Leveraging Mobile Mapping Systems

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SUMMARY

Land based mobile data acquisition has evolved significantly over the last decade with respect to the mixture of sensors surrounding the collection platform and resulting data. Users of these solutions, whether government agencies, private engineering firms or research institutions, are becoming increasingly pressurized to maximize their investments in the technology.

This paper will focus on elements that should be considered by management prior to investing in a mobile data capture system, regardless of the application for which it is intended.

The following points will be discussed, looking at both the benefits and challenges associated to each of them:

- Use of a single technology for multiple applications and stakeholders within an agency
- Use of a single data capture vehicle to meet diverse data collection requirements (ex. asset management, pavement management, and survey)
- Quality assurance and control considerations relative to converging applications
- Project types

Ultimately, this paper wants to address the following question : “How can I maximize the use and best leverage the capabilities of my mobile mapping solution?”

SOMMAIRE

Les systèmes d’acquisition de données installés sur véhicule ont grandement évolué ces dernières années intégrant une grande variété de senseurs fournissant une multitude de données. Les utilisateurs de ces solutions, qu’ils soient des firmes privées, organisations publiques ou centres de recherche, doivent s’assurer de rentabiliser leur investissement.

Cet article décris certains éléments à considérer par les gestionnaires avant d’investir dans un système d’acquisition mobile indépendamment de l’application visée.

Les points suivants seront couverts en identifiant les bénéfices et les défis pour chacun :

- Utilisation d’une technologie unique pour plusieurs applications variées
- Utilisation d’un seul véhicule combinant plusieurs différents senseurs
- Assurance qualité et contrôle de la qualité dans le processus d’acquisition et de traitement des données

— Différents types de projets

Le but ultime du document est de répondre à la question : « Comment puis-je rentabiliser mon système d’acquisition de données mobile en maximisant sont utilisation ? »

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1. INTRODUCTION

Mobile survey systems represent significant investments for public agencies and private firms. Initial acquisition costs can be significant due to capital investment in hardware as well as the large commitment associated to training human resources on field survey and software processing methodologies. Traditional data capture methods have matured over the past decade, making the introduction of new mobile data capture technologies less attractive for specific applications. Conversely, significant advancements have been made over recent years relative to sensors, software, mass data storage and management capabilities, and collection workflows; making a single mobile data capture system more flexible to use on multiple types of roadside data capture projects.

In order to achieve an acceptable return on their investment, managers of public organizations and private firms must be aware of potential markets and applications for these systems. It is not uncommon that the use of a mobile survey solution can prove to be a great asset for multiple stakeholders within a single agency; the concept of sharing a single investment makes good business sense from both financial and operational standpoints. However, it is the lack of inter-agency awareness of the system's technical capabilities that can typically become one of the biggest challenges decision makers face when considering an investment in a mobile survey system.

This paper describes some of the most promising uses of mobile data capture technologies as well as some intrinsic requirements associated to specific applications. It also explores the potential convergence of LiDAR (light detection and ranging) mobile survey technology with other vehicle based inspection systems in an effort to save survey costs by driving the road once and collecting it all.

2. USE OF MOBILE LIDAR FOR MULTIPLE APPLICATIONS

LiDAR has been used for airborne mapping for decades. Many applications have benefited from this type of airborne laser scanning survey, namely flood mapping, vegetation encroachment and route planning.

The same phenomenon is taking place again today as mobile laser scanning systems become more widely accepted for installation on road vehicles. Most commonly used applications currently include asset management, road safety monitoring and precise road survey for design and as-built surveys.

2.1 Mobile laser scanning for asset managers

Information for asset managers - in fact, for all managers - is key. Without information, decisions cannot be made. How often do asset managers rely on outdated or partial information? The Ministry of Transportation of Quebec (MTQ) in Canada used to perform province wide asset inventory every 25 years because of cost related issues (Frédéric Brière, MTQ). You can only imagine how irrelevant the information must have been after such a long period of time.

For asset managers, mobile laser scanning solutions provide an efficient means of mapping and measuring roadside features. Traditionnal methods used to perform asset inventories typically included the digitization of paper records, the analysis of aerial photography and the completion of handheld GNSS surveys. Early mobile mapping techniques using digital cameras and GNSS base navigation systems appeared in the early nineties and became commercially available during the mid nineties. Most of these systems required manual data processing to locate assets on images and complement the computed locations with desired attributes. State wide asset inventories were often undertaken using such technology.
By integrating laser scanners on mobile mapping vehicles, asset extraction can be automated for certain types of assets, such as road signs. Previous research ([2][4]) indicates that that 3 times the efficiency can be achieved on road sign surveys using an automated approach. This very important efficiency gain translates to a reduced need for extraction specialists and training; resulting in significant cost savings over time. Another interesting application associated to automating asset detection is the possibility of using the technology for automatically monitoring assets, such as signs. For instance, a department of transportation (DOT) could use this technology to automatically find where signs have gone missing or been added over time.

2.2 Road safety survey

In the United States, the economic impact of motor vehicle related injury is notable: motor vehicle crashes cost around $230 billion in 2000 [7]. In Great-Britain, average value of prevention per casualty was around 1.5£ million, in 2006 [6]. Although safety audits are gaining in popularity, they are usually performed after fatalities occur or when an especially high casualty rate is observed on a specific road segment. Mobile data collection systems provide a means of conducting safety audits proactively, not only reacting after the fact. Many parameters associated to road safety can be collected using LiDAR survey techniques. Some of these include road crossfall and superelevation measurements, road radius of curvature computations from painted markings, horizontal and vertical line of sight analysis, as well as lateral and vertical clearance measurements.

Road crossfalls are computed from pavement scan points. A cross-section line is computed using linear regression or averaging techniques to increase slope precisions. Better than 0.5% measurements are achievable with low end scanners. Crossfall can be measured between pavement markings or between edges of pavement depending on tools used and application requirements.

When combined with radius of curvature measurements, crossfall measurements are used to compute superelevations for further comparison with design standards. Traditionally, mobile mapping systems offered data and tools to measure radii of curvature from driven vehicle traces collected with GPS-INS systems. New tools are now available to precisely detect and locate pavement markings from LiDAR survey data, which now makes it possible to measure radii of curvature from lane markings and even from road edges.

Line of sight is also a key element to road safety. With LiDAR data collection, the entire road surface can be mapped and data can be used for vertical line of sight analysis. Edges of roadway can also be automatically detected and applied to line of sight analyses. Lateral obstacle detection can be performed if analysis needs to be pushed outside of roadway limits. Software tools also offer area computations where line of sight may be blocked and where work may be required to apply line of sight standards.

2.3 Road design survey

Roadway design engineers need very accurate roadway mapping data in order to perform appropriate designs and best plan road realignment, rehabilitation and construction projects. Most of these surveys are typically done using traditional survey methods and sometimes, static scanning technologies. With its increased accuracy, mobile survey technology becomes an efficient alternative to traditional survey and static scanning. The challenge remains in the adoption of the technology by the market. Service providers, on the other end, need to fully master the technology and more importantly, the workflow to make the most out of it.

The density of information collected on road rehabilitation projects enables the creation of very detailed road surface models . These models can be used to compute standard cross-sections as well as to compute precise cut and fill volume estimates.

Ultimately, the efficiency of the method should allow for more as-built surveys to be performed and more efficient monitoring of construction work to be undertaken. The MTQ is currently considering as-built mapping as a possible Quebec methodology and requirement after construction. This can only be possible if cost efficient solutions exist.

3. CONVERGENCE OF MOBILE DATA COLLECTION

One important element agencies should understand is that it is now possible to have a single vehicle configuration combining many different types of sensors. These so called “supervans” integrate pavement inspection sensors with imaging, laser scanning and GPS-INS systems ([3][5]). Many departments within a single agency may then use portions of a dataset generated by such vehicle for their specific purpose and needs; not all datasets are necessarily used by one department. For example, the pavement management department will most likely be interested by profile, rutting and distress data. However, if distress information indicates structural issues, they may then refer to image or profile information to complement their assessment of drainage items. The use of the collected data then becomes limitless.

Converged supervans can be very expensive. This means that for some agencies it will be more feasible to upgrade their capital investment over time. If this is the case, it is important to consider future requirements during the initial procurement phases to make sure the selected system offers potential for any possible upgrade requirements.

There are many ways to build a converged system. Common to all sub-systems is a timing mechanism that most often uses a GPS receiver as a common denominator. GPS time becomes the common clock for all sensors. Georeferencing all information combines collected data on a common coordinate system. Most roadway management systems use linear referencing, with the geographic location of mile posts then becoming important geocoding information. The linear referencing location of an object can be computed dynamically using the location of mile posts as well as centerline data files. Having dynamic ways of recomputing linear referencing locations from an absolute coordinate system (provided by GPS) is important to maintain the integrity of the data once roadwork affecting centerline information has been undertaken.

Pavement inspection specific sensors include IRI (International Roughness Index) profilers. These are built with a single point laser (or ultra-sonic device) and combine a vertical accelerometer installed in the vehicle wheelpath. Two types of systems are used to measure rut depth: multiple point lasers (at least 3, one in each wheelpath and one in the middle of vehicle), and laser-camera triangulation systems designed with a line laser projected on the pavement and an angled camera measuring line deformation. Finally, distress (or pavement cracking) can be mapped either with angle area scan cameras (same camera as for assets) or linescan cameras installed vertically. All data collected with those sensors are either referenced with GPS clock or with distance measurement instrument (DMI) counts. When using DMI counts, counters will typically be reset at the beginning of roadway segments.

Forward looking camera systems can be configured with a single spherical camera or through a combination of multiple camera models. Image acquisition is achievable using a triggering mechanism that prevents unecessary image acquisition when the vehicle is stopped. Pulses generated by the DMI are counted to trigger the camera(s) when a specified image interval is reached. GPS time is associated to each image providing a specific geographic location.

Laser scanners provide range and angle measurements. Each measurement is time tagged with GPS time. Location and orientation measurements are used to compute individual laser point location based on the input of a GPS-INS system.

Data can be shared among users and departments using central GIS servers. Due to the georeferenced attributes available, spatial and temporal indexes can be used for increased efficiency. Availability of centralized data ensures integrity as well as complete data coverage of a network under maintenance. Time comparison becomes a huge asset in litigation cases as well.

From the central GIS server, different software packages access the data and are used to extract all relevant information. Pavement specific information can feed pavement management systems. Roadway images may be distributed throughout the organization using web applications. Some departments will use photogrammetric software to extract more information from the images (e.g. asset inventory or specific measurements), and laser data may be used by asset managers and road engineers for design purposes or safety analysis.

4. QUALITY ASSURANCE AND CONTROL

Quality assurance and quality control are important at every process level. The further errors are found in the process chain, the more expensive they become. For example, an error in a sign location can originate from multiple sources. It may be due to manipulation errors caused by the extractor, errors could have been made during data post-processing or archiving operations, or it could be associated to data collection errors. Finding the source of the mistake becomes very cumbersome and therefore, proper quality assessment needs to be established within the process. More importantly, if the error is found to be resulting from a data collection issue (poor satellite coverage during collection), part of the survey might have to be reconducted. The vehicle might be far from the location or not available at all, resulting in skyrocketing costs due to poor quality.

Quality can mean different things to different managers. For an asset manager, accuracy is important but completion is equally, if not more, important. Having signs located at a centimeter level accuracy may not be required but having as close as possible to 100% coverage may be. The following paragraphs describe some of the techniques used to optimize quality.

During data collection, operators must make sure that all sensors are working properly. Real time navigation information overlayed on road maps confirms the proper functioning of the GPS-INS system. Alerts when a degraded navigation solution is observed (accuracy falls below desired level) can be key tools. At the end of day, completion and data integrity must be verified. Operators should confirm that all sensor data was recorded properly (no portions missing), all files on hard drive are usable (a broken cluster chain is horrible to find during extraction). Validation of image quality is important as well. Point cloud coverage should be checked also to make sure completeness is achieved. Re-survey plans can be organized on a daily basis.

Validation of GPS accuracy, whether in real time or during post-processing requires more effort and is typically done in an office environment, ideally in parallel of data collection. Traces (GPS locations of vehicle during survey) are layed over orthophotos or road maps to locate errors or deviations. Post-processing can be used to fix errors or improve accuracy if required. Post-processed traces should also be validated.

Validation of final accuracy is best achieved with control targets. Pre-surveyed targets are useful to assess the overall quality of the data but may sometimes be unavailable. It is a good methodology to have a test site surveyed for a project and have the test site re-surveyed at different times to validate system stability. This could be located in a location central to the survey area or close to the vehicle overnight parking.

An alternative is to make use of repeatability in measurements. Re-surveying portions of roads in different directions at different times can be a useful means of validating the system's precision. Again, a routine test track can be used to implement this type of validation.

When errors are found and re-surveying is not possible, alternative methods may sometimes be used. For instance, it is possible with georegistration techniques to align data with a known reference. For example, if control points are available in a deviation error zone, the GPS trace can be fitted so that the point cloud matches with the control targets.

An organization, when submitting data, should also submit a certificate of accuracy qualifying the said data. Accuracy assessment should be recorded as metadata to make different dataset combinations usable.

5. NETWORK LEVEL VERSUS SITE LEVEL SURVEYS

The best return on investment of a multi-purpose mobile survey system is based on maximizing the use of the system. This section brings up the concept of the type of project that the system is intended to be used for, which can be summarized into 3 categories:

1. Network Level Surveys: governed routes are driven and data is collected for network level reporting/planning
   - Asset management data collection
     - Government (signs, guiderails, pavement condition
     - Utilities (power poles and usage)
2. Corridor Assessment Surveys: key routes are surveyed
   - Road safety audits
     - Signage (warning, hidden, speed/passing zones)
     - Vertical/horizontal clearance
     - Stopping sight distance
     - Superelevation/design speeds
3. Project Level Surveys: small sections of roads are driven for specific needs
   As-built surveys
   - As-built surveys
     - TIN/DTM
     - Breaklines (edge of pavement, curb, markings)
     - Cross section modeling
     - CAD exports

Mobile survey systems are being purchased worldwide by agencies requiring them either for exclusive use on a specific application or for combined uses. The type of system and hardware required is independent of the type of data collection (network, corridor, project) that it will be used for, thus allowing a single investment to be flexible for each of these types of surveys.

A specific workflow might be required on a specific project level but the same equipment should be usable to meet the project requirements. As an example, the MTQ is conducting network level surveys over the summer to take advantage of longer days and higher sun elevation. During spring and fall seasons, when the sun on the horizon makes it difficult to achieve good quality image, survey vehicles are used for project level surveys. E.g. surveying tunnels at slower than traffic speeds with pre-established control targets and multi-pass routing to ensure full coverage of the right-of-way.

Various stakeholders associated to a mobile survey system can have very different needs based on the type of information required and the types of projects being surveyed. Proper coordination to associate these needs with available resources can be established to maximize the return on investment.

6. CONCLUSION

This paper demonstrates that although an expensive technology, mobile data collection systems can be profitable. This holds true as long as multiple applications are taken into consideration when operating the system and the various stakeholders work in collaboration to maximize their return on investment.

In most organizations where this collaboration process has been put in place successfully, a single department seemed to be responsible for managing the vehicle operation. This department would also be responsible for distributing the data throughout the organization to different stakeholders. Whether this department is part of the organization or outsourced, it plays a key role in selling the technology and its benefits to the rest of the organization.

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BIOGRAPHICAL NOTES

Rob Huber
Rob Huber has been involved with mobile mapping since 1996 with tenures as field manager and operations manager for a fleet of mapping vehicles, and most recently, involved with product and portfolio direction as Transportation Segment Manager for Trimble's GeoSpatial Division. His experience is primarily based around mobile technologies for asset management, pavement management, and survey applications. Rob holds a Bachelor degree of Applied Science in Civil Engineering.

Claude Laflamme
Since 1997, Claude Laflamme has been acting as Development Manager at Geo-3D, a Trimble company and an innovator in georeferenced mobile mapping technologies. Claude holds a Bachelor degree in Computer Science from McGill University.

Eric McCuaig
Eric McCuaig has been active in the mobile mapping industry during the past eight years, working on international projects in China, Thailand, France, UK, Italy and Brazil among

others. These projects included various applications for mobile mapping such as pavement condition surveys and best value performance indicators, asset management, and survey grade LiDAR data collection. Now with Trimble`s GeoSpatial Division, Eric is responsible for mobile mapping business development in Europe, the Middle East and Africa. He also represents Canada on the World Road Association Technical Committee D.1 - Management of Road Infrastructure Assets from 2008 - 2011.

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