AN INTEGRATED MOBILE MAPPING SYSTEM FOR DATA ACQUISITION AND AUTOMATED ASSET EXTRACTION

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Commission V

KEY WORDS: Mobile mapping, Sensor Integration, Videography, Asset Extraction

ABSTRACT:

In recent years, public and private organizations worldwide are facing a continuously increasing demand to build and maintain the asset inventory of their infrastructure network. This is due to standing legislature or is associated with operations relative to maintenance, procurement, traffic, valuation or safety and emergency response issues. In response to this urgency, today's technology allows the integration of various sensors that enable efficient products for mobile mapping solutions. Geo-3D is a leading provider of geomatics and GIS data acquisition hardware and software solutions, who works closely with clients and academia to optimize products and solutions. The Trident-3D solution is a georeferenced land videography system that utilizes the latest generation of positioning sensors (GPS, INS, DMI), high-resolution digital cameras, laser scanners and photogrammetry to create an advanced tool for large-scale data collection and asset management. The most recent developments of the system are automated road sign detection and transverse slope determination. Future developments will include pavement markings in the automated process. In this paper, Trident-3D technology and its advanced features are presented and discussed in the frame of collaboration with the National Technical University of Athens (NTUA), Greece.

1. INTRODUCTION

A road database consists of a dynamic inventory of geo-referenced assets and their attributes, as well as road geometry features such as centerline mapping and road profile information. Most of this information can be collected using different surveying techniques. In recent years, the accuracy requirements and the amount of information necessary to build and maintain a road inventory have increased drastically. This has caused manual field measurement techniques and traditional processing methods to give way to radically new solutions. Mobile mapping systems represent an advanced technique for the dynamic inventory of road networks and all of their surrounding features. These systems integrate advanced navigation sensors, digital imagery equipment, and powerful processors to create digital maps that include both the road's geometry and roadside assets.

Trident-3D is a georeferenced digital image capture and extraction system, designed and developed by Geo-3D Inc. for the purpose of performing the inventory of road infrastructure assets and their geometry. The system relies on state of the art digital imagery coupled with advanced positioning systems and photogrammetric algorithms [Laflamme et al, 2004]. A key element that differentiates Trident-3D technology from similar systems is centered upon its ability to produce generic and scalable solutions, which are based on an open architecture [Laflamme et al, 2006]. As Trident-3D is not tied to any specific brand of camera, positioning system, etc., the users have the ability to customize the system to meet their needs and budget. Likewise, a variety of sensors can be integrated into the Trident-3D solution, from pavement analysis applications to laser scanners. This provides even more flexibility to the user, while giving Geo-3D the opportunity to collaborate with vendors and academic institutions in order to design and assemble its systems to best meet market needs. Furthermore, Trident-3D end products are suitably customizable and can be exported for use with third party software modules. An example of this is the exportation of vehicle navigation data for generating a centerline geometry database.

2. DATA ACQUISITION SYSTEM

2.1 Hardware Components

Trident-3D can integrate most types of positioning systems that are commercially available; however, for projects that exact stringent positional accuracy, the POS LV from Applanix is the proposed solution [Scherzinger, 2003]. The POS LV navigation system consists of a single and dual frequency GPS receiver, an antenna mounted on a specific location on the roof of the survey vehicle, an Inertial Measurement Unit (IMU) and a precise Distance Measuring Instrument (DMI). The IMU is comprised of three accelerometers and three gyroscopes. The data from the GPS receiver and the IMU is passed through an advanced Kalman Filter algorithm to determine the optimum blended navigation solution according to the processing scheme shown in Figure 1. By filtering the GPS data with the IMU data, it provides a more robust solution to noise from multipath and GPS shadows. In this regard, the total loss of GPS signal, or even small degradation in signal, will not impede the collection of continuous positioning trace. The DMI is also

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used by Trident-3D technologies for triggering the image captures at fixed distance intervals.

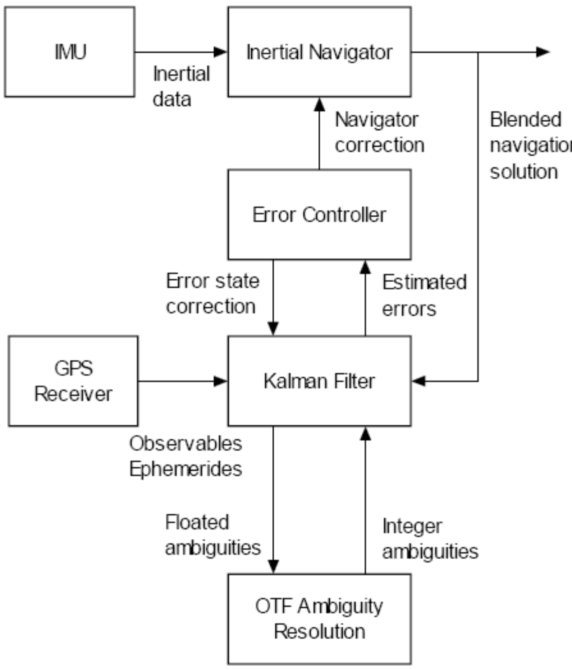

Figure 1. Vehicle navigation processing scheme (Scherzinger 2003)

Typically, images are generated with one, or multiple, digital (CCD) cameras offering a variety of pixel resolutions: from the common 1280x960 to 2048x2048 and more. The image's high resolution allows the images to be zoomed in on to view specific details. A multispectral camera has also been integrated. The data acquisition system makes it possible for the user to maintain the visual quality of the imagery through built-in camera and image controls, such as camera shutter speed, and white balance.

Depending on specific project requirements, the data acquisition system can integrate one or multiple 2D laser scanners. Observations made on distance, angle and intensity parameters can be used to generate a dense grid of 3D points. As detailed in Section 4, this offers a significant potential for automation in a number of data extraction processes. Furthermore, it is possible to couple Trident-3D technology with other types of sensors, such as pavement profilers.

2.2 System Architecture

The data acquisition system is based on a client-server architecture used with multiple sensors (cameras, laser ranging, etc.). The server triggers all cameras from the same signal source, ensuring images acquisition is synchronized. The GPS receiver is connected to the server, which computes GPS time tags for the triggered digital frame and sends this information to all connected clients. The clients are responsible for controlling the cameras, laser scanners and other sensors and displaying data for quality control.

2.3 Data Synchronization

Data synchronization is based on the use of the Pulse per Second (PPS) generated by the GPS unit. This synchronizes triggered images and laser-scanning shots to within 0.1 ms, due to the 10µs resolution of the laser's clock. Moreover, an electronic interface is used to dispatch trigger signals coming from the server to all installed cameras. This ensures signal quality, noise reduction and proper camera synchronization. Thus, each image is then tagged with the appropriate GPS position.

2.4 Camera Calibration

2.4.1 Interior camera calibration: Machine vision cameras do not usually generate imagery on which precise measurements can be made. Therefore, a calibration must be performed to determine the internal parameters of the camera. These include the focal length, the position of the principal point, the pixel size and spacing, and the radial and tangential lens distortion. A calibration cube with known target and camera locations is used for the calibration. As shown in Figure 2, a series of images of the cube are taken for each known camera location. Once image acquisition is complete, observations are made on the images to determine coordinates (x, y) of all visible targets. Finally, all observations and known information are gathered into a data input file. This file is processed using camera self-calibration software that is based on a bundle adjustment algorithm. The following generic observation model forms the mathematical basis for interior camera calibration [Slama, 1980]:

$$x - x_0 = -f\,\frac{r_{11}(X - X_0) + r_{12}(Y - Y_0) + r_{13}(Z - Z_0)}{r_{31}(X - X_0) + r_{32}(Y - Y_0) + r_{33}(Z - Z_0)}$$

$$y - y_0 = -f\,\frac{r_{21}(X - X_0) + r_{22}(Y - Y_0) + r_{23}(Z - Z_0)}{r_{31}(X - X_0) + r_{32}(Y - Y_0) + r_{33}(Z - Z_0)} \quad (1)$$

where f= focal length
x, y= object coordinates in image coordinate system
X, Y, Z= object coordinates in ground coordinate system
x_0, y_0= image coordinates of the principal point
X_0, Y_0, Z_0= coordinates of projection centre
r_{ij}= transformation matrix coefficients, i,j= 1, …,3

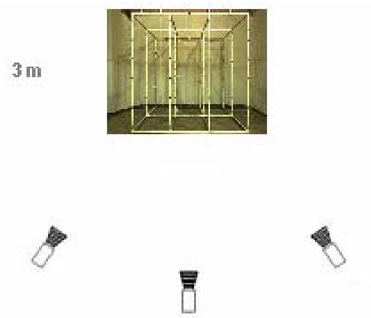

Figure 2. Interior camera calibration

This application outputs the necessary interior camera parameters that will allow optimal accuracy observations on the full image surface.

2.4.2 Exterior parameter calibration: The second calibration step focuses on the exterior parameters, the results of which are used to refine installation parameters on the vehicle. These parameters include the orientation of the camera, as well as offsets from the positioning system (typically GPS antenna, IMU) or some other fixed point to the camera, known as the reference point or origin. A set of known target points is also required. Target points are defined using conventional surveying methods or a dual frequency GPS receiver with post-processing. Observations are made on the images to determine image coordinates (x, y) of all visible targets. Finally, all observations and known information are gathered into a data input file, which is processed using an in-house camera calibration tool (Figure 4). The software outputs the necessary exterior camera parameters, allowing for optimal accuracy measurements of ground point coordinates.

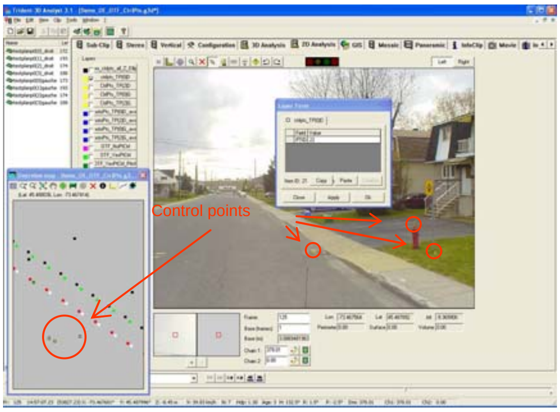

Figure 4. On The Fly (OTF) software calibration tool

3. FEATURE EXTRACTION

3.1 Manual Feature Extraction

The Trident-3D Analyst software is used to analyze and interpret the data and imagery collected by the survey vehicle. The application's user interface features the ability to position any object visible on the imagery and to measure objects in three dimensions. For this purpose, a suite of stereo photogrammetric algorithms is used to locate objects that appear on a conjugate pair of images. Notably, the greatest asset of the proposed method is that only one camera is required to position objects. The paradigm is to obtain a stereoscopic view using two cameras. A fixed stereobase is required to when there are two points of view of the same object. In contrast, the proposed methodology enables the second point of view to be generated by the same camera. In this case, the stereobase results from subsequent camera locations associated with subsequent vehicle positions. This concept is depicted in Figure 5.

The stereoscopic base can be increased or decreased to optimize the triangulation by modifying the lag between two retained images. It is thereby possible to perform measurement and positioning operations in three dimensions for objects that are located both close to and far from the survey vehicle without losing accuracy. Furthermore, a number of features and plug-ins are available with Trident-3D Analyst. These include tools for image extraction at regular intervals, use of vocal annotations, ODBC connectivity and GIS layer relations linking data layers to one another and thus, allowing better data encapsulation.

Figure 5. Stereoscopy using dual (left) and single (right) camera

3.2 Road Geometry Extraction

As stated previously, the processed data produced by Trident-3D software can be used in a diverse variety of applications. In this regard, it is proposed that laser-scanning data combined with vehicle navigation data can be used to extract centerline geometry in the form of design alignment elements (straight lines, circle arcs and clothoids). For this purpose, two-way spatial data needs to be collected in opposite directions and combined to generate centerline locations. The algorithm adopted for the geometric modeling of road axis relies on the combined use of the bearing diagram and the horizontal alignment, or planar drawing of the road axis [Gikas and Daskalakis, 2005].

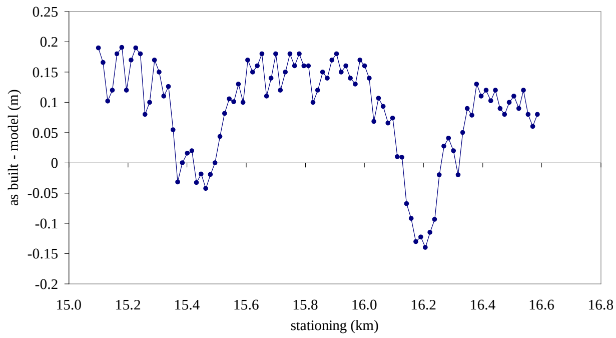

Figure 6. Road axis geometry: as-built minus model

In effect, the prime use of the bearing diagram is to identify the type and location of the start and end points of adjacent geometric elements; whereas the horizontal alignment plot is used for computing the values of the design parameters, such as the circle radius and the clothoid parameter. For this purpose, an iterative regression algorithm is used that is based on the generalized least squares method. Figure 6 shows comparative results for a 1.5 km long road segment consisting of two lanes in each direction. More specifically, it shows that the deviations (perpendicular distances) derived between the as-built plans and the geometric modeling software are considerably small; less than 0.2 m and the mean error is even smaller.

3.3 Automated Feature Extraction

In the past, most research and development in the mobile mapping industry has concentrated on the accuracy and reliability of image georeferencing. As the technology is becoming more widespread in its use, and the industry expands, this concentration is shifting to efficiency and cost effectiveness. Mobile mapping systems are designed with many features to make data analysis and extraction a simple and efficient process; however, manual extraction inescapably requires a high level of user manipulation and input. To address market demands for effective and economical systems, Geo-3D has focused on automated solutions using laser technology.

Figure 7. Two laser configurations for automation

During data acquisition, a two-dimensional laser scanner is mounted on the survey vehicle (Figure 7). As the vehicle progresses down the road, a beam of light is emitted and reflected back to the laser once it has come into contact with objects. This data provides a multitude of information that can be used for detection, geographic positioning, measurements and recognition.

4. APPLICATIONS FOR AUTOMATION

4.1 Road Sign Detection and Recognition

Automated road sign detection is achieved through the use of a plurality of customisable filters in the Trident-3D Analyst software, which distinguish signs from their surrounding environment. Once this has been accomplished, geographic coordinates are assigned to the sign's position, and height and width measurements made. The laser also has the ability to measure reflectivity, an extremely important characteristic of sign visibility.

Figure 8. Road Sign Recognition software

Road sign recognition occurs when an asset that has been located, either manually or automatically, is matched to a template of images from a database. This is a semi-automatic process that utilizes sign libraries, such as the Manual on Uniform Traffic Control Devices (MUTCD) from the U.S.A. As this technology is semi-automatic, it gives the user the opportunity to perform quality control and assurance, while greatly reducing the time required to identify a sign (Figure 8).

A pilot project was conducted in Québec, Canada to evaluate the precision, timing, detection and accuracy rates of the automated technology versus manual asset extraction. A 37.9 km section of road was initially used, where 416 signs were detected, geographically positioned and measured for height and width in just 90 seconds using the Automated Road Sign Detection tool. Of the 416 signs, a subset of 181 signs was used to determine the precision, detection rates and the actual time to make the measurements. Verification of the sign, its position, measurements and the assignment of signcodes took 45 minutes for the 181 signs in the subset. As Figure 9 displays, Geo-3D's automated technology uses a fraction of the time that manual extraction requires, while still maintaining high levels of accuracy and precision.

COMPARISON CRITERIA	MANUAL	AUTOMATIC
Time to Detect, Locate & Measure	120 sec/sign	15 sec/sign
Detection Rate	100%	99%
False Detection	0%	9%
Location Precision	Sub-Meter	Sub-Meter

Figure 9. Comparison of manual and automated data extraction methods in an urban environment

4.2 Measuring Horizontal Cross-Slope

The observations of distance, angle and intensity parameters that are generated by the laser's point cloud can be used to generate a dense and precise grid of three-dimensional points. Geo-3D has developed a software tool that can automatically generate road profiles (cross sections), using this grid. As illustrated in Figure 10, the road profiles can be produced at a defined frequency.

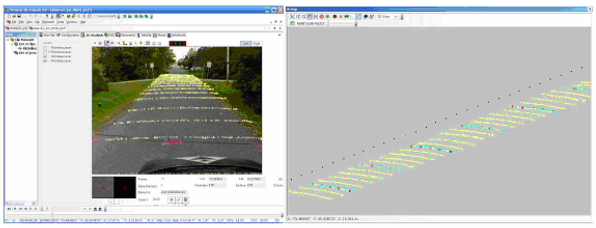

Figure 10. Road profile at frequency of 2 meters

Once the profile has been automatically generated, it is possible to extract strategically located points in order to calculate slopes, one between each pair of points. This allows the road profile and slopes to be saved in two different data layers that may then be imported to, and exported from, Trident-3D Analyst software.

This software tool is still in the prototype phase; however, the results obtained thus far are very promising. The automated method was compared to a traditional method using a four-foot level over a distance of 100 meters, with individual sections being measured at intervals of 10 meters. The results obtained are comparable and similar. The average percentage of difference between the slope measurements taken with the laser versus the traditional method using a four-foot level was found to be –0.07 for the edge of the left lane and 0.09 at the centre of the lane. The right lane had an average difference of –0.44 at the centre of the lane and –0.81 at the edge. The standard deviation ranged between 0.81% and 1.45%. The large number of points produced by the laser solution and the possibility of generating profiles at a higher frequency illustrate the efficiency, accuracy and the significant potential of this solution.

4.4 Other Applications for Automation

Innumerable possibilities exist for applications of automated technology. The tools that have already been developed lend themselves to a variety of uses; such as the Horizontal Cross Slope solution can also be used for shoulder and ditch profiling. Other possible applications include curb height measurement and pavement marking detection. The laser can also be used to calculate the vertical clearance of the road; assets such as overhead wires can be clearly identified in the laser's point cloud, as shown in Figure 11. Lasers with higher accuracy levels would allow for detection of even more specific features of the road and the assets found alongside it.

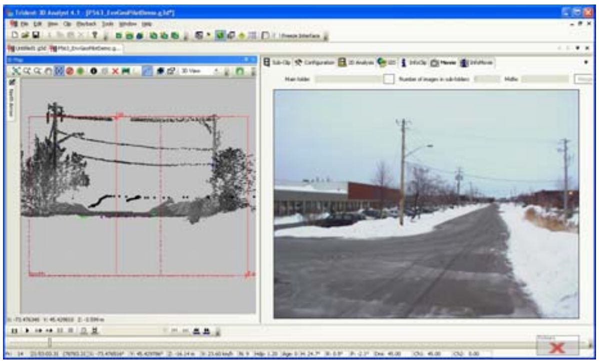

Figure 11. Laser point cloud (left) and image (right) showing overhead wires using Trident-3D Analyst

5. CONCLUDING REMARKS

Mobile mapping systems present an exciting alternative to traditional methods for the collection, analysis and extraction of roadside inventory data for a variety of applications. Systems such as Trident-3D are being increasingly used in the fields of transportation, municipal and civil engineering, utilities such as electrical distribution and telecommunications, and for public works. Furthermore, multiple departments in a single organization have the ability to use the same georeferenced imagery for their specific needs. The integration of lasers and automated technologies exponentially decreases the time and economic resources necessary for an infrastructure inventory. This technology presents the opportunity to use mobile mapping for the data collection of elements that have previously only been collected using traditional methods, such as overhead clearance. Advances such as these demonstrate that mobile mapping is the road to the future for infrastructure inventory and maintenance.

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