TopoDOT™ Tech Notes

Certainty 3D

April 10, 2012

To: General Release

From: Ted Knaak
Certainty 3D, Inc.

Re: Developing Requirements for Mobile LiDAR Data (#1015)

Introduction

Recent discussions within the industry have revolved around requirements for the acquisition of mobile LiDAR system data. While no formal best practices have been published, there exists sufficient experience and expertise within the industry to provide some guidelines.

This document summarizes information necessary to make informed decisions as to the development of project requirements. It should be noted that this document does not intend nor does it claim to be a formal standard or guideline for establishing such requirements. Rather it is simply meant to share the experience and expertise of Certainty 3D and our colleagues with the industry. We welcome comments and critiques.

Topics covered are:

- Project stage
- Suggested best practice guidelines

Project Stage

One might begin by defining Mobile LiDAR Project (MLP) requirements within the context of the overall project stage for which the data is to be applied. The following is thus a brief discussion of project Phases and how each phase may impact a MLP.

Phase I – Long Range Planning

MLP data used for long range planning typically would be characterized by much longer corridors. This data would be applied in support of environmental impact studies, new intersection development, road widening, etc.. The data would be geospatially

7035 Grand National Drive, Suite 100, Orlando, FL 32819
Phone: 407-248-9927 Fax: 407-248-2636

referenced to the level of the IMU trajectory accuracy, which could deviate 30cm or more from survey level coordinates. Note however that point cloud and image data “relative to the trajectory” are much more accurate thereby providing a rich 3D description of the corridor for GIS purposes.

It typically would not make much sense to achieve greater absolute accuracies for long range planning given the added time and expense of establishing ground control and further data post processing. Furthermore the environment along any corridor changes so much that MLP data can often lose sufficient integrity in as little as six to 12 months after it was acquired.

Phase II – Design & Construction Planning

Design and construction planning require the establishment of the survey coordinate system. The signed and sealed set of engineering drawings is the product of Phase II.

Currently MLPs are not typically applied at during Phase II however there are potential applications. Phase II operations would typically impose a higher level of accuracy on the MLP data. In this case it becomes necessary to bring in traditional survey control along the corridor to be used as a reference for MLP data adjustment as well as establishing lineage to a “sealed” survey control.

In order to achieve survey quality consistent with Design and Construction requirements, a higher level of system calibration and data processing performance will be necessary for the MLP. This level of quality will typically call for mutually agreed upon QA/QC processes between data provider and customer.

Phase III – Field Engineering and Construction

These operations require the highest level of precision and accuracy. Such projects necessitate the establishment of a clear lineage from the MLP data back to the “sealed” survey control reference network. This lineage should be defined is such a way that there is a common analysis process agreeable to both the MLP data supplier and customer.

Both Phase II and III accuracy requirements will necessitate the most stringent requirements in the overall processing of the MLP data. Note that this processing does not include feature and 3D model extraction. Rather this stage of processing will include:

System Calibration
Acquisition
Adjustment
Geometric Correction
Map projections
Organization
Post-Acquisition QA/QC

Storage/Archive

The MLP data customer should have mutually acceptable processes in place to QA/QC the incoming data to assure it meets specification. Note that such QA/QC procedures need not rectify any error. Rather they need only identify if an error exists such that the data can be returned to the provider for further processing and associated documentation.

The geodetic quality transition from Phase I through Phase II can thus be thought of as a progression from GIS to high accuracy land survey. Progression through these requirements is accompanied by significant increases in cost. *Therefore it is useful to well define the intended application of the MLP data in order to optimize its' cost/benefit.*

Suggested Best Practice Guidelines

The following are some common sense guidelines for defining MLP requirements developed through the experience of Certainty 3D and some of our colleagues in the industry. One will note that our recommendations are principled in nature and do not lean toward specific equipment and/or workflows. Rather we attempt to lay out the concepts as we understand them so as to encourage an informed dialogue between suppliers and purchasers of MLP data. It will be incumbent upon these parties to define specific processes which fulfill the principles contained herein.

Mobile LiDAR Deliverable Data Components

Typically the most prominent data component of a MLP is the resultant **point cloud**. It is also become increasingly common for high resolution **color images** to be included as well. From these two data components are extracted the features and 3D models typically desired from the MLP data. It should be pointed out however, that there are other readily available data components inherently tied to the structure and integrity of the point cloud and image data.

Vehicle Trajectory and RMSE Trajectory Requirements

Of particular importance are the **trajectory** and **the root mean squared error (RMSE) trajectory**. The trajectory describes the path of the vehicle within the project space. Without going into detail far beyond the scope of this paper, we can describe how the trajectory is developed as follows.

The GPS, measuring position geodetic position/heading, and the inertial measurement unit (IMU), measuring roll/pitch/heading orientation, are acquired and input into a computer model or "estimator". The estimator models the system and "predicts" where it believes it should be based on past sensor measurements. The estimator then corrects its model based on the error between its "prediction" and the sensor readings. This error is actually the source of the RMSE trajectory.

The significance of the RMSE trajectory is that it is a measure of the “convergence” of the estimator model and the sensor readings. A small convergence indicates the acquired sensor readings were consistent with where the estimator predicated it should be. The RMSE trajectory can be correlated with the spatial trajectory and serve as a strong indicator as to the *quality of the trajectory and resultant data integrity*. A typical “high quality” RMSE trajectory might be on the order of 2 cm (1 sigma) with occasional spikes at bridges and areas of GPS loss. (Note: this does not mean the data is all within 2 cm accuracy—only that the model has rather strongly converged.)

The following description is intended to provide a more intuitive understanding. Begin by thinking of the trajectory as a tube and not a thin line. A thin tube of say 2 cm radius indicates that the estimator and sensors reached an agreement along the trajectory as to where the vehicle was. The probability is high that this trajectory and point cloud/image data can be adjusted such that it “fits” to reference survey coordinates relatively well.

Now consider a much larger RSME trajectory implying a much thicker tube. This means that the sensors and the estimator never agreed too much on where they thought the vehicle was. Perhaps the GPS configuration was poor or there was a misalignment between the IMU and/or GPS to the vehicles reference frame. Such a situation would cause the sensor inputs and estimator to consistently “disagree” more and the tube gets thicker. As the radius of the tube increases, it becomes more difficult to fit the trajectory and point cloud/image data tightly to the survey reference coordinates—there’s just too much uncertainty as to the relative position of the vehicle within the tube.

Note that a complete delivery of RSME trajectory information would be relatively complex, require special software for complete analysis and typically exceed the data customer’s ability for direct analysis. However a fully processed and spatially correlated RSME trajectory plot or similar format would be relatively easy to interpret. One can then identify varying quality along a trajectory and accept/reject accordingly. Note this also allows the customer to accept/rejects “portions” of the project instead of applying one standard to the entire data set.

Point Cloud Requirements

Laser scanners mounted to the mobile system platform generate the point cloud. In effect one can think of each point’s measured coordinates as the result of a “vector” with the origin tied to vehicle trajectory pointing to a point on an object’s surface . For current mobile system technology, these vectors do not contribute to trajectory position—they kind of “hang on” to the trajectory.

One can divide up the scanner errors into two categories: 1) systematic and 2) random.

Random error is basically a measure of the uncertainty in each individual range measurement. The result of this error is “noise” or “fuzziness” of the point cloud. This is relatively easy to measure. Examine data in an area covering a “flat” surface (flat for transportation corridors can be a sign, sidewalk section, etc.) Fit a plane and measure the deviation of the points about that surface. This will be the random noise or “fuzziness”. Select a deviation number that assures one can identify features to be extracted from the data. For example, one could extract just about anything along a roadway if the deviation was say +/-3mm. However it would be difficult to extract curb lines, edge of pavement, etc. if the deviation was say +/-6cm or more. Look at sample data, consider was must be extracted and agree on a number that works.

Systematic error is basically “fixed” error(s) in the system. Such errors typically produce offsets in the data and typically must be corrected at the “system” level. . These errors could be caused by scanner misalignment, scanner rangefinder performance, or some combination of both. The easiest way to identify such error is to *exploit the static scene* by requiring at least two passes from different lanes and/or direction over the same area. As systematic errors typically manifest themselves as “shifts” and/or “rotations” of the data, multiple passes to common objects will result in “residual” point cloud misalignments that cannot be removed through translations adjusting individual point clouds to match one another.

Theoretically there will always be some error. But selecting a maximum allowable deviation of say X cm in elevation over the road surface between multiple passes, maximum allowable horizontal deviations between point clouds covering common vertical objects of say Y cm would inherently establish a systematic error requirement.

Density is primarily the spacing between point cloud shots on the surface of interest. As a matter of practicality, little focus is necessary along the density of each scan line. Modern scanners take measurements so quickly that the spacing between successive points along a scan line is relative dense. An agreement on say point density along each scan line across a road could be easily reached as say less than a few cm.

The density issue arises along the direction of vehicle travel. The spacing between the successive lines is a function of the scanner mirror angular velocity, or lines per second, and the vehicle speed. An agreement between data producer and purchaser should be reached that will meet downstream extraction requirements while achieving reasonable levels of productivity via vehicle speed. As a reference, one might expect 20 cm line spacing at highway speeds (60mph) for the latest technology scanners.

Relative Precision refers to the fidelity of the point cloud structure referenced to the trajectory. More simply spoken, the trajectory might be off by 30cm or more. However the accuracy between points measured within the point cloud is of much higher precision. Therefore this accuracy requirement would relate to relative distances within the point cloud, say for example bridge clearance measurement.

Absolute Accuracy would refer to the accuracy of the point cloud data within the project coordinate frame. The typical way to assess this accuracy is to compare the point cloud against individual surveyed points measured from the Primary Survey network within the point cloud. Such points are commonly referred to as the survey control and are often validated and "sealed" by a professional land surveyor (PLS). Note that such points need to be an order of magnitude higher precision than the mobile mapper. Thus typically these points are established with traditional total station/level survey technology.

As elevation error is typically the prime concern in MLP data, assessment of point cloud data is relatively straightforward. Typically the control points in the network are placed on hard surfaces such as roadway, sidewalk, etc. Software applications will typically average the elevation of point cloud elements within a radius of the NE location of the control point and compare elevations. The entire control network compared to the point cloud elevations at those NE locations can then be collected and analyzed statistically.

Referring back to the "systematic" error analysis, horizontal NE errors are inherently identified by examining how vertical features common to multiple scans line up. Multiple scans lining up over common arbitrary stable features serve as a good indicator of horizontal accuracy. One should note that strong RSME trajectory typically results in acceptable NE errors. Thus a typical requirement for NE accuracy might be written such as ". . . X number of random checks between vertical elements contained in multiple scans shall not reveal misalignments greater than Y".

File Management Requirements

Typically mobile LiDAR systems will feature automated cutoff of files sizes based on distance travelled. File sizes should be limited to a distance of reasonable lengths so they are easier to transfer and manage. This is by no means the only requirement for file management. However this can be accomplished by an open discussion between data provider and consumer as to the best strategy for managing the data. So it will not be discussed here.

Survey Control

Any land survey data acquired to support the alignment and/or QA/QC of MLP data should be included as a deliverable.

Images

Calibrated images have become an increasingly important component of the MLP data set. Images increase information content and decrease the time requirement to identify and extract features, 3D models, etc. from the data. "Calibrated" images typically contain metadata on the camera model, image location and orientation within the project coordinate frame—same frame as the delivered point cloud. These images can be mapped very accurate to the point cloud data.

Image metadata requirements can be summarized as

- Camera calibration model (for each camera)
- Image out file format (example- jpeg)
- Image location in project coordinates (same as final point cloud)
- Image orientation in project coordinates

Performance requirements can simply be given as images shall be aligned with point cloud to within X pixels. This is easily checked by using the point cloud to extract CAD elements of vertical and horizontal objects, ie corner of building, paint line edge in road, etc. Then the image is mapped to the point cloud and the misalignment in pixels can be counted between the element and the image.

Requirements Summary

The following summarizes this discussion of suggested technical guidelines for procurement MLP data.

<u>Phase I Type MLP</u>

Mobile LiDAR Deliverable Data Components
Point Cloud
Images (optional)

- Camera model
- Position of each image (final project coordinate system)
- Orientation of each image (final project coordinate system)

Trajectory
RMSE Trajectory
Survey control (if used)

Vehicle Trajectory and RMSE Trajectory Requirements
Trajectory – No Test
RMSE trajectory (spatially correlated) – Test: Assure within specified tolerance with some spiking expected.

Point Cloud Requirements
Random Error – Test: standard deviation along flat plane to desired level
Systematic Error – Test: Multiple pass alignment checks within some tolerance
Density – Test: Measure samples of data density along and across direction of travel
Accuracy
  Relative – Test: Measure & verify sample distances within point cloud
  Absolute – Test: not applicable if no ground control network used.

Image Requirements
Image Alignment – Test: Extract lines in point cloud and compare to corresponding image. Count pixel misalignment.

Phase II & III Type MLP

Mobile LiDAR Deliverable Data Components
Point Cloud
Images (optional)
- Camera model
- Position of each image (final project coordinate system)
- Orientation of each image (final project coordinate system)

Trajectory
RMSE Trajectory
Survey control

Vehicle Trajectory and RMSE Trajectory Requirements
Trajectory – No Test
RMSE trajectory (spatially correlated) – Test: Assure within specified tolerance with some spiking expected.

Point Cloud Requirements
- Random Error – Test: point cloud standard deviation along flat plane(s) to desired level
- Systematic Error – Test: Multiple pass alignment checks within some tolerance
- Density – Test: Measure samples of data density along and across direction of travel
- Accuracy
    - Relative – Test: Measure & verify sample distances within point cloud
    - Absolute – Test: Measure elevation difference between survey control coordinates and point cloud at corresponding NE (horizontal) location.
        - Major horizontal shifts will typically be obvious. “Systematic Error” test results above will typically assure absolute accuracy also.

Image Requirements
- Image Alignment – Test: Extract lines in point cloud and compare to corresponding image. Count pixel misalignment.

Mixed-Use Phase I, II & III MLP

Several proposed MLPs have intended to acquire very long corridors quickly as a database and use this data for Phase I, II or III projects as needed. For the higher accuracy required by Phase II & III projects the approach is to select the data along the corridor section of interest when needed, acquire traditional survey control along that section and adjust the data accordingly.

We should note here that the contributors to this paper remain skeptical of this approach due to decreasing integrity with time, errors in the original data collect that might not have been identified, etc. However we offer the following recommendations to "maximize" the probability of success for such an approach.

To increase the probability of success, one must assure that the data procured is of such quality that it "could" be adjusted to control and yield results sufficiently accurate for Phase II & III type projects. Our "opinion" is that this would call for a "mixed" approach to defining the MLP requirements and quality assurance tests. Specifically one might consider the following:

- Divide very large projects into sections. Define sections such that the Mobile LiDAR system configuration will stay stable during the acquisition (no mount, dismount, no need for recalibration, etc.)
- Apply the more stringent Phase II & III MLP requirements along short corridor intervals approximately at the beginning, midpoint and end of each project section.
- Adjust the blind intervals down to the control survey points applying tests accordingly.

We expect this approach will increase the "probability" that the remaining data outside the smaller test intervals for each section can be adjusted down to project control at some later date.

Conclusion

This document should be considered a white paper reflecting Certainty 3D's understanding of the Mobile LiDAR system technology and processing methods at this time. The information is only intended to communicate our understanding to customers and industry colleagues. We strongly urge use of this information as a basis for a constructive dialogue between data producers and consumers. In the end, it will be up to these parties to agree on, document and execute the deliverable requirements, testing and evaluation methods appropriate to their project.

We would like to conclude with a special thanks to Mr. Chris Siebern, Director of the HNTB LiDAR Lab at Purdue Research Park and Mr. Josh France, Applications Systems Engineer Riegl USA, for their comments and recommendations.

Questions and/or Comments
Please contact:
Author: Ted Knaak, President
Certainty 3D, LLC
7039 Grand National Drive, Suite 100
Orlando, FL 32819
Tel: 407 248 0160
Email: ted.knaak@certainty3d.com
www.certainty3d.com