Mobile Laser Scanning Technology for Surveying Application: From Data Collection to End-Products

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SUMMARY

Over the past few years, Optech Incorporated, the world leader in the development, manufacture and support of advanced laser-based survey equipment, has been focused on the development of new lidar instruments, which would meet growing demands of the community of surveying professionals for efficient data collection systems with superior performance. This paper presents the advantages of new mobile lidar technology for surveying service providers as well as for academic research and outlines the newly established workflow including project planning, data collection and production of the lidar-derived end-products. The unique capabilities of the mobile lidar systems and the value-adding features including hardware, software and peripheral features will be highlighted, and their potential use to maximize efficiency of data collection and achieving superior characteristics of the end products will be discussed.

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1. SUMMARY

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2. INTRODUCTION

There are verities of methods, tools and techniques that can be used to collect spatial data for topographic mapping and other surveying applications. These methods include conventional ground surveys, photogrammetry and different types of remote sensing techniques including laser scanning. This technology, which is based on laser range-finding measurements of the distance between the sensor and the targeted object, can provide spatial data of exceptional accuracy. In order to generate geo-referenced spatial data, the laser rangefinder measurements have to be combined with geo-positioning technology based on GPS measurements, and the integrated instrument, which capable of taking both type of measurements is often referred as a lidar system.

Mobile lidar is a term widely used for a laser scanner deployed on any mobile platform such as a van, a boat, or even a 4 × 4 all-terrain vehicle, and often does not imply an airborne lidar. However, the general principles of operation are the same for airborne and ground-based mobile lidar systems and the data processing workflows are very similar or almost identical in both cases. For the airborne lidar, a more mature technology, which came on the market in mid 90s, the initial uptake in the marketplace was slow, and the newcomers to the lidar business had to learn hard way to work with the uncertainties associated with the use of new technology, huge data volumes, new data formats and conservative mentality of the surveying community, where acceptance of the lidar-derived end-products had gone through a difficult way.

However, within a decade airborne lidar technology had moved had moved far enough into the mapping mainstream, and practical applications of mobile lidar technology have grown dramatically because of revolutionary advancements in the enabling technologies:

- advancement in navigation and GPS technology enabling highly accurate determination of position and orientation of the moving platform
- newly developed electro-optical and mechanical components in the laser scanner subsystem dramatically improved control and quality of lidar measurements taken from a moving platform
- unprecedented developments of exceptionally performing software tools for processing and handling of high-volume data

Based on the research conducted TMS International a few years ago (BC-CARMS, 2006), several important trends in the use of airborne lidar technology developed by 2005 had been identified. It was found that computer software and hardware capabilities imposed limitations on the ability of lidar data users to manipulate large files and realize the data value. Another important conclusion indicated that the wide acceptance of lidar technology by surveying professionals is limited by lack of understanding of lidar capabilities, application and benefits. Some of other trends found in that research are listed below:

- In North America, 29 commercial companies and 3 universities were operating 51 topographic lidar systems
- In Europe, 19 commercial companies and 1 university were operating 30 lidar mapping systems
- In the rest of the world, 18 commercial companies were operating 29 topographic lidar systems

The further research conducted by Tina Cary and Associates (Cary, 2009), which used these results as a 2005-baseline, indicated that the number of operators of airborne lidar systems worldwide increased 44%, and the number of systems increased 64% by 2008. In North America there was a 38% increase in organizations and a 51% increase in number of systems; in Europe, there was a 55% increase in organizations and a 107% in number of systems; in the rest of the world, there was a 44% increase in organizations and a 41% in number of systems compared to 2005. Such an impressive dynamics shows definite and rapid growth of the commercial use of lidar technology, and even in the troubled economy of late 2008, most members of the lidar surveying community expected further growth over the next 3-5 years.

Ground-based mobile lidar technology is relatively new in the community of professional surveyors, and it currently faces similar challenges overcame by the airborne lidar a decade ago. However, since both the lidar and the surveying community have gone through the airborne lidar experience, the ground-based mobile lidar seems to be more rapidly accepted as an ideal solution for surveying large areas that are impractical with static lidar sensors but require an accuracy and resolution that exceed airborne technologies.

This paper will be focused more on ground-based mobile lidar technology while the airborne predecessor is going to be used for showing comparison and trends. The paper will demonstrate that a ground-based mobile lidar can be an excellent tool for surveying railways, highways, urban modeling, etc. because of very efficient, safe and accurate data collection and high-quality end-products. The entire survey workflow from project planning to deriving end-products is highlighted, the advantages and limitations of the new technology for various applications are discussed, and a few examples of practical use of a new mobile lidar system developed at Optech Incorporated in cooperation with the business partners are presented.

3. PRINCIPLES OF OPERATION AND WORKFLOW

3.1. Main Subsystems

On the functional level, any mobile lidar system could be defined as an integration of several subsystems: laser scanner, GPS receiver and antenna, inertial navigation system (INS), which includes Inertial Measurement Unit (IMU) for orientation measurements of the moving platform, and a sophisticated software unit to control all of these components, synchronize the time of all taken measurements, and record the collected data.

A basic laser scanner instrument combines a pulsed laser emitting the beam, a scanner deflecting the beam towards the scanned area, and an optical receiver subsystem, which detects the laser pulse reflected from the target. Since the speed of light is known, the travel time of the laser pulse can be converted to precise range measurement. Combining the laser range, scan angle, laser position from GPS and orientation of the laser platform from INS, highly accurate xyz-coordinates of the ground points for each laser pulse can be calculated. The laser pulse repetition rate in combination with scanning mirror deflecting pattern determine lidar data collection rate. In the most advanced commercially available lidar systems, the data measurement rate is typically 50,000 - 200,000 measurements per second, which allows the user to collect highly accurate data of required ground point density within very short period of time.

The navigation solution, INS, integrated with the laser scanner is a critical component for any mobile lidar system as it is used to obtain geo-referenced coordinates of the collected lidar data. INS measurements are based on combine collection and processing of GPS and IMU data is often integrated into a position and orientation system (POS). Since the accuracy of the laser scanner instrument are of the order of few cm, the overall accuracy of any integrated mobile lidar system is often determined by the accuracy of the navigation solution (Ussyshkin, 2008). For an airborne lidar, where very advanced, highly accurate POS systems, like Applanix's POS-AV-510 are often used, the GPS and IMU data collection and processing are controlled so the GPS data help to remove the error originated form the IMU drifting, while IMU data and additional software algorithms used for the data processing help to reduce the error of GPS measurements. As the result, POS system generates data of exceptional positioning accuracy (Applanix, 2009)

However, for a ground based mobile lidar, navigation solution has to be even more sophisticated because various obstacles on the ground like trees, buildings, bridges, etc., create periods of GPS, when the GPS data is not available to aid the navigation solution. As a result advanced ground-based mobile lidar systems employ auxiliary sensors and advanced processing solutions to maintain accuracy during periods of GPS outages. In this case a specially designed POS system for land-based operation, like Applanix POS/LV 420, could be used to correct the orientation and position of the two lidar sensors generating a complete geo-referenced point cloud automatically (Applanix, 2009). This system utilizes an accurate IMU, dual GPS antennas and a DMI (distance measurement instrument) to generate the navigation solution. The additional GPS antenna can be used to aid in heading calculation in areas of high latitude while the DMI is used to provide accurate vehicle velocity updates. This aids in the overall solution when the vehicle is moving but the GPS quality is poor. It is also effective when the vehicle is stopped as the DMI provides Zero Velocity Updates (ZUPT).

One of the most critical components of the overall navigation solution, either airborne or ground-based, is the use of POS-MMS software tool with 'tightly coupled processing'. The term 'tightly coupled' references the fact that POS-MMS simultaneously processes the raw GPS, IMU, DMI and secondary GPS data to generate the navigation solution – thereby making optimal use of auxiliary sources of information.

3.2. Workflow

The overall workflow of airborne and ground-based mobile lidar systems is almost identical, and could be represented by a flow-chart shown in Fig 1

One of the most inherent features of lidar data is that it is acquired, processed and delivered in digital format. This is one of the fundamental advantages of the lidar technology, which allows the user to generate lidar-derived end products, which are needed for very wide range of applications. The simplest form of the processed lidar data is so called "point cloud", which could be saved in an ASCII format file containing xyz geo-referenced data.

The point cloud data can be imported into various software packages including GIS, and others. Further data manipulation and/or fusing other type of data and analytical tools with the imported point cloud create a verity of value-added products. Since lidar data can be imported and exported buy most commercially available packages, vast majority of 3D format programs, like AutoCAD, ArcView, etc. have capability to work with the point cloud data. Fig 2 gives and example of a point cloud dataset converted into a CAD model.

The main drawback of this process is the commercial 3D software packages have limitation on the number of imported points, and the lidar data have to be tiled for further data handling. Many of lidar data providers have developed proprietary software, which not only helps to handle the data volume, but also can add more value to the lidar-derived end products.

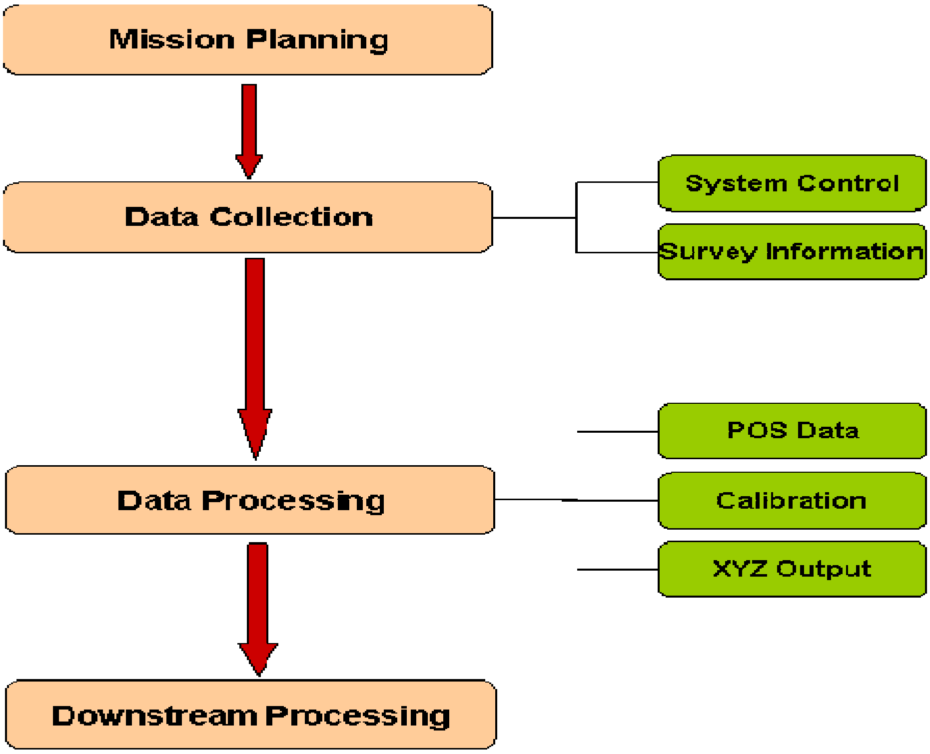

Figure 1. Mobile lidar workflow

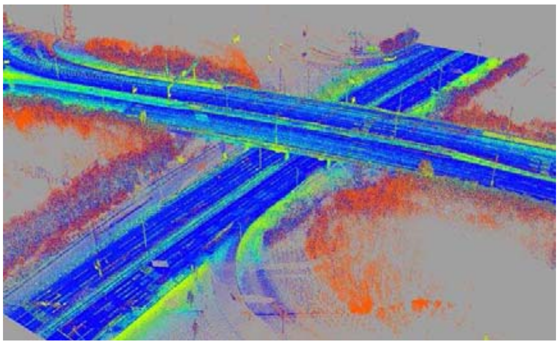

Figure 2 From point cloud (left) to CAD model (right)

4. DATA ACQUISITION PLATFORMS

Most airborne lidar systems are used aboard small and medium fixed wing aircrafts but some of them are installed on a helicopter platform as well. Some aircraft may require additional fitting for mounts and power supplies but generally, any aircraft used for aerial photography can be used to fly a commercially available airborne lidar system.

Ground-based mobile lidar systems are typically installed on a minivan (Fig 3), which makes this technology much more affordable and attractive for the newcomers because of minimum organizational effort – no pilot, aircraft or special permissions are required. Moreover, the lasers utilized in ground-based mobile systems are often completely eye-safe, and the data collection missions can be conducted during normal hours without imposing restrictions on the road traffic in heavily populated areas.

Figure 3. LYNX Mobile Mapper^{TM} installed on a minivan (left) and an image of data point cloud (right)

Recently, new ground-based mobile platforms have been successfully used for lidar data acquisition by the LYNX Mobile Mapper^{TM}, a new mobile lidar system developed at Optech Incorporated. Figures 4-5 show installation of LYNX aboard a motor jet and a railway platform and all-terrain vehicle, and some examples of the datasets collected during those projects.

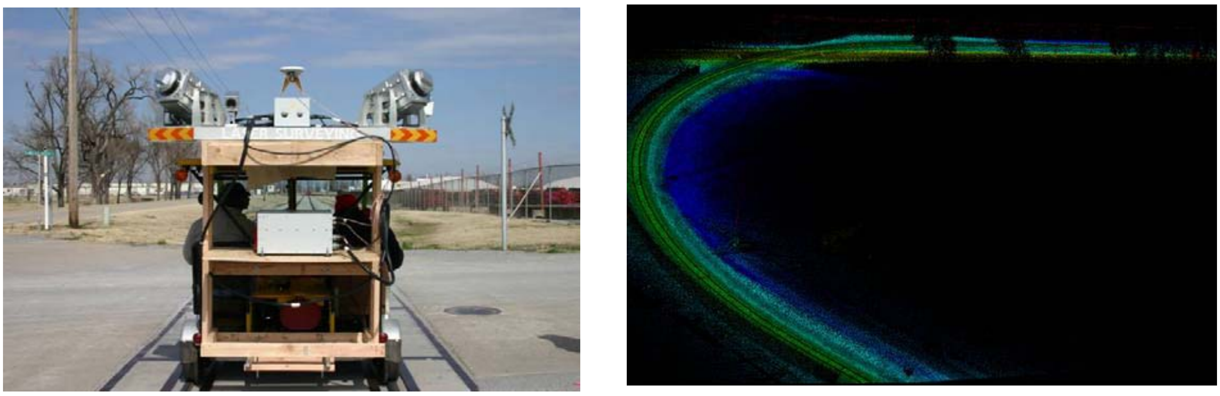

Figure 4. LYNX Mobile Mapper^{TM} installed on a railway platform (left) and an image of data point cloud (right)

 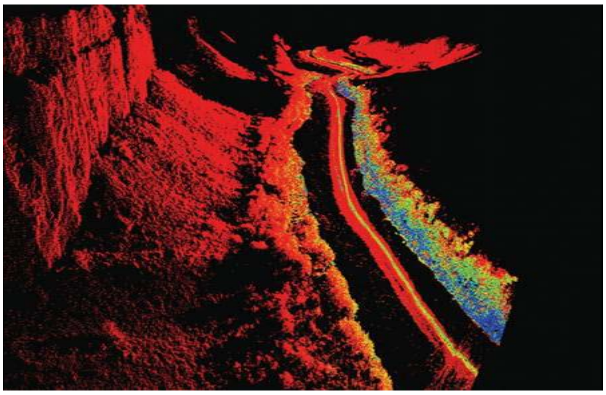

Figure 5. LYNX Mobile Mapper^{TM} installed on a jet boat (left) and an image of data point cloud (right)

4. APPLICATIONS

The following list of applications for airborne lidar technology was identified by Tina Cary and Associates (Cary, 2009) during their extensive research on global airborne lidar market conducted in 2008:

- Topography
- Transportation – railroads, highways, airports
- Urban mapping and modeling
- Utility transmission corridors – power lines, pipelines
- Coastal zone erosion analysis
- Building analysis
- Flood risk mapping
- Emergency response/disaster mitigation
- Logistic planning – military, geology, etc.
- Line of sight analysis
- Watershed analysis
- Oil/gas exploration
- Forestry and tree canopy analysis
- Quarries and earth-moving volumes
- Climate change

Most of these areas are applicable to ground-based mobile technology, which offers unique technical capabilities, like exceptionally efficient data collection dramatically reducing the field-operation costs, reduced post-processing time and effort compared to traditional survey methods. However, each individual end user has particular needs and specifications for the end-products that are expected to be met for a particular application, but due to relatively recent introduction of the ground-based mobile lidar technology, many of these end products are still being defined, and the best practices to meet the end-user expectations are still under development. As the result, fast growth and development of the new lidar technology might strongly depend on further optimization of the existing and established workflow from mission planning through field data collection to post-processing and final QA/QC of lidar-derived end products for a specific application.

Automated data handling and manipulation, rigorous quantification and appropriate reporting procedures could be identified as the key areas of importance for successful acceptance of new lidar technology by the community of professional surveyors (Flood, 2001) and here academic and research institutions may play an important role in this process. Automated or semi-automated sensor calibration, quality control and accuracy assessment tools and methodologies developed by academic sector may provide essential input for lidar service provider community, which bridging the capabilities of new lidar technology and the expectations of the end users of lidar-derived end products.

The following examples demonstrate the advantages of the use of ground-based mobile lidar technology for infrastructural and urban modeling applications.

5. LYNX MOBILE MAPPER: NEW TECHNOLOGY FOR SURVEYING APPLICATIONS

All projects presented below have been done by the LYNX Mobile Mapper™ instrument, a fully integrated system with 360° laser sensors that surveys large areas from a mobile platform at very high speeds (up to 100 km/hour), obtaining a high-resolution (up to 1cm) point cloud. With the system accuracy better than 5 cm, precision of 7 mm, and the data collection rate of 100.000 points per second per sensor, the Lynx Mobile Mapper™ has a feature set that allows for the generation of high resolution data with exceptional efficiency, which allows to reduce the cost of field work to its fractions comparing to the traditional surveying methods. In addition to all that, completely eye-safe laser operation enables the data collection mission to be performed without disruptions to traffic in densely populated areas.

5.1 Railroad Survey

The project on collecting the railroad data has recently been performed by Optech Incorporated and Aerial Data Services, Oklahoma. The project was aimed to acquire complete inventory including clearance of overhanging wires, natural and artificial obstructions – trees, tunnel and bridges, and mapping of the location and type of switches and turns with high accuracy. Traditional survey methods would require frequent measurements on the rail base, the top of the rail, and the rail base of the opposite side. These measurements are labor-intense, time-consuming, sometimes dangerous and highly disruptive to the railway traffic. By contrast, LYNX data acquisition took hours instead of days, which minimized the disruption to the traffic, and resulted in exceptionally efficient data collection with precisely mapped switches and turns (Figure 6)

Figure 6. Switchers and turns of a railway road could be easily mapped by LYNX Mobile Mapper^{TM}

5.2 Highway and Road Infrastructure

The LYNX Mobile Mapper^{TM} provides remarkable capacity for the rapid 3D mapping of highways. One of the first projects, where unique capabilities of LYNX have been used for highway survey, was conducted in March 2008 in Greece (Zampa, 2009) on the highway connecting Korinthos to Athens, which had three lanes plus the shoulder one. The aim of the project was obtaining the CAD reconstruction of the existing main features (pavement, structures, slopes, road signs, poles, etc.), as new works are planned to be done on this highway, such as the construction of a new link-up motorway and the preservation of existing parts.

The highway has been surveyed in only three hours at an average speed of 50Km/h acquiring 980 million points. The point cloud was generated in WGS84/UTM34 and converted in the Greek reference system CGR87 afterwards with a final average spot spacing of 11 cm. All this can be compared with 120 working days needed to scan 80 km of similar highway in that area using static laser scanner and a total-station. In order to increase the final point cloud accuracy six base stations and some ground control points (every 50-80 meters) have been located along the entire survey area. The final point cloud accuracy is within 1-2 cm. In order to get all the results needed, different software have been used for data processing such as PolyWorks and Pointools (Figure 7).

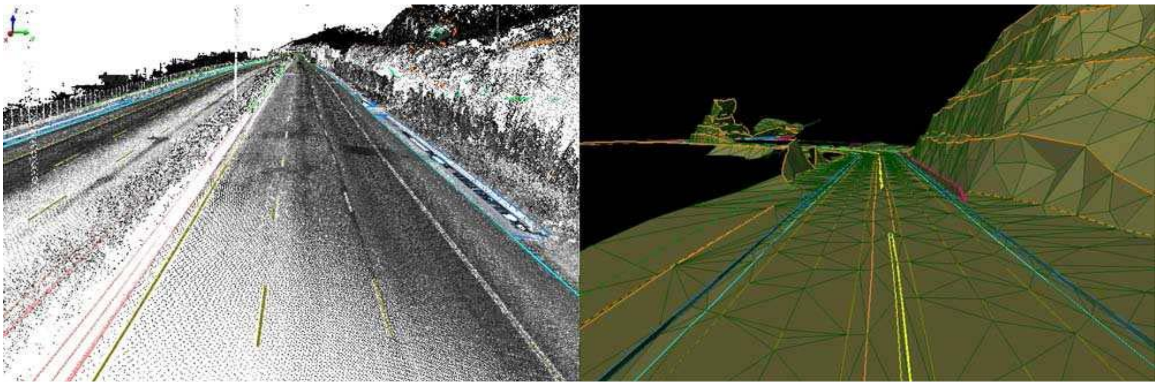

Figure 7. Pont cloud (left) and CAD drawing (right) of the highway (Zampa, 2009)

5.3 Urban Modeling

This survey has been carried out on January 2008 in Leicester, England (Zampa, 2009). The aim of the project was obtaining the faithful model reconstruction of some main buildings in the historical area for having a complete archive. Due to the narrow streets and the tall buildings the GPS can run sometimes outrange and the POS can correct the location though the DMI (Distance Measurement Indicator): The DMI is a wheel-mounted rotary shaft encoder that measure precise linear distance traveled. These measurements give the POS LV a very accurate velocity measurement that helps constrain drift errors during GPS outrages. Due to the traffic the entire area has been scanned at an average speed of 30 km/h, collecting data with a spot spacing of about 4 cm. In 20 minutes has been collected 5 blocks for a total of 144 million points. The pre-processing has been carried out using a single base station placed around the area and further the processing has been done with Pointools software (Figure 8).

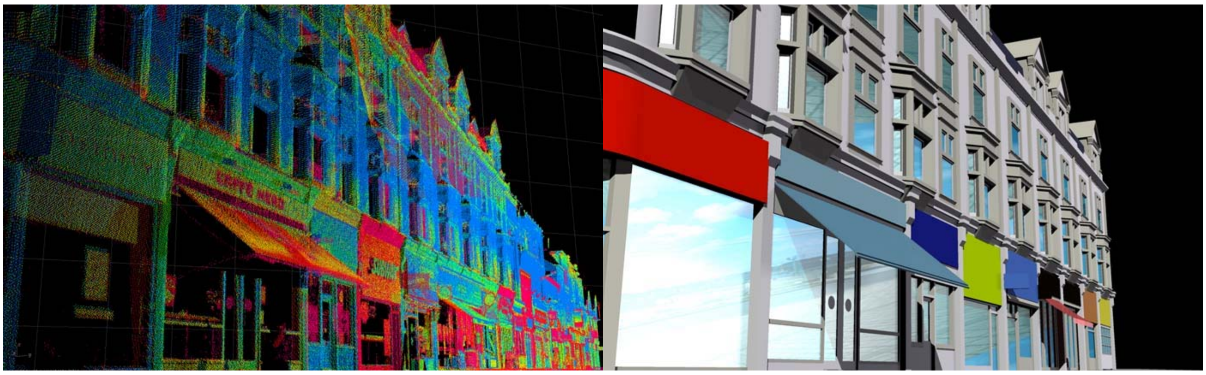

Figure 8. Pont cloud (left) and CAD drawing (right) of the city street (Zampa, 2009)

6. CONCLUSIONS

Mobile lidar technology is a widely accepted tool providing exceptionally efficient data collection of high accuracy for various surveying applications. Airborne lidar market, being more mature, is experiencing high growth over the recent years, which helps the relatively new ground-based mobile lidar technology get accepted by the community of professional surveyors as an efficient solution for surveying large areas that are impractical with static lidar sensors but require an accuracy and resolution that exceed airborne technologies. The entire mobile lidar workflow from project planning to deriving end-products is reviewed, and advantages and limitations are discussed. A few examples of practical use of new ground-based mobile lidar system, LYNX Mobile Mapper^{TM}, developed at Optech Incorporated demonstrated impressive capabilities of the new technology enabling exceptionally fast, safe and efficient collection of highly accurate spatial data.

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BIOGRAPHICAL NOTES

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