White Paper

LiDAR QC Tools | The Ultimate Point Cloud & Trajectory Adjustment using SLAM

Authors: Joe Hutton, Dr. Manfred Sever, Dr. Mohamed Mostafa, & Nico Jaeger
Trimble Applanix

https://www.applanix.com/products/pospac8/lidar-qc-tools.htm

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Applanix LiDAR QC Tools

Applanix LiDAR QC Tools are a set of POSPac software tools to achieve the highest level of georeferencing accuracy with LiDAR sensors, supporting *boresight* calibration between IMU and LiDAR sensor, *trajectory adjustment* and *LAS file* point cloud generation. The tools are primarily used in the uncrewed airborne (UAV), land mobile mapping and indoor survey industry. The software is hardware-agnostic and can work on any LiDAR system. Ground reference data (e.g. GCP) are not needed. The main goal is to create a consistent and homogenous point cloud and a corrected vehicle trajectory using the LiDAR data.

Applanix Point Cloud Data Adjustment (PCDA™) Technology

The LiDAR QC Tools use the Applanix Point Cloud Data Adjustment (PCDA) technology. The Applanix PCDA technology is an advanced version of LiDAR Simultaneous Location and Mapping (SLAM) based on a robust global *Voxel* iterative least squares adjustment (LSQ). The Voxels are similar to pixels in the image processing world, just that they are 3-dimensional and derived from the LiDAR point cloud. Voxels (3D pixels) are created from the LiDAR data and matched in overlap regions. An iterative least squares adjustment using the matched points is then run to solve for the constant IMU boresight angles and makes corrections to the trajectory (position and orientation [SBET]) used to generate the points. In that context, the LiDAR becomes an aiding sensor to contribute to trajectory optimization which has been generated in POSPac using data collected from Trimble Inertial hardware (such as the Trimble Applanix POS or Trimble AP+ solutions).

Applanix PCDA corrects for errors in the raw point cloud, such as errors in the sensors or errors introduced during data collection, in order to produce accurate point cloud data. While it is essential to create a homogeneous matching point cloud of the entire mission, Applanix PCDA technology can also be used to correct critical trajectory segments. Such segments can occur in urban and GNSS foliage areas. Creating sufficient point cloud overlap in such regions (by repeated visits of the same area) will enforce LiDAR QC to correct the GNSS-INS derived trajectory which in turn will ensure a high precise point cloud being used for topographic mapping, 3D modeling and other geospatial products/analysis.

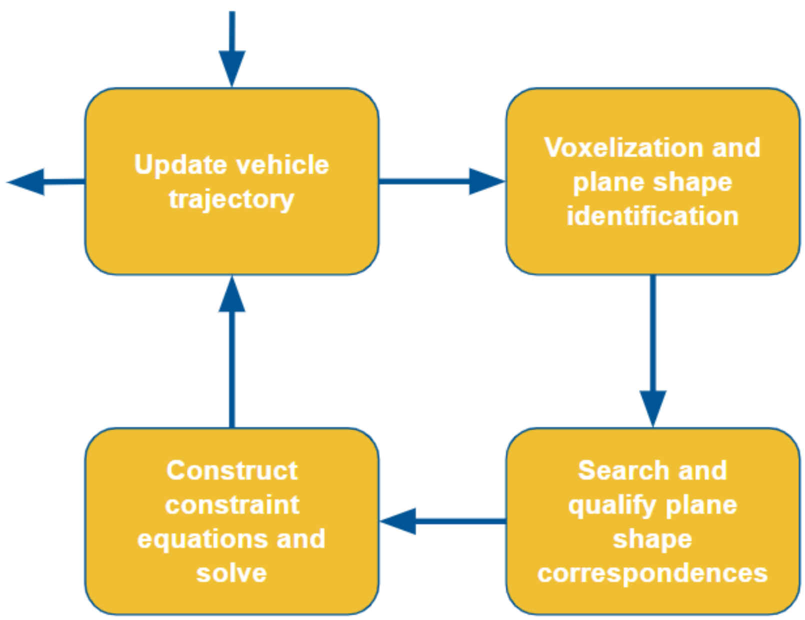

Fig 1: PCDA Process Diagram

Furthermore, the LiDAR corrected trajectory can then be used to georeference other sensors such as cameras colocated with the LiDAR to produce the final products. It is also possible to use a low-cost LiDAR strictly for trajectory correction for other applications where the point cloud from the LiDAR is not required.

The Applanix PCDA technology can also be used in completely GNSS denied environments such as when indoor. Here an approximate trajectory derived using inertial dead reckoning or other methods is used which then becomes fully corrected using the LiDAR.

Requirements

The LiDAR raw data need to be time tagged in the native LiDAR frame with the data from Trimble Hardware. This time tag is either the GPS week seconds or UTC time to microsecond accuracy. The trajectory used for point cloud generation and adjustment process should ideally be post-processed in POSPac prior to using the LiDAR QC Tools. Pre-knowledge about the coarse rotation and the displacement vector (lever arm) between the Inertial Measurement Unit (IMU) and the LiDAR Sensor need to be present. The lever arm shall be surveyed in better than cm level while the rotational difference (boresight) as initial values is ok to be within a level of 5° - 10°. The remaining bias is calibrated as part of the LiDAR QC process.

In terms of LiDAR format support, Trimble Applanix suggests converting the native LiDAR format into a 5-double (L5D) or LQC format. The L5D format carries the time, x, y, z and intensity information. The LQC format supports additional details such as classification and pulse return number feeding LAS file generation with more details. Since the LQC format uses the float format instead of the double format it does increase the efficiency of disk space usage without impacting the LiDAR QC results. LiDAR QC supports other native LiDAR formats such as VLP-32/VLP-16, Trimble TMX format and the Hesai PCAP XT32/XT16.

The process requires a fast and powerful Windows based computer with preferably 256 GB RAM for land mobile mapping data and a minimum of 32 GB for uncrewed airborne data, a fast solid state drive (SSD) with at least 1 TB free storage and Matlab libraries.

Boresight Calibration

One component of the Applanix LiDAR QC Tools is the boresight calibration between the Inertial Measurement Unit (IMU) and the LiDAR Sensor. Physically it is impossible to align the IMU frame with the LiDAR frame and the angular difference is known as misalignment while the calibration process to determine this bias is called boresight calibration. For highest point cloud accuracy it is mandatory to calibrate the boresight angles (3-dimensional). This calibration process can be part of the overall point cloud adjustment ("on-the-job" calibration) or it can be run separately to obtain the highest quality and reliability for the boresight angles. There are suggested boresight calibration patterns for uncrewed airborne and land mobile mapping applications[1].

Mobile Mapping (Land) Boresight Pattern:

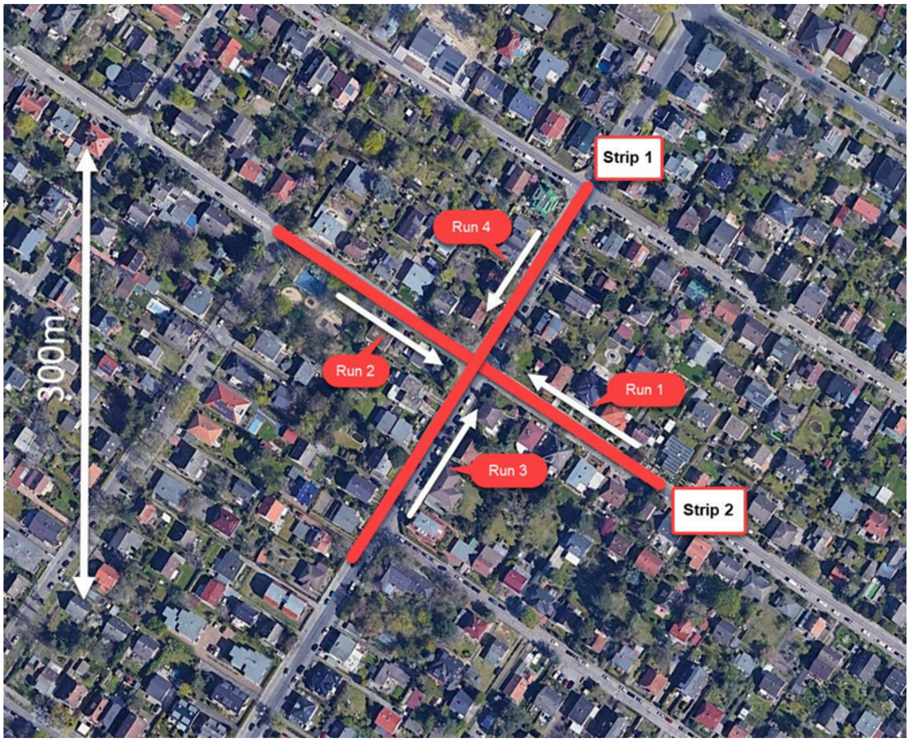

Fig 2: Minimum Boresight Pattern (Land)

[1] Dual LiDAR is supported with POSPac version 9.2.

- 2 x perpendicular strips with opposing runs for each strip (1 strip = 2 runs) resulting in 4 runs in total
- Strip length 250 - 300m
- Scene needs to be "structured" such as in a residential area with detached houses and objects within maximum range of the used LiDAR sensor
- Open sky terrain (good GNSS satellite visibility)

Uncrewed Airborne (UAV) Boresight Pattern:

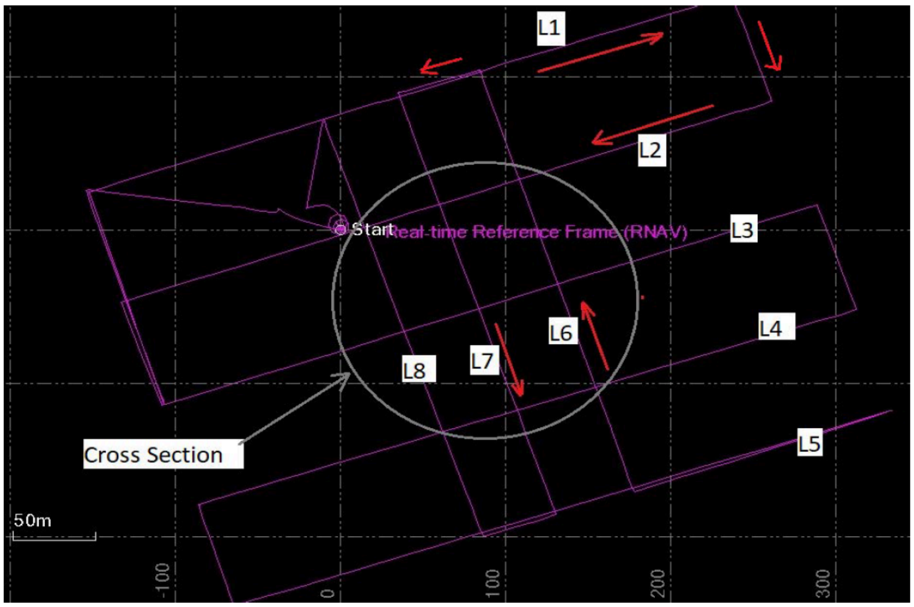

Fig 3: Minimum Boresight Pattern (Air)

- Minimum 4 parallel strips in opposite directions
- Few perpendicular strips
- Terrain with distinctive features located in the cross section
- 50% side lap coverage and no gaps on the ground

Once the boresight calibration is complete, boresight angles can be kept fixed in the point cloud adjustment for subsequent missions as needed. Boresight angles should not change significantly unless the hardware integration does change or wasn't done properly. Please note that input of two LiDAR's is supported with POSPac version 9.2.

Limitations

Achieving the optimal accuracy is subject to the LiDAR Sensor noise and quality of the integration. The captured features in the scene and the enforcement of overlapping points from revisits of the same district are mandatory for the success rate of LiDAR QC.

Advantages

LiDAR QC is a modular component of POSPac ensuring precise georeferencing of LiDAR data. Depending on what the user wants to achieve, it can run the boresight calibration of the LiDAR sensor, improve the GNSS-Inertial trajectory by using the LiDAR data as an aiding sensor source and ensure perfect point cloud matching in the 3D global world. The core benefit lies with "distorted" data in GNSS-critical/denied areas and with mapping systems equipped with an inertial sensor of lower accuracy. Key features include a function that detects "critical/weak" trajectory sections requiring point cloud adjustment while "good" sections are disregarded. This decreases the overall processing time while still creating one single adjusted trajectory (SBET). Eventually, the user can export the adjusted trajectory to create the point cloud in a 3rd party software tool or export the adjusted point cloud in a LAS file straight from POSPac. In addition to the full support in our desktop POSPac product including batch processing, LiDAR QC is also supported in our POSPac Cloud Solution.

Workflow

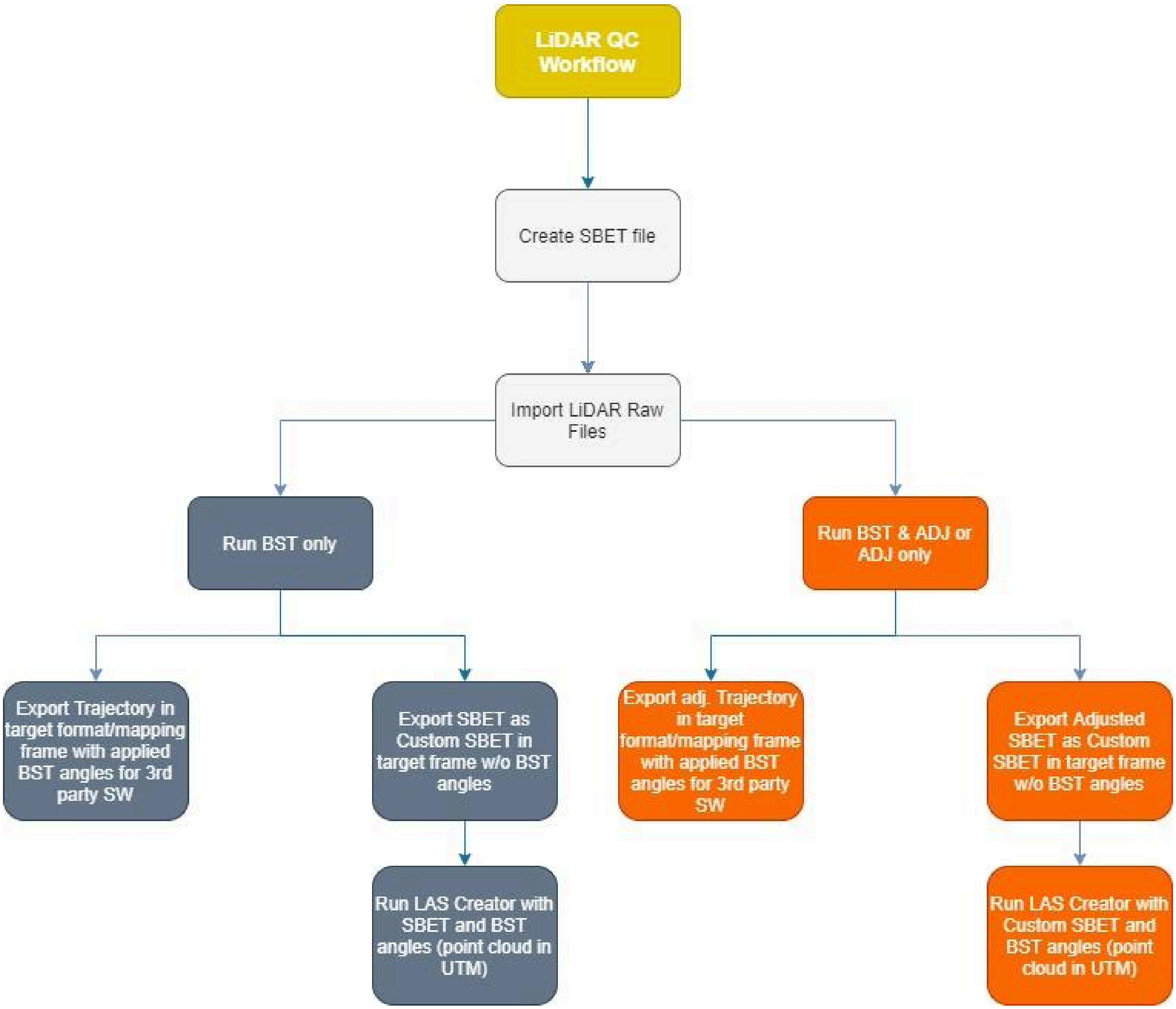

Fig 4: Workflow Options LiDAR QC

Deliveries

The deliveries of the LiDAR QC Tools are:

- Boresight Angles (Tx, Ty, Tz)
- Adjusted/Improved Trajectory (Adjusted SBET)
- Accurate and matching Point Cloud (LAS)
- PCDA statistics for quality check (LOG)

Conclusion

The LiDAR QC Tools with the Applanix PCDA technology "fuses" all measurements to produce matching point clouds from LiDAR sensors integrated with Applanix hardware (POS System). The application spans uncrewed airborne (UAV) missions, land mobile mapping and indoor surveys. The robust and reliable point cloud adjustment process can compensate for errors such as:

- Boresight Angles
- GNSS-Inertial Trajectory Inaccuracies (e.g. drift)
- Sensor Errors
- Data Acquisition Errors

Dual LiDAR support has been added to POSPac v9.2 release. With the improved redundancy provided by a dual LiDAR platform, the corrected trajectory is more reliable. This minimizes the need to revisit scenes and results in a higher quality final point cloud.