DESIGN AND APPLICATION OF THE GPSVISION MOBILE MAPPING SYSTEM

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ABSTRACT:

The continuous improvement and application of computer technology is rapidly changing the way the people manage their environments. With the sophisticated software in use, data acquisition is becoming the most expensive part of establishing a road network database. For this challenge, the mobile mapping technology is developed to quickly and accurately collect roadway infrastructures. One of these systems is the GPSVision system which integrates the Global Positioning System (GPS), an Inertial Navigation System (INS) and digital cameras into a moving platform. The GPSVision system captures the images of road environment at the normal driving speed. The position and orientation of each image are known from the GPS and INS. Based on the photogrammetric triangulation method, the location and attributes of any visible object can be determined from images.

Single point features such as signs and signals, line features such as street marking and guard rails, polyline features such as road edges and centerlines as well as area features can be identified, positioned, tagged with attributes and delivered in standard CAD and GIS formats. A typical user can accurately measure and inspect the infrastructures from images, can simulate the view as one drives down the road and can create complete vector map from images. The GPSVision data is also used together with aerial images to create complete vector map with detailed view both from the air and on the ground.

This paper will discuss the basic issues of a mobile mapping system. A brief description of the system configuration is given, followed by data processing procedure. Variety mapping projects are presented to demonstrate the application of the mobile mapping technology in transportation and telecommunication market.

1. INTRODUCTION

Establishing and manage the civil infrastructure is an immense task. It requires efficiently collecting vast quantities of data. New technologies offer opportunities to greatly improve our effectiveness. One of the most innovative technologies for collecting civil infrastructure data is the GPSVision -- a Mobile Mapping System developed by Lambda Tech International, Inc. It was original designed to help governments and other agencies to build interactive GIS databases, and now it becomes a standard mapping tool for roadway construction and sign inventory, it is even used for roadway traffic accident analysis in the court.

The mobile mapping system acquires highly detailed, multimedia data about highways, railroads and other transportation networks. It differs itself with traditional mapping method mainly by its fast data collection speed and its low cost, for example, one GPSVision mobile mapping system collect more than 3000km road data monthly.

The position and orientation parameter of the mobile mapping system are determined by GPS and inertial navigation system. Depending on the type of the GPS receiver and the processing software used, positioning accuracy can range from meters to centimeter. Because obstructions such bridges, trees, tunnels or high rise buildings can interrupt satellite signals, GPS alone can not meet the requirement for a mobile mapping system. An INS consists of the accelerometer and gyroscopes. It is a self contained system. It measures the velocity and direction changes very accurately for short periods, but its error grows rapidly with time. An integration solution of GPS and INS can greatly improve the system performance. GPS is used to update the INS system and the INS outputs the accurate position, velocity and attitude of the system between the GPS updates.

From photogrammetric perspective, the mobile mapping system captures massive overlapped images with known position and orientation parameters. After system calibration, any visible feature from overlapped images can be precisely located in a global coordinate system.

The GPSVision is an ideal platform for cost-efficient multimedia collection. A typical client can accurately measure and inspect the infrastructures from images and simulate the view as one drives down the road. The GPSVision images are used to create complete vector maps for road network. It is widely used for sign inventory and roadway construction by transportation department. In telecommunication industry, it is used as rapid and detailed base maps for the construction and maintenance. The GPSVision data is also used together with aerial images to create complete vector map with detailed view both from the air and from the ground.

2. GPSVISION DATA COLLECTION SYSTEM

The hardware component of the GPSVision mobile mapping system consists of three major components: a dual frequency GPS receiver, an inertial navigation system and high resolution multiple digital cameras.

The GPSVision is a very flexible system and many different types of GPS receivers or cameras are used depending on the application requirement. Another feature of the GPSVision is its independence with the moving platform. It is portable and can be mounted on different vehicles. Fig. 1 shows the GPSVision syetm with GPS receiver, four digital cameras, and the INS system which is under the GPS receiver.

Figure 1. Portable GPSVision system consists of GPS, INS and four digital cameras

A PC-computer provides the overall control, storage, display and operator interaction during the data acquisition. It is constructed on a passive back plane chassis and mounted in a rugged industrial chassis with a single board CPU. The single board CPU executes a standard multi-tasking operating system. The back plane also has an INS interface consisting of a SDCC digital interface, Built-In-Test (BIT) board, and a timing interface board. In addition to the boards, the chassis will also contain a solid state or standard storage device and a boot device.

The Built-In-Test Diagnostic System provides hardware status of all sub-systems to the operator and warns of pending maintenance action or failure. The BIT consists of a digital I/0, a digital to analog converter and an analog to digital converter board for monitoring each subsystem.

The GPS unit provides the system computer with GPS timing, satellite data and satellite status information. The solid state INS provides changes in direction and speed data. The GPS time is unique and all collected data are correlated on the GPS time. Data are stored in a binary format and used in post-processing software.

The vision system consists of two to four high resolution CCD cameras, digital frame buffers and removable hard disks for image storage. The cameras are progressive scan CCD units with auto IRIS wide angle lenses. The image capture frequency is user definable by distance or time. For example, a stereo pair of images can be captured at an interval of 16 meters.

3. GPSVISION DATA PROCESSING

The GPSVision data processing consist of two steps: determining the position and rotation of image and positioning an object from stereo image pair. The first step is achieved by combining GPS and INS and the second step determines three-dimensional coordinate of an object by a photogrammetric triangulation and transfers it into the global coordinate system.

3.1 GPS Positioning

Depending on the GPS receiver, the positioning accuracy varies. In the first generation of the GPSVision system, the code-phase sub-meter receiver is used. The CA pseudoranges are used for differential positioning. In the second generation of the GPSVision system, the dual frequency GPS receiver is used to obtain up to 10cm level positioning accuracy.

Due to the inherent integer ambiguities, the carrier phase measurements lack the geometric strength required for high accuracy positioning. It is necessary to determine the exact integer ambiguities. One method is to used the wide lane technology [Hofmann-Wellenhof 1993, Dedes 1995]. With the known integer ambiguities, the carrier phase data are then conversed to wide lane pseudo-ranges data and are used to calculate the high accurate position.

The dynamic positioning with the wide lane pseudoranges is performed with two passes through the data. In the first pass, the wide lane ambiguities are estimated between each cycle slips. In the second pass, ambiguities are fixed and then used to perform high accuracy positioning.

3.2 GPS/INS Integration

The integration of GPS/INS can be performed at different levels and using different methods. GPSVision technology benefits from the Kalman filter method [Gelb, 1974, Wei, 1990, Lapucha, 1990] which consists of a prediction and an update. Fig. 2 shows the procedure of this method. The state vector includes attitude, position, velocity, accelerometer biases and gyrodrifts. The measurement of an inertial system come from two sensor triads, an accelerometers block and a gyro block. They are defined as three components of the specific force vector and three component of the body rotation rate.

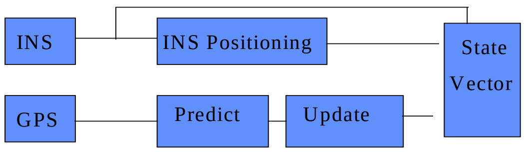

Figure 2. The GPS/INS integration procedure

After establishing the dynamic model of the system, the prediction estimates the state vector and its covariance matrix of the system. Whenever a measurement is available, the update will use it to calculate more accurate state vector and covariance. This will repeat until all data is processed. In the GPS/INS integration, the data from the INS is very accurate for a short period, so instead of using the Kalman prediction, the INS positioning equation is used as the prediction module. To achieve the most smooth result, the Kalman filter is used in forward and backward.

3.3 Feature Extraction from Stereo Imagery

After the GPS/INS integration, every image pair is georeferenced with three position parameters and three rotation parameters. A three-dimensional coordinate of an object is calculated by a photogrammetric intersection procedure using its left and right image coordinate and then transferred into a global coordinate system.

The feature extraction software was developed to collect features from images. It runs under Microsoft Windows operating system and is external rule based driven and language neutral. The user will interact with the software and point at features of interest in the stereo image pairs. The software then triangulates the relative position of the selected feature and transfers it into the global coordinate system. Fig. 3 illustrates how to locate and measure infrastructure from stereo images.

Figure 3. Stereo images are used to locate and measure roadway infrastructure.

In addition to calculating locations, the software provides the ability to select, control and display images. A map window displays the tracking line of the GPSVision, the location of images and the extracted features. An image pair is displayed by selecting from the map window or by using forward/backward image function. The image can be viewed in the zoom mode and its contrast is easily adjustable. The user selects the active feature and assigns attributes to it. After measuring the left and right image coordinate, the global coordinate or the distance measurement is also displayed.

After the feature extraction is completed, a standard output file is created containing all feature information about the collected data. The re-formatting software process the standardized output files to create input files for a targeted GIS system.

4. APPLICATION OF THE MOBILE MAPPING SYSTEM

4.1 Assets Inventory for Transportation Management

Monitoring and maintaining public transportation network is a enormous task. GPSVision system has been used to collect data for asset management system. Streets are driven with the GPSVision system in both directions to obtain 360 degree coverage of all roads and right-of-ways. Stereo pairs are used to locate all transportation assets. Fig. 4 shows the visible features, such as traffic signs, utility poles, trees, guardrails, etc are mapped for city of Waukesha, Wisconsin.

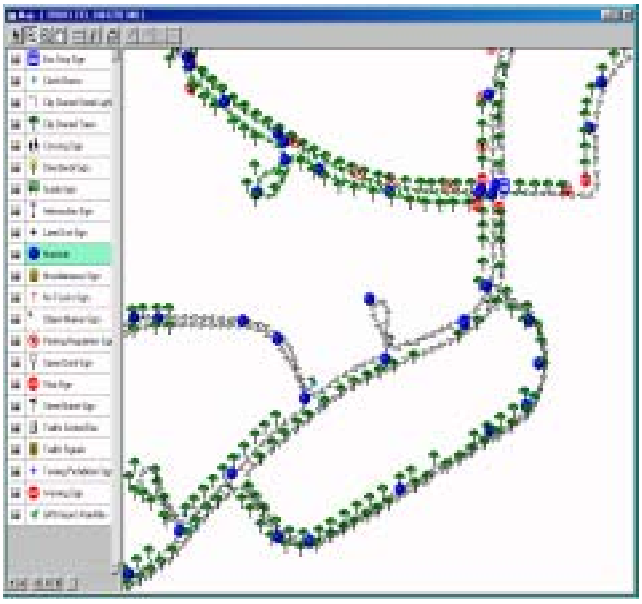

Figure 4. Roadway assets, like traffic signs, poles, guardrails, etc. are extracted from the GPSVision mobile mapping system

After data are processed and loaded into asset management system, the city officials will know where their roadway assets are, and will be able to develop a preventive maintenance plan, and achieve high return on their maintenance investment.

4.2 Creation of the Road Centerline Networks

A fundamental requirement in establishing a GIS is a consistent digital base map. GPSVision system is used to addresses this need by creating sub-meter accuracy road centerline networks that serve as the land base for our customers' GIS. Compared with other mapping method, image data allows users to precisely and efficiently locate the road centerline points.

The GPSvision system was used to map more than 65,000 km road centrelines in the State of Virginia. For the two way street, the GPSVision was drove only in one direction, for divided highway, the system was drove in both direction. The GPSVision system with two cameras pointed in driving direction was used for centerline project. Average data collection rate is about 3000km per month for one GPSVision system. After data is processed, each image has known position and orientation parameter. Using Feature Extraction software in the office, technicians produced data files containing the locations of road centerlines with sub-meter accuracy. To fit into client’s existing data system, base map data was further processed to add the following attributes:

- Linear reference system: Adding distance as attribute and matching it to the existing distance mark.
- Segment road network and attach road name and road segment identification number.
- Links to the digital images

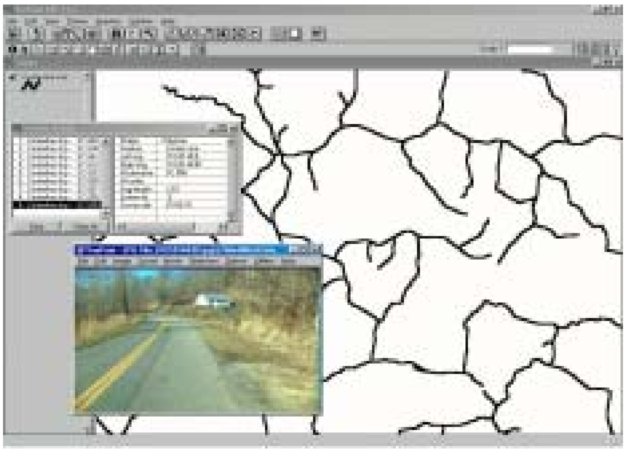

Figure 5. Road centerline with attributes and links to the digital images

The positioning module based on the GPS and inertial navigation system also provides road geometry information. Beside the mapping ability, images are also used to visual observe pavement condition, to visual inspect road infrastructure and to simulate the road environment as one driving down the road.

4.3 Create GIS Base Map for Telecommunication Industry

In recent years, rapid development has been made in telecommunication industry. For construction and maintenance of cable network, accurate land-based maps are necessary. To date, most of these data is created by traditional photogrammetric method or by digitizing existing vector maps. The mobile mapping technology is a new comer. Compare with the aerial photogrammetry, the mobile mapping technology provides more detailed maps with low cost and fast delivery time, while the traditional aerial mapping has advantage by covering wide area.

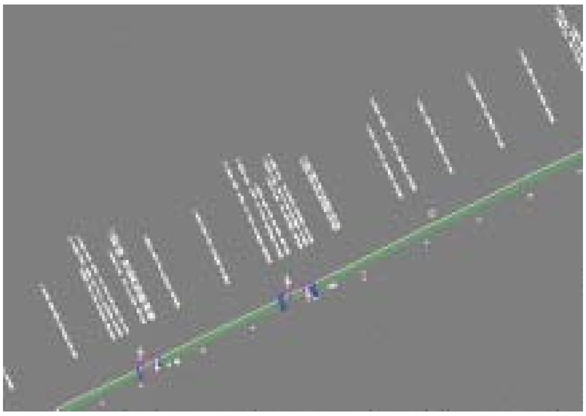

Figure 6. GIS base map for cable network

Lambda Tech was contracted to map 650km cable line along the railroad between Detroit and Chicago, USA. The GPSVision mobile mapping system mounted on a high rail vehicle was used for this project. Data was collected in three and half days. All man made features like railroad signals, road crossing, traffic signals, parallel tracks, utility poles, are extracted from stereo images. Attributes are also tagged to each feature. Detailed electronic maps were delivered to the project engineer five weeks later. Fig. 6 displayed a section of cable network base maps created by the GPSvision mobile mapping system.

4.4 Data Fusion with Aerial Images

To better serve the user's needs, GPSVision data was collected on the ground and digital aerial images were captured in the air. The main objective was to use the GPSVision to measure feature along the railroad and then use them as controls points to rectify digital aerial images. The geo-referenced aerial images are then served as the background images, and also are used to digitize the features far away from roads. Software were developed to measure the control point from terrestrial image and to rectify the aerial image. After rectification, all aerial images are mosaiced and tiled in small image size for easy displaying and handling .

Figure 7. The GPSVision data overlaid on the aerial photography. This provides the view of the infrastructure both from the ground and in the air. It is used for engineering design.

All features extracted from the terrestrial GPSVision images are overlaid on the rectified aerial photography. This enable user not only to have very detailed vector map, but also to view interested features both from the ground and in the air [Fig. 7]. With the digital imagery in hand, engineers and technicians avoided the costly effort of having to drive to the field to inspect a particular road conditions.

5. CONCLUSION

In the last ten years, the mobile mapping technology has grown from the theory to a standard mapping tool. It differs itself with traditional mapping method mainly by its fast data collection speed and its low cost. With more mobile mapping projects successfully completed, the market share of the mobile mapping system will be increased rapidly in the future.

The digital cameras of the GPSVision collect huge amount digital data. Automated feature extraction is very important to the mobile mapping system. How to more efficiently extract the information from images will be the next focus of our new development.

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