If the Map Fits

Team Members:

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Esther Cho

Edmond Leahy

Academic Supervisor: Dr. Mozhdeh Shahbazi

Sponsor Supervisor: Greg Roesler, P.Eng., NovAtel Inc.

Abstract

In mobile mapping systems, the usage of at least three different sensors are required for the system; global navigation satellite system (GNSS) receivers, inertial measurement units (IMU's), and an imaging sensor such as a lidar sensor. The measurements being collected from the three different systems must be calibrated to the in the same reference frame. We are developing an application that can compute boresight calibration parameters between the GNSS+INS system (using a NovAtel SPAN system) and the lidar unit. With boresight calibration parameters computed, we can calibrate the lidar measurements to reference the IMU center. Our application simply needs raw datasets from each sensor as input and will output a three-dimensional dataset. Our algorithm does the rest of the work so that the user has a functional dataset immediately after data acquisition.

1 Project Overview

1.1 Project Description

Mobile mapping system (MMS) is a three-dimensional (3D) geospatial data-collection system that acquires geo-referenced data using various imaging and ranging sensors from a mobile platform (e.g. terrestrial vehicle). The navigation components of an MMS typically include an inertial measurement unit (IMU) and global navigation satellite system (GNSS) receivers. Several types of imaging and ranging sensors might be integrated into an MMS; one of the most popular sensors is a 3D laser scanner, a.k.a lidar. A laser scanner performs range and angle measurements to the surface via a range-finding technique (e.g., time-of-flight). This data is collected in the local coordinate system of the lidar (i.e. lidar sensor body-frame). Therefore, the navigation components (GNSS/IMU) are required to directly geo-reference the collected range data by the laser scanner into a global coordinate system.

The main problem in direct georeferencing is to determine the relative orientation of the lidar sensor with respect to the navigation sensors. The parameters of the relative orientation include i) the bore-sight matrix, which represents the rotational differences between two coordinate systems; and ii) the lever-arm offset, which denotes the translational offset between the origins of two coordinate systems. To determine these parameters accurately, we must perform boresight calibration.

1.2 Proponent Profile

Our goal at "If the Map Fits" project is to perform boresight calibration and determine the relative orientation parameters between the local mapping frame of lidar, measurement frame of the inertial measurement unit and positioning frame of GNSS. Composed of aspiring Geomatics Engineers, the If-the-Map-Fits team is skilled in the acquisition, analysis, and interpretation of spatial data. With our common background as NovAtel interns, we have combined knowledge in data acquisition and validation with various GNSS receivers. Along with our extended knowledge about receivers, we also have experience in sensor fusion. As such, we can set up and integrate multiple types of sensors for data collection, and we have adequate knowledge of interpreting and manipulating spatial data collected from multiple sources.

1.3 Project Sponsor Profile

NovAtel is a leading provider of GPS and GNSS positioning technology including the design and manufacturing of GNSS antennas, receivers and GNSS/INS (inertial navigation systems) solutions. With NovAtel's GNSS + INS SPAN system and Inertial Explorer post-processing software, we can collect and post-process the MMS navigation data. NovAtel's team of engineers have a breadth of knowledge in navigation fundamentals and sensor logistics to guide our team in this project.

1.4 Client/User Profile

The end goal of our project is to develop an application to determine trustworthy boresight calibration parameters in post-processing. Any user who wishes to use sensor fusion to collect mapping data can use our application to seamlessly and automatically transform all collected location data into one coordinate system for their mapping purposes.

2 Project Performance Framework

2.1 Objectives, outputs, outcomes and criteria

The goal of our design project is to perform a boresight calibration to translate and rotate the coordinates systems of GNSS, LiDAR and INS systems to enable them to be used together in solving for accurate position. This will be done in the manner outlined in Table 1:

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Objectives	**Method**
Data collection	Using a NovAtel test vehicle, data will be collected in multiple environments (Open-sky, high-multipath, slow speed, etc.)
Calibration and finding boresight parameters	Compute boresight calibration parameters by differencing the positions between the lidar and GNSS+INS systems. Boresight calibration parameters are then used to translate and rotate the coordinate system of each sensor to one unified reference frame.
Vary conditions and environment to test stability of parameters	Stability of these parameters and the accuracy in the result can be tested by using the collected data in the different environments

2.2 Project Performance Measurement Plan

2.2.1 Data Collection

Using the Test Vehicle supplied by NovAtel, we will collect simultaneous GNSS, INS, and LiDAR data to compute lever arms between MMS components. Known lever arms will be provided with data as a method to verify our algorithm. This data collection can be done in multiple different environments (Open-sky, high-multipath, slow speed, etc.) for testing of calibration parameters later. All three of the members of this group are already familiar with the setup, utilization and driving of this test vehicle from previous experience.

2.2.2 Calibration and Finding Boresight Parameters

Once data has been collected, boresight calibrations are computed to determine translations and rotations required to transform the coordinate system of each MMS component to one reference frame. This will enable us to find the relationship between the parameters used in the boresight calibration and the environmental factors involved.

2.2.3 Vary conditions and Environment to test stability of parameters

Once the boresight calibration parameters are well known and established, the stability of these parameters and the accuracy in the result will be tested by using the collected data in the different environments. The accuracy will give an indication of the stability of these parameters.

3 Project Issues and Risks

3.1 Issue Identification

There are potential issues that arise from our sponsorship from NovAtel. Although we have not signed any specific contracts or documents, it is assumed that we must adhere to NovAtel's policies for intellectual property and safety during data collection. If we violate any of NovAtel's policies, the sponsorship may end, and we would not have access to the software and equipment provided by NovAtel.

The fact that there is limited time to complete the project also poses a risk. Data collection may take longer than expected, or poor quality of results may require repeated data collection and computation. The time taken for each part of the project must be considered during project planning. If a task takes more time than the allotted time in the project plan, all team members must be notified, and adjustments must be made to the project timeline.

Another potential issue is being unable to contact a team member, supervisor, or course instructor. Communication between all members involved is essential for the success of this project.

3.2 Feasibility and Risk

Table 1: Analysis of Risks Based on Severity, Probability, and Mitigation

No.	Risk Description	Severity (H/M/L)	Probability (H/M/L)	Mitigation strategies for dealing with each risk
1	Equipment failure during data collection (INS, LiDAR, and GNSS receivers and associated accessories such as power, antennae, cords, etc).	M	L	Issues may have been caused by the object that failed or another object used during data collection since all components are linked during data collection. Investigate the computer, equipment, and scripts used to identify issues. Dry run scripts again and rewrite code that caused issues. Repeat data collection once adjustments have been made.
2	Computer connected to receivers malfunctioning during data collection	M	L	
3	Mechanical failure of NovAtel vehicle used for collecting data (may or may not be caused by team members).	M	L	Notify NovAtel of the accident immediately and follow NovAtel procedures for vehicle accidents. Request NovAtel for access to another vehicle for data collection. Repeat data collection once new vehicle is available.
4	NovAtel equipment not available at time of data collection.	M	L	Obtain all equipment before data collection. Request equipment from NovAtel at least 1 week in advance to ensure all equipment is available.

5	Multipath and other interference resulting in poor data.	M	M	Repeat data collection in settings without interference.
6	Extreme weather preventing data collection.	L	L	Reschedule data collection to avoid extreme weather.
7	Losing data, code, and other work due to computer failure or accident.	H	L	Upload to GitHub after each work session. Store copies of collected data in multiple places.
8	Lack of time management	M	L	Plan detailed schedules and deadlines for collecting data, writing code, compiling results into reports, and creating presentations. As soon as there are deviations from the plan, create a new plan to take deviations into account.
9	Physical harm of team members or NovAtel employees during data collection.	H	L	Using proper protocols and safety measures while using equipment and the NovAtel vehicle will prevent anyone from physical harm. Seek medical care immediately if needed, using NovAtel procedures if the NovAtel vehicle was involved.
10	Change of scope	M	L	Evaluate scope frequently, implementing a scope analysis and approval process. Discuss with all supervisors to confirm scope change. Create new project plan and timeline if new scope defined.
11	Team members or supervisors are unavailable or must go on extended leave.	M	L	Work on tasks together and share the status of each task regularly so team members can accept another team member's tasks if needed. Ask if supervisors have suggestions for other potential supervisors to take their place, or seek out other experts to supervise the team.

All the components of this project have been performed previously in research and industry. Dr. Shahbazi has experience with carrying out boresight calibration with LiDAR. GNSS, INS, and LiDAR systems are also in use at NovAtel.

4 Project Plan

4.1 Project Team and Resources

Name	Kiera Fulton
Organization	Student team
Role	Project Management, Algorithms and Verification
Responsibilities	Keeping the team on schedule with the WBS, handle communications with project sponsor, developing code, verification, post-processing
Key Skills	Communication, task/quality management, organization, programming, technical writing, attention to detail, technical analysis, experience with GNSS+INS verification and post-processing

Name	Edmond Leahy
Organization	Student team
Role	Project Management, Algorithms and Verification
Responsibilities	Come up with algorithm for computing boresight calibration parameters, developing code, verification
Key Skills	Communication, task/quality management, organization, programming, technical writing, attention to detail, technical analysis, experience with GNSS verification

Name	Esther Cho
Organization	Student team
Role	Project Management, Algorithms and Verification
Responsibilities	Developing code, verifying code with test data, identifying issues with code and processing, editing of technical reports and status updates
Key Skills	Communication, task/quality management, organization, programming, technical writing, attention to detail, technical analysis, experience with GNSS verification

Name	Dr. Mozhdeh Shahbazi
Organization	University of Calgary - Department of Geomatics Engineering
Role	Academic supervisor
Responsibilities	Provide theoretical knowledge in boresight calibration and practical knowledge in using and calibrating a LiDAR sensor.
Key Skills	Expertise in photogrammetry and LiDAR

Name	Greg Roesler
Organization	NovAtel Inc.
Role	Sponsorship supervisor
Responsibilities	Provide resources for data collection and post-processing, provide theoretical and practical knowledge of GNSS and inertial data collection and interpretation of data.
Key Skills	Project management skills, technical knowledge of GNSS/INS/LiDAR systems

Name	Dr. Steve Liang
Organization	University of Calgary - Department of Geomatics Engineering
Role	ENGO 500 Supervisor
Responsibilities	Teaching the project team skills on project management and providing milestones for the project (i.e. proposal, check-in, deadline)
Key Skills	Experience in creating his own start-up company, driven, zoo enthusiast, time management

4.2 Project Management and Control

Closely following the communication plan and schedule outlined in the Project Implementation Plan (see Table 2). Team members will hold each other accountable and have effective communication with supervisors for them to hold the student team accountable as well. Internally, the student team will uphold a team contract to ensure that all members are contributing to the project in a time-effective manner and to the Capstone supervisor's satisfaction.

4.3 Project Implementation Plan

Table 2: Work Breakdown Structure

WBS	Task & work breakdown	Days effort	Outputs	Start Date	Delivery Date
1	**Planning Phase**	**20**	**Project Proposal**	**2018-10-02**	**2018-10-26**
1.1	Kick-off meeting	1	GitHub tasks (issues) to divvy up proposal	2018-10-05	2018-10-05
1.2	Write up the proposal	11		2018-10-05	2018-10-17
1.3	Put together proposal	2	First draft of proposal	2018-10-17	2018-10-18
1.4	Review by supervisors and make applicable changes	6	Final draft of proposal	2018-10-18	2018-10-26
2	**Initial data collection**	**28**		**2018-10-23**	**2018-11-19**
2.1	Gather resources and schedule time for data collection	6	Equipment for data collection	2018-10-23	2018-10-29
2.2	Collect data	16	Raw data	2018-10-29	2018-11-14
2.3	Process data in Inertial Explorer and export useful data	6	Processed dataset for computing	2018-11-14	2018-11-20
3	**Develop algorithm/code to compute parameters and location**	**50**	**-**	**2018-10-23**	**2018-12-18**
3.1	Develop algorithm on paper		Pseudo-code	2018-10-23	2018-11-08
3.2	Read in processed data		Accessible data	2018-11-21	2018-11-22
3.3	Obtain location data				
3.3.1	*Compute/obtain coordinate from GNSS data*		*GNSS location data*	*2018-11-23*	*2018-11-26*
3.3.2	*Compute/obtain coordinate from inertial data*		*Inertial location data*	*2018-11-23*	*2018-11-26*
3.3.3	*Compute/obtain coordinate from LiDAR data*		*LiDAR location data*	*2018-11-23*	*2018-11-26*
3.4	Computation of parameters		Boresight calibration parameters	2018-11-27	2018-12-07
3.5	Transform coordinates to one frame		Final set of coordinates for each epoch (trajectory)	2018-12-10	2018-12-18
4	**Subsidiary data collections**	**31**	**-**	**2019-01-07**	**2019-02-06**
4.1	Gather resources and schedule time for data collection	5	Equipment for data collection	2019-01-07	2019-01-11

4.2	Collect data	10	Raw data	2019-01-14	2019-01-30
4.3	Process data in Inertial Explorer and export useful data	6	Processed dataset for computing	2019-01-30	2019-02-06
5	**Test code on new datasets**	**7**	**-**	**2019-02-06**	**2019-02-13**
5.1	Run code on new datasets	7	-	2019-02-06	2019-02-13
5.2	Output statistics for each run	7	Statistics for analysis	2019-02-06	2019-02-13
6	**Compute analytics on stability of solution**	**11**	**-**	**2019-02-14**	**2019-02-22**
6.1	Use statistics to compute solution stability		Solution stability	2019-02-11	2019-02-15
6.2	Plot and interpret results		Plots for presentation	2019-02-18	2019-02-22
7	**Create presentation material**	**7**	**-**	**2019-02-25**	**2018-03-06**
7.1	Gather results	2	-	2019-02-25	2019-02-27
7.2	Create presentation trifold	5	Trifold for Capstone Fair	2019-02-28	2019-03-06
7.3	Create presentation slides	5	PowerPoint presentation	2019-02-28	2019-03-06
7.4	Prepare oral presentation	5	-	2019-02-28	2019-03-06

4.4 Budget Summary

Table 3: Summary of Project Expenses and Budget

Expense	Amount	Comment
Van Rental	N/A	Provided by NovAtel
GNSS Receiver Rental	N/A	Provided by NovAtel
IMU Rental	N/A	Provided by NovAtel
Inertial Explorer License	N/A	Inertial Explorer processing for GNSS + INS provided by NovAtel
Lidar post-processing software	N/A	LiDAR point cloud viewing, and CAD modelling provided through U of C

4.5 Communications Plan and Accessibility of Project Results

The main method of communication with our course instructor Steve Liang is scheduled classes, email, and Slack messaging. We can contact our academic supervisor Dr. Shahbazi and our NovAtel supervisor Greg through email. We have been in meetings with our supervisors and can contact them for more meetings if necessary. We will send our course instructor and supervisors samples of our work periodically and ask for feedback. After completing our project, we will present our results to our instructor, both supervisors, and attendees of the Capstone Fair by providing them with our report, equipment demonstrations, and video presentation.