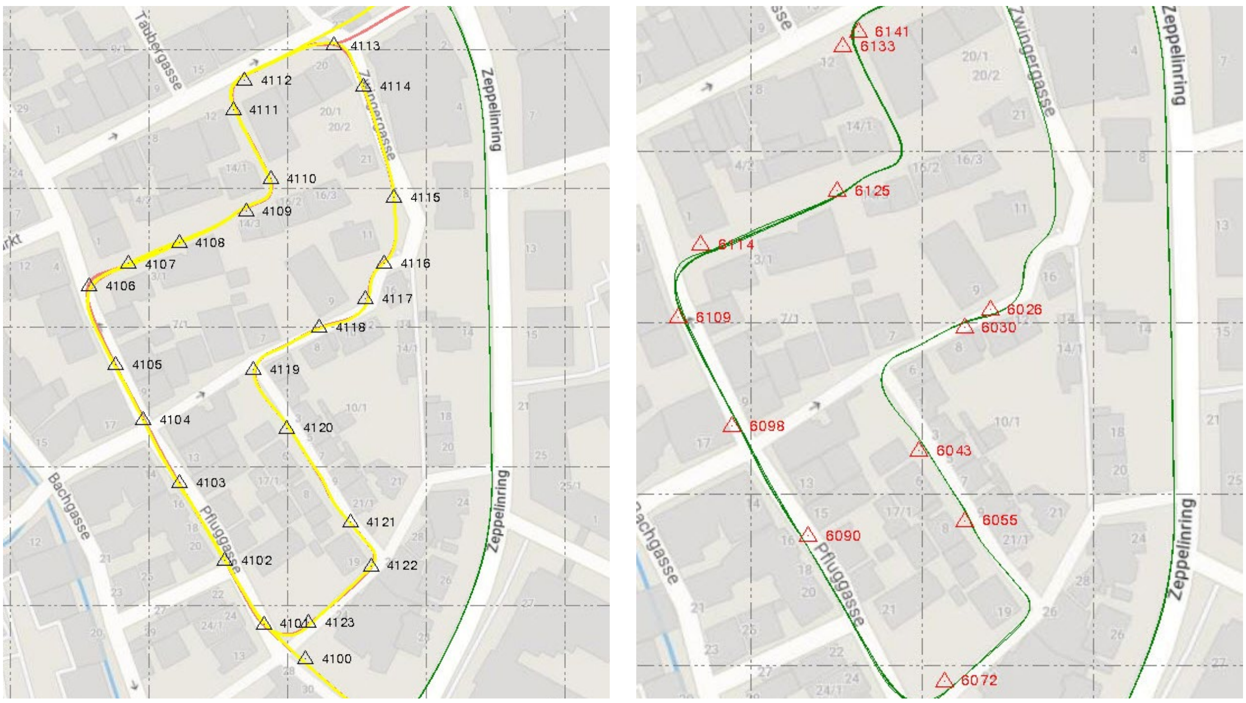

Figure 4: Left - Vertical GCPs, Right - 3D GCPs for horizontal performance

Data Evaluation

The GNSS-INS trajectory, also known as SBET (smoothed best estimate of trajectory), underwent post-processing in the **IN-Fusion+ Single Base** mode with a maximum baseline of 3.5 km. Within the challenging town center, characterized by narrow roads and surrounded by buildings, the majority of GNSS epochs were in float mode due to satellite shading. The highest estimated 3D root mean square (RMS) error in the GNSS-INS Kalman Filter process was approximately 50 cm.

All lever arms, including GNSS offset, IMU offset and DMI offset, are known parameters and were maintained as fixed values during post-processing to minimize errors and noise. The Trimble MX50 system underwent prior boresight calibration, addressing misalignments between the IMU and LiDAR sensors, using a specific calibration pattern. A swift verification of the boresight angles was performed using LiDAR QC Tools, confirming the accuracy of the original calibration values. Subsequently, LiDAR QC Tools were employed to refine the initially derived GNSS-INS trajectory by utilizing LiDAR data as aiding observations. For more in-depth technical information, please refer to the White Paper.

The difference in 3D positions between the original GNSS-INS trajectory and the enhanced trajectory aided by LiDAR is depicted in Figure 5. The flat line occurs outside the LiDAR data recording, indicating no differences for these segments. The adjustment of the SBET is driven by the LiDAR data in the town area:

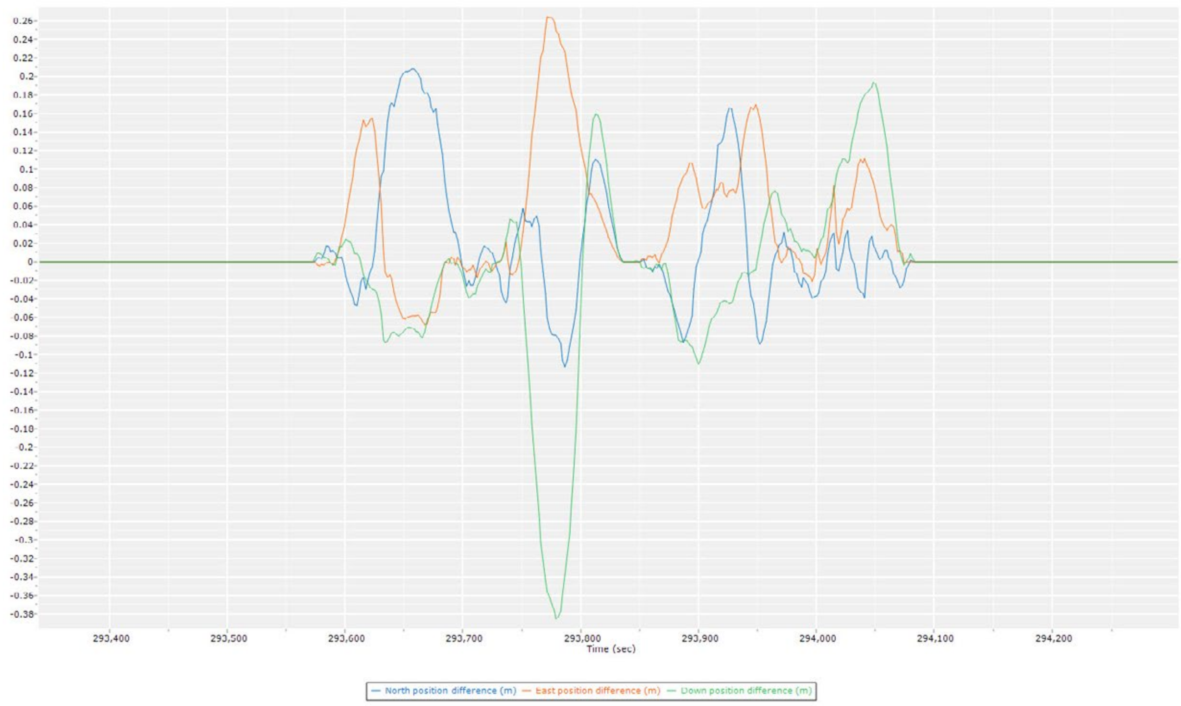

Figure 5: 3D Difference SBET vs. Adjusted SBET

Vertical Performance

The 24 non-marked points are spread across the 1 km loop, as illustrated in Figure 4. The delta height extraction between the vertical GCP and the point cloud (LAS - generated in Trimble Business Center) was done automatically. Given the presence of 2 runs/loops and a left and right LiDAR sensor in each, all four point clouds were individually compared against the set of 24 vertical GCPs. The following statistics, expressed in centimeters, are provided below:

Unit [cm]	Left LiDAR		Right LiDAR		Total
Value	Run 1	Run 2	Run 1	Run 2	
Mean	-2.2	-0.1	-2.0	-0.9	-1.5
StdDev	2.6	4.6	2.5	4.4	3.5
MIN	-7.9	-8.2	-7.1	-8.8	**-8.8**
MAX	1.3	8.8	1.7	6.8	**8.8**
Z RMS	**3.4**	**4.5**	**3.2**	**4.3**	**3.8**

Table 1: Absolute vertical accuracy (cm) based on original SBET

We achieve an absolute vertical RMS value of **3.8 cm** and a maximum outlier of 9 cm with the **IN-Fusion+ Single Base** trajectory. The following statistics are presented after the utilization of LiDAR QC Tools, which resulted in an adjusted trajectory, in centimeters:

Unit [cm]	Left LiDAR		Right LiDAR		Total
Value	Run 1	Run 2	Run 1	Run 2	
Mean	-0.4	-0.4	-0.2	-0.2	0.1
StdDev	1.4	1.4	1.4	1.4	1.4
MIN	-2.7	-2.7	-2.6	-2.5	**-2.7**
MAX	2.8	3.1	3.3	3.3	**3.3**
Z RMS	**1.4**	**1.5**	**1.4**	**1.4**	**1.4**

Table 2: Absolute vertical accuracy (cm) based on LiDAR adjusted SBET

LiDAR QC Tools improve the absolute vertical accuracy by more than 250%, yielding a performance of **1.4 cm** with a maximum residual of 3.3 cm. Looking at the other statistical values (Mean, StdDev, MIN, MAX) reveals a strong alignment of the point clouds between the runs. This underscores the fundamental role of LiDAR QC in ensuring uniform and consistent point clouds. The following illustrates an example of vertical point cloud displacement both before and after the trajectory adjustment (refer to Figure 6):

Figure 6: Vertical displacement before (Top) and after LiDAR QC (Bottom)

Horizontal Performance

Thirteen (13) GCPs were used to derive the absolute horizontal performance. These points were measured in Trimble Business Center (TBC), as depicted in Figure 7. In this context, the distinction between the Left and Right LiDAR was not made; instead, the runs/loops were treated separately, and the GCP residuals were derived from each individual point cloud. The subsequent result is presented below for the point cloud derived from the original trajectory, expressed in centimeters:

Unit [cm]	Run 1	Run 2	Total
StdDev	5.3	3.7	4.5
MIN	0.4	0.7	**0.4**
MAX	16.6	12.6	**16.6**
2D RMS	**9.3**	**7.4**	**8.4**

Table 3: Absolute horizontal accuracy (cm) based on original SBET

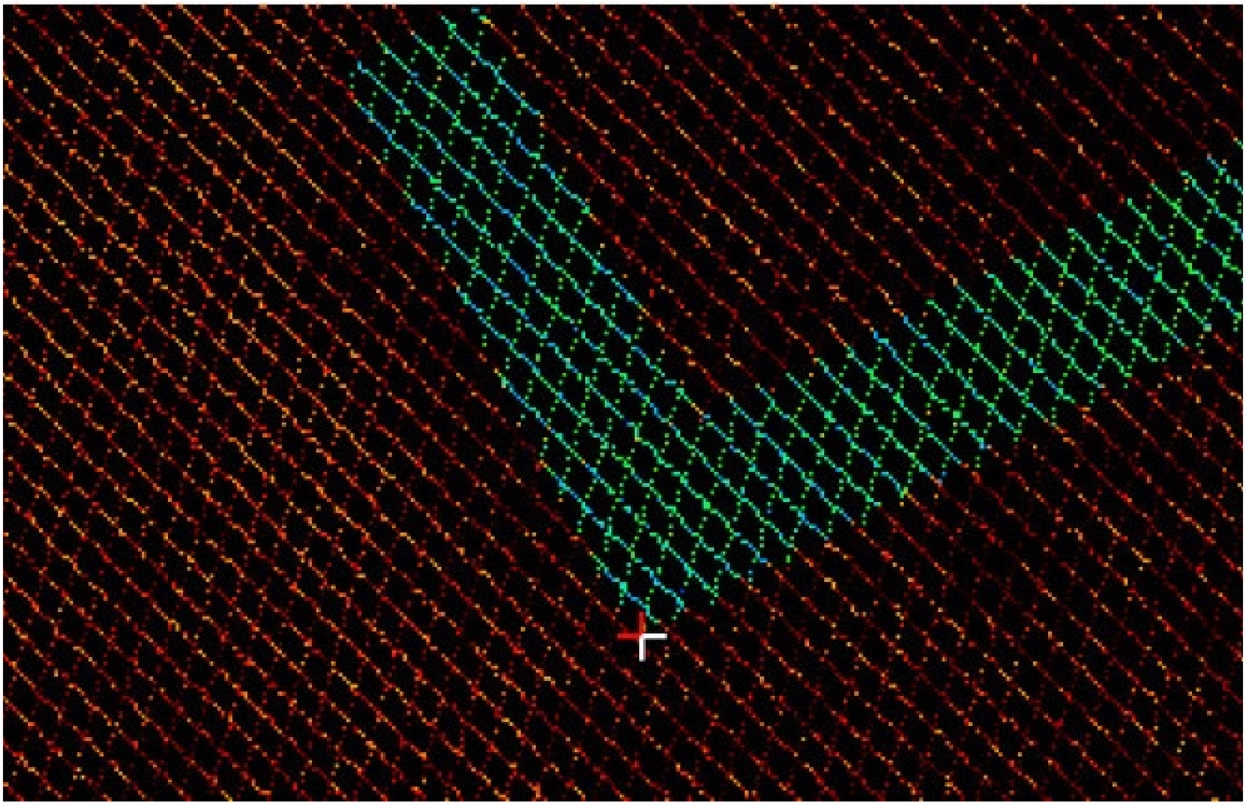

Figure 7: GCP Point Measurement in Trimble Business Center

The results after the LiDAR-improved trajectory are presented in Table 4 below (in cm):

Unit [cm]	Run 1	Run 2	Total
StdDev	1.0	1.3	1.1
MIN	0.8	0.4	**0.4**
MAX	4.1	4.8	**4.8**
2D RMS	**2.8**	**3.1**	**3.0**

Table 4: Absolute horizontal accuracy (cm) based on LiDAR adjusted SBET

Similar to the enhancement observed in the vertical accuracy, we witness a performance gain of over 280%, resulting in a horizontal RMS of **3.0 cm** compared to the original trajectory's **8.4 cm**. The maximum outlier came down from appr. 17 cm to 5 cm. Notably, LiDAR QC has successfully eliminated any horizontal displacements between the point cloud runs in the critical GNSS area. The following example illustrates a building and the impact of LiDAR QC Tools:

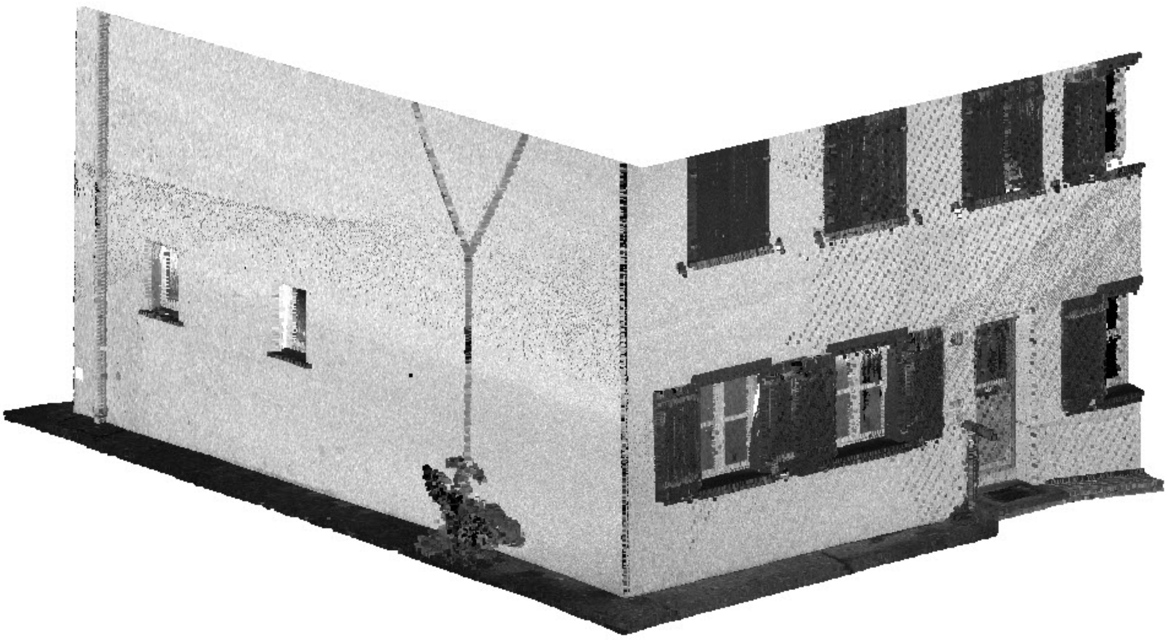

Figure 8: Building Example for horizontal displacement check

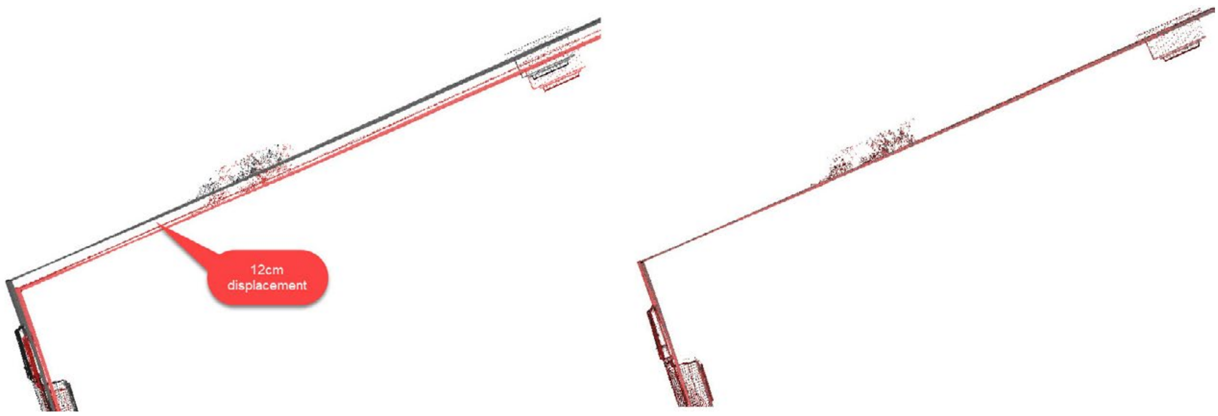

Figure 9: Horizontal Displacement both before and after LiDAR QC

3D Performance

By combining the horizontal and vertical absolute RMS values, we obtain a 3D absolute performance of 3.3 cm after the LiDAR QC trajectory adjustment, in contrast to the original 3D RMS of 9.2 cm. This marks a substantial improvement, comparable to a Mobile Mapping dataset acquired in open sky terrain.

Conclusion

The utilization of LiDAR QC Tools, incorporating Applanix PCDA technology, has the potential to enhance the final mapping product quality by 280% in critical GNSS environments. While the primary objective of this technology is to generate homogeneous point clouds from overlapping scenes, it also demonstrates the capability to elevate absolute performance. Notably, this concept does not necessitate a low-cost 360° LiDAR sensor; instead, it can effectively leverage high-quality mapping LiDAR sensors through the application of the LiDAR SLAM approach. LiDAR QC "fuses" all measurements and compensates for errors such as boresight, GNSS-INS inaccuracies, sensor errors, and data acquisition errors.

> …potential to enhance the final mapping product quality by
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For more information

For more information, contact our Customer Support Team (techsupport@applanix.com) or visit our Customer Support Portal.

Acknowledgement

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