FEATURE POSITIONING ACCURACY IN MOBILE MAPPING: RESULTS OBTAINED BY THE GPSVan™

John D. Bossler and Charles K. Toth

Center for Mapping
The Ohio State University
1216 Kinnear Road, Columbus, OH 43212-1154
e-mail: *bossler@cfm.ohio-state.edu*
USA

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ABSTRACT

Technology developed over the past five years at the Center for Mapping at The Ohio State University is being utilized for surveying in a variety of applications. One of the most demanding tasks required of this technology in the past year was to determine the coordinates of features to submeter accuracy along the Burlington Northern Railroad (BNR) right-of-way. Features include adjacent tracks, switches, and other items of interest to BNR.

This paper discusses results obtained in this survey using the Global Positioning System (GPS) combined with dead reckoning (DR) (vector) observations, integrated with an imaging system. The image coordinates of features along the track are transformed to coordinates on the ground (object space). The "internal" accuracy of the photogrammetry is very good and the dominant error of the positions of features near the van is contributed by the GPS/DR system. To obtain the final system accuracy we compared the photogrammetrically derived coordinates of the features with ground truth acquired by using static GPS observations.

1. INTRODUCTION

The Center for Mapping at The Ohio State University (OSU) pioneered Mobile Mapping technology, realizing that GISs require current, high quality spatial data for enhanced decision-making. The focus of this paper is to prove the assertion that the GPSVan™ technology can obtain extremely high quality data in an effective manner.

Mobile Mapping Systems (MMS) can be defined as moving platforms upon which multiple sensor/measurement systems have been integrated to provide near-continuous positioning of both the platform's path in space and other simultaneously collected geo-spatial data. As a result of GPS technology, MMSs have grown in use and popularity over the past five years.[1] The concept of acquiring spatially referenced digital data at normal highway speed from a vehicle is powerful. This feat is possible by integrating GPS, DR, and imaging data to make a *system* that is as accurate as necessary for almost any application. New and exciting applications for MMS are rapidly emerging (Novak and Bossler, 1995). To discuss each one is impossible. However, two key applications that are briefly described are: E-911 and Facilities Management.

E-911

There is a need to locate houses, driveways, phone booths, fire hydrants, and other objects that will help emergency personnel (and their vehicles) as they come to the aid of callers. There are several competing data acquisition systems, but a survey with a hand-held GPS unit seems to be the most formidable competition to an MMS. However, the hand-held GPS unit cannot compete with the GPSVan™ technology, since one only needs to drive the van past the property to acquire

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[1] A recent two-day symposium in Columbus, Ohio sponsored by the Center for Mapping at The OSU drew 188 attendees.

coordinates on these features, while receiving the additional benefit of colored and geo-referenced digital images of all features of interest. Moreover, in the future, these images will be of enormous value, as emergency vehicles begin to carry computers with screens capable of displaying those images and using the data for emergency purposes. Both the positional data and the image data are compatible with modern GIS.

Facilities Management

It was clear from the outset that the GPSVan™ technology should be very effective for facilities management (FM) purposes. This is true along highways where culverts, signage, bridges, ramps, guardrails, and other features are considered important to highway engineers. It is especially true along railroads, where the vast majority of features of interest are within 100 feet or so of the track. The GPSVan™ technology has proven to be efficient in capturing digital data and mapping the right-of-way. This paper focuses on the accuracy obtained in this application environment.

Figure 1. GPSVan™

2. THE GPSVAN™ SYSTEM

The concept of the system is very simple: combine GPS and dead-reckoning-based positioning systems with electronic image acquisition (Toth, 1995). The GPSVan™ is an ideal tool for corridor mapping, such as surveys along transportation lines where time and/or access is restricted. Instead of the labor-intensive individual surveying of objects, images are collected along the whole corridor and the actual measurements are performed in a post-processing center, using simple image processing tools (He *et al.*, 1994a,b). During data acquisition, the captured images are time-stamped by GPS time; thus, by reconstructing the vehicle's motion, the camera orientation parameters can be computed. The GPSVan™ technology itself defines only the concept; the actual hardware implementations depend very much on the specifics of the individual applications.

Figures 1 and 2 show the GPSVan™ and the functional block diagram of the most recent systems built and used in normal production.

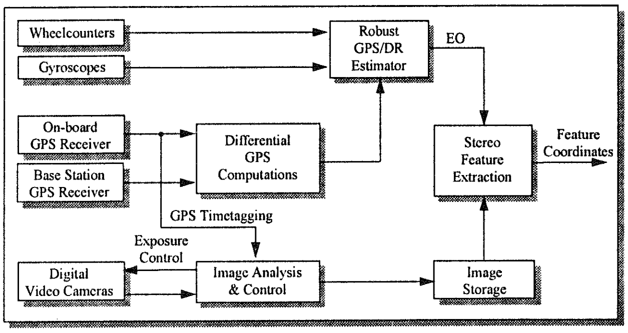

Figure 2. GPSVan™ technology

Unlike traditional aerial mapping, control points in the GPSVan™ images are rarely available, and therefore, they cannot be used in image measurements to establish the exterior orientation. The camera orientation is provided by the positioning component of the MMS, which includes GPS with DR or inertial navigation (INS) systems. In the simplest model, the absolute positioning error of object space points using stereo imagery is comprised of two factors. The first group represents the error of the six exterior orientation parameters, e_{EO}, basically the longitude, latitude, and height or the three Cartesian coordinates of the camera projection center, along with the three attitude angles:

$$\begin{aligned} e_{Absolute} &= f(e_{EO}, e_{IS}) \\ e_{EO} &= f(e_{XYZ}, e_{Attitude}). \end{aligned} \qquad (1)$$

The second group, the imaging system, e_{IS}, includes all the errors introduced by photogrammetric processing, including terms for errors in the transformation parameters, the operator pointing error, and base/depth ratio:

$$e_{IS} = f(e_{Tr\text{-}par}, e_{Opeator}, e_{Dist}). \qquad (2)$$

The transformation parameters can be further broken down into components:

$$e_{Tr\text{-}par} = f(e_{IO}, e_{RO}, e_{Offset}, e_{Att}). \qquad (3)$$

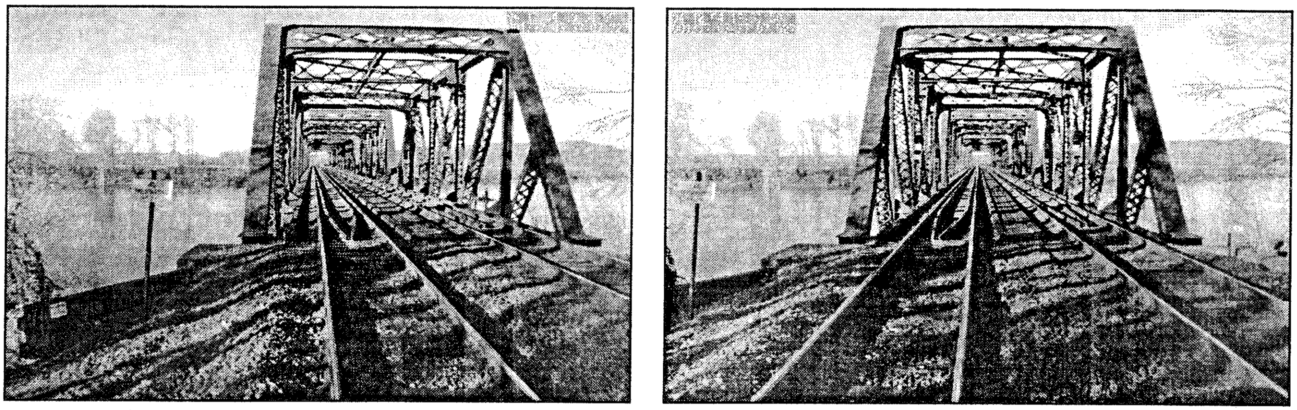

Figure 3. A stereo image pair taken by GRS's GPSVan™ (Courtesy of Burlington Northern)

Estimating the range of the different error terms is quite different for the camera exterior orientation than it is for the imaging system parameters. In the first case, the large variations in the application environment make it rather difficult to estimate error terms in general. Most of the components, such as the positioning data, are field-dependent. The imaging system, however, is quite predictable, and all the terms can be appropriately approximated after performing a calibration procedure.

The accuracy range of the imaging system is determined by the resolution power of the imaging sensor system, the base-length, the calibration procedure, and the depth range of the application. Mobile data acquisition environments almost always require imaging systems based on CCD sensors. The image resolution of the camera used in the BNR project is 768 pixels by 480 pixels, resulting in roughly 1-2 cm nadir pixel size at a 10m object distance. Assuming operator positioning accuracy of half of a pixel, the range for the maximum achievable accuracy is immediately bounded at 5-15cm. For shorter object distances, the 5cm value applies, but for objects farther away, the errors soon become unacceptable, due to the base/depth ratio. The calibration of the imaging system comprises the determination of the interior and relative orientation parameters and the registration of the local camera coordinate system to the vehicle coordinate system, defined by the GPS antenna as an origin and by gyro determined directions as the coordinate axes. It is important to note that since uncalibrated cameras are typically used, the interior orientation should include a sufficient number of parameters to correct for lens distortion. If the calibration procedure is properly executed, errors introduced by the imperfections of parameters and random changes (such as change in the base-length due to temperature fluctuation) can be generally ignored when compared to the positioning errors caused by the relatively large pixel size. Our experiments show that using a 1K by 1K CCD sensor with 1.8m camera base results in positioning accuracies that are better than 3cm for object distances of 5m and 15cm for 25m, respectively (He *et al.,* 1994c).

3. RESULTS

In 1994, General Railroad Signal Corporation (GRS) was awarded a contract by BNR to perform GPS/DR surveying and image processing services. GRS is the general contractor for the BNR engagement and is subcontracting position and image post-processing activities to TransMap Corporation, an Ohio State University spin-off company. BNR's objective is to determine the position of tracks and the coordinates of switches and other wayside features at better than one meter accuracy. A typical stereo-pair from the BNR survey is shown in Figure 3 (Blaho and Toth, 1995).

To date, GRS and TransMap have conducted field surveys and post-processed data for more than 9000km along the BNR network. These numbers represent sufficient statistical data to analyze the achieved accuracy of the GPSVan™ technology in a real production environment. The typical BNR project survey lasts less than two hours and covers 50 km. Usually there are two GPS base stations, and at a minimum, one quality control point (QC) is measured per survey. Based on thirty-five surveys of a 2000km railroad segment, detailed accuracy statistics were computed for major components of the GPSVan™ system.

Figure 4 displays the differences between the GPS/DR positions and GPS positions — in other words, the combined GPS/DR "modeled" trajectory of the van compared to GPS alone — and indicates an average error due to modeling of about 30cm.

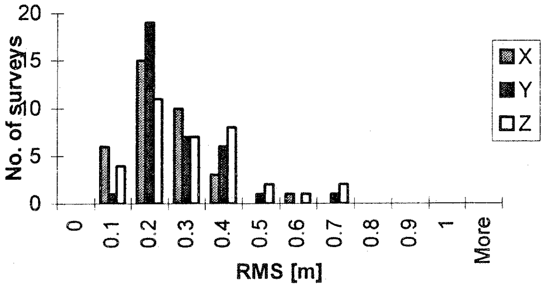

Figure 4. Difference between the GPS and integrated GPS/DR trajectories

Figure 5 displays the differences between the GPSVan™-determined coordinates of QA/QC points along the railroad and the statically measured QC points. By comparing Figures 4 and 5 we see that the photogrammetric feature extraction and post-processing add very little to the overall error budget. The dominant error is from the DR system. While we cannot isolate each error component, indications are that e_{EO} (from the DR system) and $e_{Opeator}$ are by far the largest components of the error budget. Having said that, the 50cm average planimetric results are enormously impressive (Bossler and Toth, 1995).

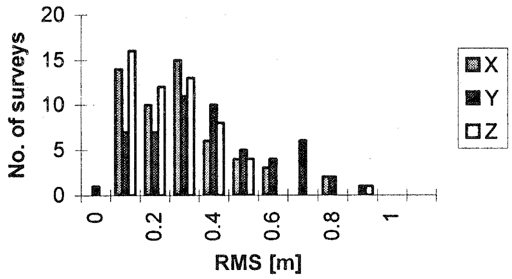

Figure 5. Distribution of differences at QC points

4. CONCLUSION

GPSVan™ technology is being used to collect current, accurate, and complete spatially referenced digital data for railroad right-of-ways. The two-dimensional (horizontal) positional accuracy obtained in the BNR project for well-defined features is approximately 50cm ($\sqrt{\sigma_X^2 + \sigma_Y^2}$), without *any* data editing. Clearly, even more accuracy can be squeezed from the system and that will likely occur. However, we are now at the point where questions such as ``Where on the top of the rail is the coordinate?" are critical in the context of such accuracy. Now our attention should be directed toward *presenting* these data in a more enhanced fashion and toward integrating these data with other datasets. It is also clear that real-time data will be valuable for checking on errors (QA/QC) and for changing surveying strategies in the field. We are very close to being able to do just that, and we expect that this system will be available commercially in 2-3 years.

Mobile Mapping Systems, primarily because of GPS, have revolutionized the mapping sciences. The next steps in multimedia presentation, real-time processing, and integration with other data will also be enormously exciting.

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