Towards automatic boresight angles adjustment of road based Mobile LiDAR System

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Introduction

• Research specifications:
  • Concentrate on boresight angles adjustment
  • Use planar targets
  • Automate the boresight angles estimation procedure

• General Objective:
  • Introduce an automatic, repeatable and easily accessible approach for estimation of terrestrial Mobile LiDAR System boresight angles
Introduction

• Mobile LiDAR Systems (MLS)
  • LiDAR scanner
  • Position and Orientation System (POS)
    • INS (Inertial Navigation System)
    • GNSS receiver

• Various Platform
  • Airplane
  • Vehicle
  • Boat

• Application
  • 3D city modelling
  • Coastal mapping
  • Forest inventory surveying
  • Infrastructure mapping
Terrestrial mobile LiDAR system

- **Z+F PROFILER 9012**
  - Phase-based scanner
  - 119 (m) range
  - 360 degree field of view
  - Max scan rate (data acquisition rate) is 1.016 million point/sec
  - Scanning speed up to 200 profiles/sec
  - Accuracy: 0.2 (mm) to 3.1 (mm)
  - GPS input (PPS pulse + UTC message)

- **ATLANS-C**
  - High performance
  - All-in-one position and orientation solution
  - Integrated smart coupling between:
    - iXblue fiber-optic gyroscope (FOG) Inertial Navigation System
    - Integrated real-time kinematic (RTK) data from Septentrio GNSS receiver
  - Robust continuous positioning in urban environments
  - Linear speed, angular speed
  - SD of the attitude angles and positioning
  - ATLANS POST-PROCESSING SOFTWARE
Direct georeferencing

- Mathematical model
  \[
  \begin{bmatrix}
  X_{LGF} \\
  Y_{LGF} \\
  Z_{LGF}
  \end{bmatrix} = \begin{bmatrix}
  P_{LGF} + R_{INS}^{LGF}(\varphi, \theta, \psi) (R_{LI}^{INS}(\delta\varphi, \delta\theta, \delta\psi)) \\
  \rho \sin(\alpha) \\
  \rho \cos(\alpha) \cos(\gamma) \\
  \rho \cos(\alpha) \sin(\gamma)
  \end{bmatrix} + a_{INS}
  \]

- Boresight angles \((\delta\varphi, \delta\theta, \delta\psi)\)
  - 3x3 transformation matrix
  - Mis-alignment between INS frame and LiDAR frame
  - Cause angular bias on the LiDAR ranging return
Direct georeferencing

\[
\begin{bmatrix}
\rho \sin(\alpha) \\
\rho \cos(\alpha) \cos(\gamma) \\
\rho \cos(\alpha) \sin(\gamma)
\end{bmatrix} \rightarrow \rho \text{ (range)}, \alpha \text{ (oscillation angle)}, \gamma \text{ (scan angle)}
\]

- \( R_{INS}^{LGF} (\varphi, \theta, \psi) = M_Z(\psi)M_Y(\theta)M_X(\varphi) \)

- \( P_{LGF} = R_{ECEF}^{LGF} (\lambda_{Ref}, \varphi_{Ref}) [P_{ECEF} (\lambda, \varphi) - P_{ECEF} (\lambda_{Ref}, \varphi_{Ref})] \)
Line Pattern design

• Ten survey lines
• One planar target
• Boresight angles observability issue
Line Pattern design

• Ten survey lines
• Six planar target
• Best line pattern design
  • Metrology Lab (Université Laval)
Extraction of planar surface

• Objective of the research: **Automatic procedure**
• Combined method (RANSAC - Region Growing)
  • RANSAC (RANdom SAmple Consensus):
    • First detection of the planar surface
  • Region growing
    • Complete the area that is not detected by RANSAC
Reducing the data

• Redundancy – Too much unnecessary points

• Algorithm:
  • Calculate the normal to the planar surface
  • Calculate the centroid of the planar surface
  • Eliminate points with respect to the orthogonal distance
Boresight angles estimation

- Iterative weighted least squares
- Provide boresight angles estimation and their standard deviation, simultaneously
- Principle of the method
  - All the points on the surface elements satisfy the same plane equation,
    \[ AX_{LGF} + BY_{LGF} + CZ_{LGF} + D = 0 \]
  - Thus, because of boresight the above equation is not zero for the points on a planar target
  - Left-side of the function is a non-linear function equivalent of georeferencing equation
    \[ AX_{LGF} + BY_{LGF} + CZ_{LGF} + D = f_p(\delta \varphi, \delta \theta, \delta \psi, A, B, C, D) \]
- **Unknown:** 3 boresight angles and 4 planar targets parameters
- **Observations:** positioning, INS, LiDAR and Lever arms
- The problem of boresight calibration is to find the boresight angles and the planar targets parameters such that,
  \[ \forall p \in P, \quad f_p(\delta \varphi, \delta \theta, \delta \psi, A, B, C, D) = 0 \]
Validation of the resulted point cloud

• Comparison with static LiDAR system like FARO
  • FAROX130
  • SX10 Trimble

• Comparison of adjusted MLS point cloud with control point (GCP)
Surveying procedure – MLS-CIDCO

- ZFS File
  - ZFS Convertor
  - Lever-arms measurements
  - Reference point cloud
- SBET File
  - SBET Decoder
  - Georeferencing Module
  - Validation & Quality analysis
- APPS
  - Base station

- Iterative least squares
- Boresight angles
- Best planar target detection
- TPU/CSMU
- Reference point cloud
- Validation & Quality analysis
- Boresight angles estimator
Project sample

• Hydro-Québec
  • Scan the infrastructure routinely
  • 33600 square meters
  • 2 hours
  • 2.1 km trajectory
Adaptation to the naval MLS

- Georeferencing
- Estimation of boresight
- Quality analysis and validation
Conclusion

• Boresight angles estimation of the mobile lidar system
• Planar target (one or more)
• Automatic, repeatable and easily accessible approach
• Adaptation for boat-base mobile LiDAR system
Thank you
Definition of terms

• Calibration
  • An operation under specified and controlled test conditions
  • Compare the values or measurements indicated by certain instrument or system (Instrument Under Test) against those indicated by a standard (Calibrator)
  • Usually in lab

• Adjustment of a Measuring System
  • Process of altering a measuring instrument’s performance, so that the values indicated by it are accurate within specified limits.
  • Calibration may be carried out first, to determine the type and magnitude of adjustment required.
  • Note that adjustment of a measuring system should not be confused with calibration, which is a prerequisite for adjustment.
Annexe

• International Vocabulary of Metrology-Basic and General Concepts and Associated Terms (VIM) 3rd edition

• Calibration is an operation that, under specified and controlled test conditions:
  • Comparison of the values or measurements indicated by certain instrument or system (Instrument Under Test, or IUT) against those indicated by a standard (Calibrator)
  • **First Step:** Establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties.
  • **Second Step:** Uses this information to establish a relation for obtaining a measurement result from an indication.
  • Note that calibration should not be confused with adjustment of a measuring system, often mistakenly called "self-calibration", nor with verification of calibration.

• Adjustment of a Measuring System
  • The process of altering a measuring instrument’s performance, so that the values indicated by it are accurate within specified limits. Calibration may be carried out first, to determine the type and magnitude of adjustment required.
  • Set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured.
  • Note that adjustment of a measuring system should not be confused with calibration, which is a prerequisite for adjustment.
Introduction

• Skaloud and Litchi (2006)
  • Overlapping survey strips
    • Observing inconsistencies in point clouds from Error criterion
    • Optimized to adjust overlapping points on a given parametric surface
  • Determine boresight angles and surface (planes) parameters
    • Simultaneously
    • Least squares adjustment

• Hebel et al. (2012)
• Leslar et al. (2016)
• Heinz et al. (2017)