Automated Mobile Mapping for Asset Managers

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Key words: geoinformation, photogrammetry, asset inventory, mobile mapping, automation

SUMMARY

Geo-3D Inc., a Montreal based company (Canada), offers software products and services for geomatics and GIS data collection using advanced terrestrial photogrammetric techniques. The company's products provide a mobile mapping solution integrating different sensors such as digital camera(s), GPS-INS systems, optical encoders and scanning lasers. The Trident-3D Mobile Mapping Solution is divided in two main components: the georeferenced image acquisition system and the asset extraction module that enables the determination of the position of the objects in the "as built" environment with accuracies required for asset management and GIS systems. Geo-3D's newest development enables automated road sign detection, location and measurement. Future developments are planned to include guardrails, poles and trees in the automated process.

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1. INTRODUCTION

Several factors act as incentives for public and private organizations to build the equipment inventory of their infrastructure network. These may originate due to legislature or are associated with operations relative to maintenance, procurement, traffic, valuation or safety and emergency response issues.

Geographic Information Systems (GIS) are often used to meet infrastructure network goals in a variety of fields, such as transportation, electric distribution and property assessment. Asset managers are interested in populating their customized GIS application either through data conversion or data collection techniques. Although data conversion is widely used because it seems to be economical initially, in fact, it is not as accurate as field data collection nor is it economical over a period of time. Proceeding to an infrastructure network inventory by traditional surveying or GPS foot survey methods may prove to be a tedious and costly operation. Furthermore, constraints for some organizations may translate into difficulties maintaining up-to-date network data. This prevents managers from completing efficient planning over time to orientate organizational development.

In order to address these issues, Geo-3D Inc.™ has developed the Trident-3D*™* mobile mapping solution to inventory network components spread over large territories in an efficient, safe and cost-effective manner. This solution is based on several geo-technologies that are applied in an integrated fashion. It was designed for the purpose of performing the inventory of roadside infrastructure assets and features managed by transportation authorities (roads, public transit, railways, etc.), utilities (telecommunications, electric distribution, etc.) and municipalities.

2. DEVELOPMENT OF MOBILE MAPPING SYSTEMS

During the 1970's, many highway transportation departments used photo-logging systems to monitor pavement performance, maintenance effectiveness, signage etc. The processing, storage and retrieval of film was both expensive and difficult. Poor accuracy of vehicle positioning and lack of object measurement meant that photos were mainly used as a pictorial record of the roads surveyed (Tao, 1998).

With the emergence of video imagery, ponderous photo-logging systems were soon replaced by video-logging systems. While the storage and accuracy issues were alleviated, they were by no means resolved. In 1988, a major step forward was made when a new positioning and orientation component was tested for the Alberta Mobile Highway Inventory System (MHIS). Satellite methods (i.e. Differential GPS) were employed to improve the positioning accuracy and an inertial strapdown system was used to bridge GPS outages and to provide the capability for accurate camera orientation. Compared with all other methods of data acquisition used by Departments of Transportation (e.g. digitizing existing maps), the GPS system proved to be the most cost effective and efficient (El-Sheimy, 1996).

Two research groups were the main contributors in the advance of mobile mapping technology in North America, The Center for Mapping at Ohio State University, USA and the Department of Geomatics Engineering at the University of Calgary, Canada. In the early 1990's, these institutions individually developed mobile mapping systems (Tao, 1998). The initial objective was the online recording of GPS positions in a moving van at highways speeds. To obtain a visual record of the road environment, a stereo vision system was added that allowed for capture and storage of digital stereo image pairs simultaneously with the GPS positions and other sensors like gyros, distance measuring device and road profiling. Inertial measurement units (IMU) were later installed to track angular changes in all three directions when the vehicle is in motion (Novak, 1990). Direct georeferencing of digital image sequences is accomplished by the multisensor navigation and positioning techniques. Georeferencing is a crucial element of any mobile mapping system that has gained wide acceptance in geodetic engineering and public works (Gontran, 2005). Compared to video-logging systems, mobile mapping systems are able to offer full three dimensional mapping capabilities that are realized by using advanced multisensor integrated data acquisition and processing technologies.

Figure 1: A Mobile Mapping Vehicle

During the last two decades, the need for land related digital information has grown tremendously. The driving force behind this growth is the development of computer databases and especially geographic information systems (GIS). The acquisition of data has become a major area of research for the Geodetic Sciences and especially Photogrammetry (El-Sheimy, 1996). Furthermore, the type and quality of information required is changing. A cartographically less perfect product that contains the most recent information is often preferred to a product with a high cartographic standard with contents that are not up-to-date (Li, 1997). To address these issues, the transition from video-logging systems to mobile mapping systems is the next logical step.

3. A NEW APPROACH TO MOBILE MAPPING

Geo-3D Inc. has developed a mobile mapping solution to inventory network components spread over large territories, known as Trident-3D. This solution was originally derived from an aerial system; based on several geotechnologies applied in an integrated fashion. It is a georeferenced land videographic system, based on the use of high-resolution digital cameras (IEEE1394), positioning systems (GPS-INS, DMI) and photogrammetric features, which create a unique GIS data collection tool.

The data collection methodology is split in two phases. The first phase involves georeferenced image data collection performed on board a land or rail vehicle. The second phase involves data extraction undertaken from an office user's desk. As illustrated in Figure 2, it is a simple, streamlined and effective solution.

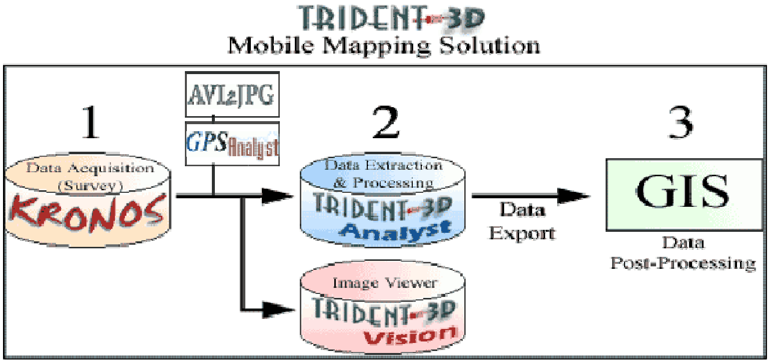

Figure 2: Trident-3D Methodology

4. DATA ACQUISITION

The data acquisition software application, Kronos, is used during land survey operations to collect digital georeferenced imagery. This is achieved by recording digital imagery and positioning information in real time using AVI or JPG format on a hard drive, and synchronizing this data accordingly. Kronos constitutes a very light, flexible and modular system; it can be installed on a portable computer in most land and rail vehicles, as well as on airplanes or helicopters. Moreover, it is compatible with most positioning systems, high-resolution digital cameras, laser scanning, road profiling and video-logging systems given its open architecture.

Figure 3: Portability & Modularity of System

Surveys are based primarily on the use of hardware and software components installed on a land based vehicle (or aircraft) traveling at traffic speeds. These components consist of:

- Kronos data acquisition software that manages different system components
- Colour digital camera(s) with 1280x960 or greater pixel resolution
- Distance Measurement Instrument (DMI), GPS/Inertial Measurement Unit (IMU) or GPS only systems (with RTK or D-GPS correction signals)
- Rack mounted computer(s)
- Kronos Server software that manages multiple clients [Pulse per Second (PPS), DMI, Vocal Annotations (VOC), GPS Odometer Filter (GOF), etc.]
- Laser Scanning Device (for automated asset extraction only)

Figure 4: Many Camera Installations Possible

The vehicle survey operation consists of collecting images and positioning information for subsequent data extraction activities. Kronos software is responsible for triggering image capture and attaching a location (X, Y, Z) attribute to each collected image. Information is recorded on removable hard drives in real time. No further processing is required on collected data prior to analysis when the system is used with a D-GPS or RTK receiver. Images are collected at fixed time or distance intervals. The system's flexibility allows for a variety of cameras to be integrated; pixel resolution ranges from 1280x960 to 2Kx2K or more, and multispectral cameras can also be incorporated. The number and orientation of the camera(s) on the vehicle is selected according to specific project requirements. For example, an electrical distribution pole survey would require that cameras be installed laterally while a transportation asset survey would favour a forward looking installation. Survey planning should account for proper lighting and weather conditions, GPS signal availability, visibility and proximity of objects to inventory as well as optimal routing and logistical parameters. Survey operations are performed at traffic speeds, with no impact on traffic flow. Upon completion of one day of survey, removable hard drives may be brought back to the office for data extraction to begin immediately, where required.

5. DATA EXTRACTION

Trident-3D Analyst software is used to analyze and interpret georeferenced digital imagery generated by the Kronos data acquisition system. This software component is used to extract the inventory information as per the project requirements. The application possesses a user interface for geographically positioning, or locating, any visible element shown on captured imagery, and for performing accurate measurements in all three dimensions.

The unique characteristic of this system resides in its ability to perform stereo-restitution from a single stream of images, only using one camera sequence (U.S. patent pending) to geographically position objects. Comparable photogrammetric software packages generally require that a camera pair be used for restitution if the cameras are pointed forward, or imply that the camera be pointed laterally. The use of stereo photogrammetric algorithms enables the determination of geographic positions of any visible object from a conjugate pair of image pixels. Trident-3D Analyst can work with georeferenced imagery originating from a single camera source oriented in any direction (from 0 to 360°). Stereo photogrammetry is performed on a time-based foundation. Instead of using fixed stereo-base from a pair of cameras, time distance frames are used to create stereo pairs as shown in Figure 5.

Figure 5: Single Camera Parallax

The advantage associated to this approach lies in the possibility of increasing the stereo base according to the distance of the surveyed objects from the vehicle, thereby allowing the photogrammetric engine to maintain a high accuracy level. Data storage requirements and costs are then also reduced.

Additionally, the software relates to the built in tool set designed to improve GIS data collection efficiency. For instance, users can create layers and define layer forms for customized data entry. Geo-3D has further developed a relational system within the extraction software that links data layers together; one type of object may be associated to other types of objects, as in the case of multiple road sign attached to a single traffic light support. Object relations reduce data redundancy and eliminate the need for multiple coding operations to define objects and their attributes during data extraction operations.

In a larger production environment, users have access to an Open Database Connectivity (ODBC) link feature to connect directly to an existing database server. Project management in a multi-user environment can be optimized with data stored in a single location, while productivity and reliability of the collected information are improved and database update is facilitated.

A GIS viewer is available in both Kronos and Trident-3D Analyst software to load background digital maps and/or orthophotos for quality control and navigational purposes. This allows users to ascertain the quality of asset positioning data.

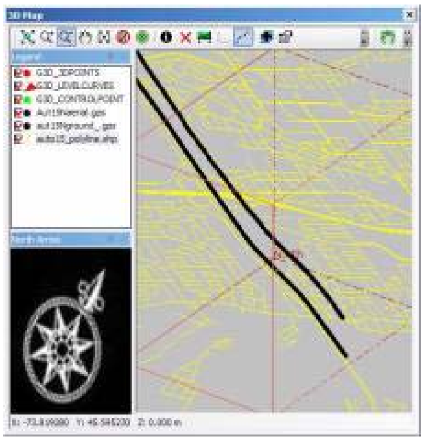

Figure 6: Digital Map

Figure 7: Orthophoto

Measurement tools are available at this stage of data extraction to manually measure objects located in the imagery. Measurements may include but are not limited to: road width, object size, height, width, surface area, offset from the road, etc. Once the attribute fields have been filled, the user closes the data entry form and plays the image sequence under analysis to the following object that needs to be inventoried and characterized. All extracted data, including georeferenced imagery, is automatically importable in a GIS.

6. AUTOMATED ASSET EXTRACTION

Until recently, the primary concern of most research and development within the mobile mapping industry has been placed on the improvement of quality and reliability of image georeferencing. At present, feature extraction is generally conducted manually, which can be time consuming. This is why Geo-3D has developed a prototype for automated asset detection that can be easily integrated into its mobile mapping solution (U.S. patent pending).

During data acquisition, a two-dimensional laser scanning device is mounted to the survey vehicle. As the vehicle advances along the road, a beam of light is emitted and reflected back to the laser once it has come into contact with various objects. This provides a wealth of information that can later be used for:

- Detection (finding an asset)
- Location (geographically positioning)
- Measurement (defining height, width, size, etc. of asset)
- Recognition (classification in a database of assets of the same type i.e. stop signs)

The data detection software, using a plurality of parameters and filters, can detect assets from surrounding objects and a geographic location can then be assigned. The asset can be measured for height and width (the most common measurements). As illustrated in Figure 8, several parameters and filters can be set to customize detection.

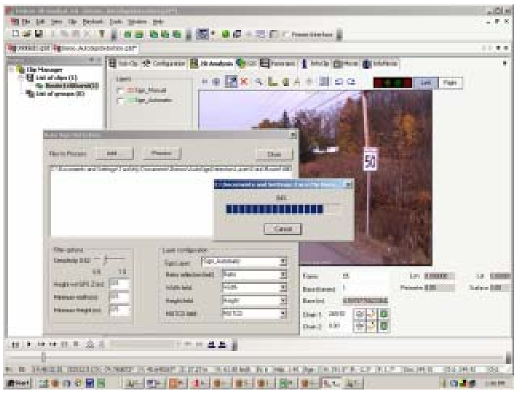

Figure 8: Automated Sign Detection

Asset recognition occurs by locating the asset in one of the images captured by the camera and matching it to a template of predefined images in a database. At the current stage of development, sign recognition is semi-automatic. Once the asset has been detected, located and measured, it is the responsibility of the operator to select the appropriate attribute layer for the asset. By opening a sign library, such as the Manual on Uniform Traffic Control Devices (MUTCD), and creating a box around the pertinent sign, the software will then automatically assign the asset with the code for the nearest matching template as shown in Figure 9. The semi-automatic nature of the technology means that while the operator is assisting in the asset recognition, the operator also has opportunity to perform quality control and assurance.

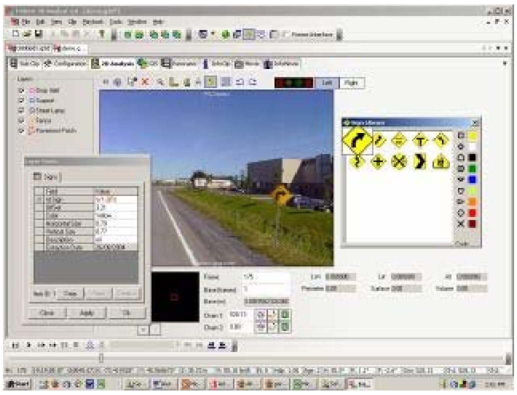

Figure 9: Road Sign Recognition

7. PRELIMINARY TESTING OF AUTOMATED ASSET DETECTION

A trial of Trident-3D's automated asset detection was conducted to evaluate the timing, precision, accuracy and detection rates of the technology versus that of traditionally manual asset extraction. A 37.9 km (23.7 mile) test section was initially used where 416 signs were detected, positioned and measured in just 90 seconds.

Of the 416 signs originally detected, a subsection was used to determine the detection, positioning and measurement times, detection rates, precision, and accuracy. Verification of the sign, its position, measurements and the assignment of the corresponding MUTCD sign code were done for 181 signs in 45 minutes. As illustrated in Figure 10, only 1 sign was missed and 16 were falsely detected.

	Manual	Automated
Detection, Positioning & Measurement Time	120 sec./sign	15 sec./sign
Detection Rate	100%	99%
False Detection	0%	9%
Location Precision (real time D-GPS)	Sub-Meter	Sub-Meter
Measurement Accuracy	3% error	H: 10% W: 30% error

Figure 10: Comparison Manual vs. Automated Asset Extraction (Preliminary Results)

It is important to note that the accuracy can be increased with the usage of a higher frequency laser scanning device; the model that was used for the test-work was limited in its frequency. This would allow for the automated detection of specific road elements such as the curb height.

By expanding on the figures obtained during the testing of automated asset detection, it is easy to see how this will save both time and money when conducting roadside infrastructure inventory.

8. ACCURACY OF TRIDENT-3D SOLUTION

Accuracy levels obtained within the Trident-3D solution are dependent on the positioning technology used during image capture operations. As the camera orientation is known accurately, the systems integrating GPS, IMU and DMI will have increased positional accuracy in the event of GPS signal outages. When using GPS only, the heading is determined using the vehicle GPS trace, which can induce noise that degrades the positional accuracy.

Other factors that will affect the positioning accuracy of the solution include the calibration of the internal parameters of the camera(s) in use (focal length, position of principal point, pixel size, pixel spacing, lens distortion, etc.), the calibration of the equipment configuration on the survey vehicle (camera orientation, distances from positioning system), the distance between the camera and the objects that are being measured or positioned, as well as the synchronization capabilities of the acquisition system relative to image and geographic position data capture. Cameras with small pixel spacing, pixel synchronization unit and built in A/D converter allow for obtaining more accurate image coordinate measurements. The use of large sensor cameras will improve the overall system accuracy and permit flexibility on the configuration of imaging parameters. Repeatable positioning accuracy levels in the range of 15cm to 2-3 meters have been observed with different system configurations.

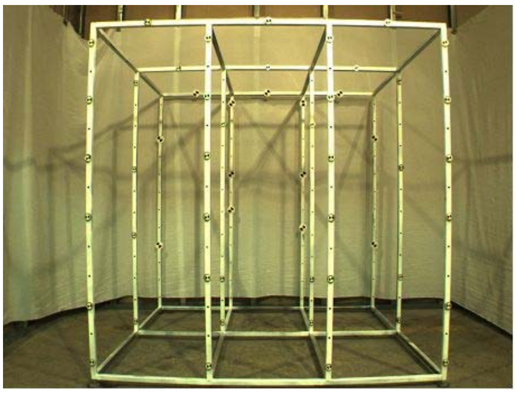

Figure 11: Cube Before Calibration

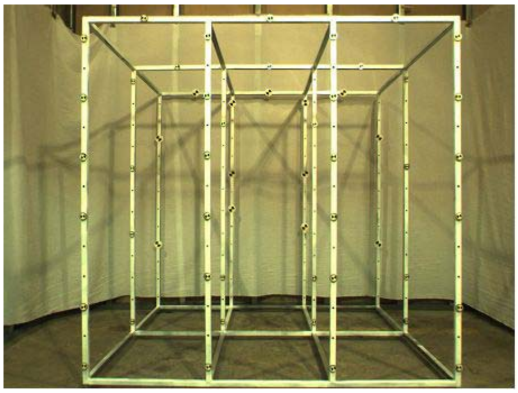

Figure 12: Cube After Calibration

9. COMPARISON BETWEEN MOBILE MAPPING AND GPS FOOT SURVEYS

The mobile mapping technology (with manual extraction) was compared to traditional GPS foot survey techniques during a project performed on three test sites, in conjunction with a local municipality in Quebec, Canada in 2003. The comparative analysis was performed primarily on the basis of precision, performance and safety.

Precision comparisons showed that the GPS by foot methodology could reach 2cm accuracy levels while the maximum average accuracy attained with the mobile mapping approach was in the 15cm range. The observed error with the mobile mapping system is due, in part, to pixel resolution. With ongoing improvements in sensor technology such as the in recent integration of 2Kx2K pixel resolution, it is believed that the accuracy gap between both approaches will be significantly reduced in the near future. Another important aspect to quantify relates to the additional capabilities gained through the inertially aided real time kinematics (IARTK) integral to the IMU used during the test work. The IARTK allows the system to maintain an RTK fix even if the number of visible GPS satellites drops below five, thereby increasing the RTK fix coverage. Any object visible on the imagery can thus be located precisely with mobile mapping when a fixed solution is available. This is true even if the object is located in a tunnel, in an urban canyon, under a tree canopy or near other obstructions.

Analysis performed on the basis of survey productivity indicates a ratio of 3:1 in favour of the mobile mapping methodology in an urban environment, and a ratio exceeding 5:1 in rural conditions. In fact, it was observed that a road surveyor's walking time between points inventoried was one of the most time consuming efforts incurred during GPS foot survey operations, with performance decreasing as the distance between objects increased. It can only be foreseen that these ratios will be further improved with increased mobile mapping automation.

Issues associated to the safety of road surveyors are significant. It would be impossible to perform foot surveys in some locations without blocking traffic. This translates into greater time and resource requirements (human resources and extra vehicles) to undertake survey tasks in a safe manner while minimizing risks of accidents. Comparatively, the mobile mapping approach does not require the installation of specific security signage or the allocation of special resources other than those required for the safety of on-board vehicle operators during survey operations.

Figure 13: A Safe Solution

Another case study was performed with the Quebec Ministry of Transportation that was focused on the inventory of road signs, guardrails, lampposts, and lane numbers. It was estimated that cost savings between 30% and 100% could be observed with the mobile mapping methodology as compared to the GPS foot survey approach along with timesavings in the 50% range. In summary, GPS foot surveys offer greater positioning accuracy compared to that of mobile mapping. However, in cases where centimeter accuracy is not required and where high inventory volumes are projected, the mobile mapping solution is a safer, more productive and less expensive alternative.

10. CONCLUSION

Mobile mapping systems such as Trident-3D, are being ever increasingly used to collect roadside GIS data in the fields of transportation, civil and municipal engineering, as well as real estate developments, property valuation, taxation and insurance. The Trident-3D Solution has evolved over the past years to adapt to market requirements. Railway asset inventory and inspection projects have been performed with equipment installed on rail vehicles. Surveys have been completed in the electrical distribution and telecommunication industries. Trident-3D data can also be used jointly with aerial remote sensing technologies and/or other types of data to complement project information. Moreover, given the georeferenced nature of the resulting imagery, it is possible to perform a comparative analysis to assess changes over time through a software image comparison feature.

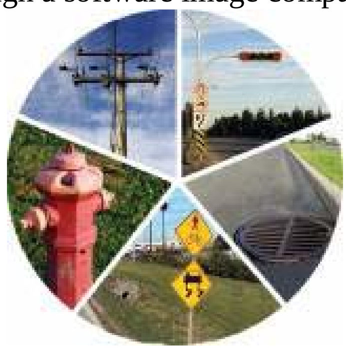

Figure 14: Multitude of Applications for Mobile Mapping

Technological benefits of a system such as Trident-3D include the overall flexibility of the open architecture system, a greater flexibility on GIS data entry, data model customization capabilities, the availability of videolog archives and field images for future referencing, the possible resale of multi-purpose imagery for different applications, and the possibility of performing data extraction based on organizational priorities as well as timing and resource constraints. With the advent of automated asset extraction, mobile mapping is moving into the future. Laser scanning devices, such as the one integrated in the Trident-3D solution, have the ability to exponentially decrease the time spent on, and expenditure for, a project. This technology, while still in the development stage, has the potential to revolutionize the way surveys are performed to inventory roadside infrastructure assets and features. Altogether, mobile mapping systems represent an efficient and inexpensive integrated approach for infrastructure management.

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BIOGRAPHICAL NOTES

C. Laflamme has been the Research & Development Director at Géo-3D Inc. since 1997. He is in charge of the development of the Cyclop-3D and Trident-3D solutions that integrate digital imagery, laser and positioning systems and photogrammetry to geoposition visible objects. Mr. Laflamme holds a B.Sc. in Computer Science from McGill University.

R. McCuaig is the Vice-President of Business Development at Géo-3D Inc. He is a professional surveyor and engineer with nearly 35 years of experience in consulting and business development. He specializes in the broad field of Geomatics, which includes Land Surveying, Survey Engineering, GIS, information technology and inertial navigation systems. Mr. McCuaig holds an M.A.Sc. in Civil Engineering from the University of Toronto.

T. Kingston is a Sales Support & Marketing Representative at Géo-3D Inc. She has extensive experience with various data collection methodologies and technologies used for pavement profiling and asset management inventory in North America. Miss Kingston holds a H.B.A. in English Literature from Lakehead University.

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