If the Map Fits

*Team Members*:

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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:

Table : Objectives of Project

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Item | Project Objectives | Project Outputs | Project Outcomes | Measurement Criteria |
| Data collection | Collect useful data that includes simultaneous GNSS, INS, and LiDAR measurements in a stable system | Observation files for GNSS, INS, and LiDAR | Learning how each sensor integrates and the types of data that are output | Three types of observation files (one for each MMS component) will be collected for each environment scenario |
| Calibration | Create an algorithm that takes the three observation files and solves for the boresight calibration parameters. | Boresight parameters (relative orientation of the MMS components), and lever arms | Learning how to create and use an algorithm that solves for boresight calibration parameters | A completed algorithm that, using observation files as input, will return the boresight parameters and relative lever arms. |
| Robustness Testing | Test the stability of the boresight algorithm by trying the calibration in challenging environments | Stable boresight parameters | Learning how different environmental factors influence the results of the boresight calibration | The algorithm will handle different environmental conditions and output stable results, given valid data. |

## 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.

Note that relevant data may be provided by NovAtel from past data collection.

|  |  |
| --- | --- |
| **Data Collection** | **Method** |
| Method of measurement | NovAtel test van, GNSS, INS, and LiDAR observations |
| Responsibility | All group members |
| Frequency of Measure | 2 or 3 datasets |
| Key Targets | Open sky, High multipath/downtown, foliage data |
| Reporting on results | Progress update report |

### 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.

|  |  |
| --- | --- |
| **Data Collection** | **Method** |
| Method of measurement | Statistical testing of Boresight calibration parameters |
| Responsibility | Edmond |
| Frequency of Measure | As many iterations on the algorithm as is necessary to produce stable results. |
| Key Targets | Stable parameter solved by algorithm |
| Reporting on results | Progress update report |

### 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.

|  |  |
| --- | --- |
| **Data Collection** | **Method** |
| Method of measurement | Statistical testing of Boresight calibration parameters, using different environmental data and conditions. |
| Responsibility | Edmond |
| Frequency of Measure | As many iterations on the algorithm as is necessary to produce results. |
| Key Targets | Stable parameter solved by algorithm for multiple environments. |
| Reporting on results | Progress update report |

## 2.3 Sustainability

The results of this project are intended to be used by NovAtel for their research and application of GNSS, INS and LiDAR fusion. This research and application is done by the SPAN and Waypoint teams at NovAtel, of which our sponsor advisor Greg Roesler is a member. The updating and sustaining of the algorithms created during this project will be done by NovAtel. Each member of the team will be available to consult on the updating and/or changing of the algorithms if NovAtel decides this is necessary.

# 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 2: 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.

# 5 Benefits

## 5.1 Benefits to Canadians

Our results from working with GNSS, INS, and LiDAR in one system will show how data from the three types of sensors can be combined. Once Canadians have access to these results, mapping with these three sensors together may become more common and as a result, maps with better accuracy may become available to Canadians. Also, maps that were previously less common such as indoor maps of buildings may become easier to create and distribute since using multiple types of sensors allows data collection to be performed in a wider variety of environments.

## 5.2 Benefits to Sponsors and Users

NovAtel has previously performed data collection and calibration with GNSS, INS, and LiDAR systems. Our results will confirm the results of Novatel testing and prove that Novatel products can be used as a part of a GNSS, INS, and LiDAR system.

If users choose to use the same equipment and system, they will be able to create accurate maps with the GNSS, INS, and LiDAR system and the boresight calibration parameters we computed for the system. If they choose to use a different system but still use a GNSS, INS, and LiDAR system, they can refer to our procedures to determine how to repeat the data collection and calibration for their system.