GEOMÒBIL: ICC LAND BASED MOBILE MAPPING SYSTEM FOR CARTOGRAPHIC DATA CAPTURE

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Abstract

Since the early developments made in the 90s, LBMMS (Land Based Mobile Mapping Systems) have successfully demonstrated how they can improve the efficiency of GIS and cartographic data capture. The final accuracy and performance of LBMMS depends on direct sensor orientation systems, which are mandatory due to the large amount of raw data that they acquire (digital photographs, laser ranging data and other sensors).

In the last few years ICC has worked on the development of a GEOMÒBIL. Thisis a LBMMS designed and built at the ICC. It is a modular system that allows the direct orientation of any sensor mounted on the roof rack of a van. The main components of the GEOMÒBIL are the orientation subsystem (based on a GPS/IMU orientation system), image subsystem, laser ranging subsystem, synchronization subsystem and the data extraction software.

This paper offers a brief description of the GEOMÒBIL, its subsystems and the data extraction software This software supports data extraction by measuring elements in pairs of stereoscopic digital images. The software is based in Microstation and uses MDL language. The system functionality for image and vector visualization, data digitalization and editing or data storage takes advantage of the basic tools of MicroStation As the same tools are used in data compilation, editing and storage for other topographic databases created at the ICC, data integration can be achieved without any data transformation.

The results in terms of accuracy and precision of several campaigns carried out under different environmental conditions are shown and conclusions are drawn. Finally, the paper provides a brief description of future developments with respect to strategies aimed at improving t trajectory computation and element collection.

INTRODUCTION

The GEOMÒBIL is the multi-sensor land based platform developed at the ICC. It can acquire data from different sensors. Up to now two CCD monochrome digital cameras and a terrestrial laser system, which are operated simultaneously with a direct orientation subsystem and are accurately synchronized to GPS time, have been integrated into the system.

In addition to being a geographic data acquisition system, the GEOMÒBIL is a system for acquiring and georeferencing sensors and a software package for extracting information from acquired data.

Based on a platform able to integrate any sensor and a direct reference subsystem, the GEOMÒBIL system is meant to be a tool capable of acquiring geographic data with cartographic accuracy requirements in a production environment.

GEOMÒBIL SYSTEM

The aim of GEOMÒBIL project is to develop an LB-MMS flexible enough to integrate several sensors for acquiring data of cartographic interest. At the current stage, it integrates the positioning and orientation subsystems, algorithms and sensors required to determine coordinates of observed elements applying photogrammetric techniques. In order to transfer the different reference frames, the system is equipped with a rigid structure where the image/laser sensors, orientation and positioning subsystems are physically installed. To begin with, two digital cameras that form stereoscopic models in the zone of interest are employed. The zone of interest is defined to be at a 10m distance from the vehicle along track and a 10m distance wide across track in order to acquire all the elements in the photographs, such as horizontal and vertical road signs. The integration platform is mounted on a vehicle that equips other auxiliary subsystems for the continuous operation of the system, like air conditioning, electrical power and other subsystems. Operator security and attenuation of the disturbing vibrations present in mobile environments are also included.

GEOMÒBIL subsystems and sensors

The GEOMÒBIL system has been divided into the following modular subsystems:

Orientation; handles the absolute temporal and geometric reference frames. It is responsible for georeferencing the images and other sensor data taken by the GEOMÒBIL. Thus, it provides the coordinates (position) and the angles (attitude) of their projection centers. This subsystem is based on an Applanix system, which is specially designed for land vehicle applications and is integrated in the GEOMÒBIL. This system is basically composed of:

·An IMU (Inertial Measurement Unit), a sensor that provides measurements of accelerations and angular velocities.

·Two sets of GPS antenna-receivers, one of double frequency to provide observations of the position and velocity, and the other one of single frequency to improve the heading angle determination. This system is called GAMS (GPS Azimuth Measurement System).

·A DMI (Distance Measurement Indicator), a sensor directly installed on one of the vehicle's rear wheels which provides information of the distance traveled.

·A POS Computer System, which contains the core of the system, IMU and DMI interfaces, two GPS receivers and a removable PC-card disk drive where data is stored.

·A POSPac, software for processing GPS data and integrating the GPS solution with the observations of the other sensors.

In order to obtain the position and attitude of photographs from the position and angles provided by the orientation subsystem, it is important to fix the relation between all the reference frames of the orientation process. For this reason, the relationship between the IMU, cameras and GPS must be totally stable.

Integration Platform; is a rigid physical base for the transference of the geometric reference frame of all the installed sensors for their operation. This platform must be sufficiently stable for the precise transference of reference frames. Two basic requirements must be considered, namely that the platform must have a maximum physical space at the top of the van, and the geometry of the platform must be totally stable in order to transfer the global reference frame (computed from the GPS/IMU data) to any sensor installed on the platform. This implies high immunity to deformations. The design of the platform was studied and several options were analyzed. This structure is equipped with equidistant anchorage points so that different sensors can be easily distributed. As explained above, the biggest constraint in the design of the platform and the anchorage system for the sensors has been the stability requirements. The maximum deformations tolerated between the reference center of the absolute frame (IMU) and the reference center of the relative frame (Camera) are 1mm in displacement and 70 arc seconds in rotation.

Image Sensors; handle scene configuration, sensor geometry and parameters. The subsystem design has been driven by two main requirements: to acquire images of at least 1Mpix and to get 10m stereoscopic overlap at a 10 m distance from the van (about 100 m2). The selected image size is a compromise between image resolution and data storage and management. The stereo overlap requirement is conditioned by two factors: getting the maximum stereoscopic overlap free of obstacles (between the vehicle and the objects of interest) and preserving a B/D ratio (stereoscopic base – object distance) as good as possible. Table 1 summarizes the image sensor subsystem characteristics.

No. Píxels	1024x1024
Píxel size	12 µm
Focal length	10.2 mm
FOV	62.13º
IFOV	3 min. 38 sec.
Stereoscopic overlap @10 m	10.55 m
Precision@10 m (across-track)	0.8 cm
Precision@10 m (along-track)	5.6 cm

Table 1: technical features of on-board image sensors.

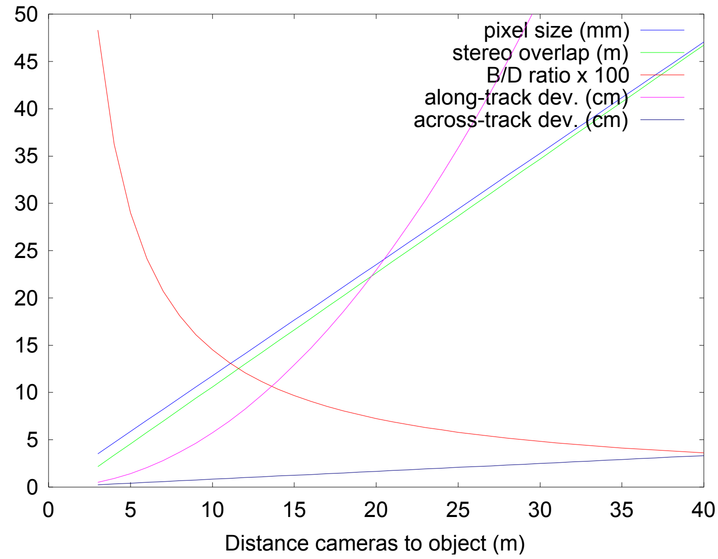

Figure 1: Relationship between distance (units in m) and photogrammetric precision (units in cm) across and along-track (along-track precision strongly depends on B/D ratio), stereo overlap (units in m), pixel size (units in mm) and B/D ratio (B/D ratio times 100).

Image Acquisition; selects photo parameters, generates the trigger pulse and handles data. In order to freeze the stereo scene, both cameras are synchronized at the time of image capture. The photographs are taken by the image acquisition subsystem, which generates a pulse train (trigger) at a frequency depending on the traveled distance or at a given constant frequency.

If the acquisition frequency is configured spatially, the trigger period depends on the distance covered by the van and partially on road turns. This required information is obtained from vehicle speed and heading, continuously provided by the orientation subsystem. A typical spatial period would be 10 meters or a turn higher than 60 degrees, which corresponds to the camera field of view.

The data storage capacity of the system has been evaluated to be higher than 100 Gbytes. Considering that a GEOMÒBIL survey session can last seven hours at 1 Mbyte image size, driving at a 72 Km/h vehicle speed and with a spatial acquisition frequency of 10 meters/image, a minimum storage capacity of 101 Gbytes is needed per session. Hence, the system storage capacity is composed of two removable 73.4 Gbytes disks. If necessary, the disks can be exchanged to increase the storage capacity. According to the current hardware configuration and to the data recording rate of disks, a maximum of four pairs of images per second can be taken by the system. This number is enough to cover the requirements of the system, and can be easily enhanced by using larger and faster disks as soon as they are available.

Lidar Sensor; handles Lidar scene configurtation. The laser selected for the integration was a Riegl Z-210 that is able to collect up to 10000 points per second. For each point a distance measurement, an intensity value and RGB data is collected. The laser has a rotating mirror that allows taking vertical profiles while a servomotor rotates horizontally the whole laser for scanning a static scene (see figure 2). For each laser point also the angle readings of the mirror and the scan encoders are obtained. These angular values, together with the distance measurement, are used to locate the measured point in a local laser reference frame. The raw data collected by a terrestrial laser are usually parameterized in a spherical coordinates frame, denoting r the distance measured by the laser, ϕ the rotation angle of the mirror and φ the laser position angle during the scanning (see figure 2). Range can take values up to 300 meters, ϕ the rotation has a view of 80º and φ scanning rang is ± 166.5º.

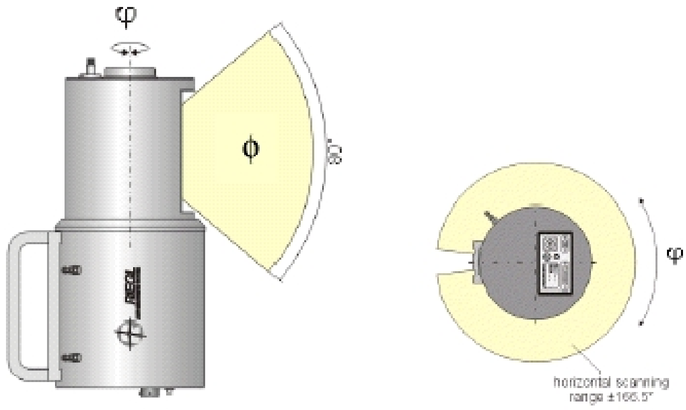

Figure 2: Terrestrial laser spherical coordinate frame (courtesy of Riegl LMS GmbH)

Lidar Acquisition; selects Lidar parameters, generates synchronization data and download Lidar measurements. Lidar set up parameters and pose on the integration platform depends on the features of the project. The laser labels the beginning of each line with a precise internal clock. The synchronization is performed by relating the laser time system to the GPS time system. The laser internal clock can be reset by external TTL signal. By using this possibility a modified PPS signal is pseudo-randomly sent to the laser. After the survey, at the office, a software synchronizes the laser internal time system to a global GPS time system by comparing the pseudo-randomly resets of the laser internal clock to the previously stored time at which the TTL signals were generated. Knowing the GPS time at the start of each line, the GPS time of every laser point is computed by adding the laser repetition period to the time of the previous laser point.

Synchronisation; The synchronization subsystem aims to synchronize in a common temporal reference (GPS time) all the sensors integrated in the GEOMÒBIL (GPS/IMU/Image sensors/laser). This subsystem integrates a timeboard and handles different synchronism signals: PPS, Trigger and Resync.

The timeboard is a device that allows timetagging of received TTL signals with 20 ns resolution. Thus, all the received signals are precisely referenced to the temporal reference system defined by the timeboard. However, the requirement is to synchronize the sensors in a global temporal reference (GPS time). Therefore, the synchronization subsystem process is divided into two steps, namely initialization and data synchronization.

The goal of the initialization process is to establish the difference between GPS time and timeboard start time, which is defined as the instant when the timeboard resets its internal time to zero and starts working. In this initialization step, T_0 is defined as the result of the subtraction between synchronism or the GPS-timetagged Resync pulse and the same pulse but timetagged by the timeboard. During subsystem operation, the drift of the timeboard internal clock is also monitored and corrected using the 1PPS signal provided by the GPS.

Power and Environment Control; guarantees power supply and stabilizes the operational environment conditions for all the sensors.

Sensor Calibration Procedure

First of all, parameters that describe the sensor geometry have to be determined. Non-metric digital cameras have to be calibrated in the sense

In order to be able to compute the absolute position of any image or laser pulse in the object space, it is mandatory to compute accurately the relative position and attitude of each sensor (camera or laser) to the inertial reference frame defined by the GEOMÒBIL orientation subsystem.

Camera parameters calibration; was carried out at the ICC facilities. Using classical surveying techniques, a local reference frame was set in the ICC exposition room, which have a regular pattern floor. The coordinates of six points on the ground in the local reference frame were measured. The position of each camera was computed on up to six different sites around the target area on a balcony situated at 8.40 meters above the target area. From each of these sites both cameras were operated to image the target area. Up to 471 points were identified in the images of the target area, with in a total amount of 4165 photogrammetric observations (average of 347 photogrammetric observations per image). Six of the 471 points are the six measured points mentioned above. These six points become six full control points. The other 465 are vertical control points at height zero (in the local reference frame). Moreover, due to the regular pattern and distribution of points, a distance restriction between the adjacent points of the 471 point network was imposed. A Bundle Block Adjustment was carried out in the above conditions using GeoTex software (Colomina et al. 1992). Focal length, the principal point parameters and radial lens distortions were adjusted.

Camera Boresight calibration; The calibration take place in the neighborhood of the ICC. The site consists of two cylindrical walls in an open environment (with excellent GPS visibility). On these walls, about 60 points are surveyed with an accuracy of 1-2 cm. A GPS Ground Reference Station is set close to the calibration site.

In the procedure, the wall is imaged by the GEOMÒBIL system from different positions, azimuths and distances. A few stereopairs are selected from this set of images. The selection criterion is to obtain some stereopairs at different distances, azimuths and positions of the GEOMÒBIL with respect to the calibration site. The acquisitions are performed in static and dynamic mode (van in movement). Dynamic acquisitions demonstrate that the synchronization subsystems work as expected.

Wall control points are identified in the selected images and a Bundle Block Adjustment is performed. In the adjustment, the adjusted camera calibration parameters are taken into account (focal length, principal point and lens distortion). The goal of the Bundle Block Adjustment is to determine a set of boresight parameters per camera (eccentricity vectors and misalignment matrix between the image reference frame and the inertial reference frame) and a set of relative orientation parameters (camera relative orientation).

Adjusted relative orientation obtained accuracies of 1 cm for position and 60-80 arc seconds for attitude. Adjusted boresight parameters obtained accuracies of 1-2 cm for the eccentricity vector and 120-150 arc seconds for the misalignment matrices.

No significant residuals in the position and attitude parameters (orientation) of the dynamic acquisitions were found. Thus, it may be concluded that the synchronization subsystem has neither drift nor biases that affect image timetagging.

Laser Scanner Boresight calibration; Laser scanner is set in a configuration according to the goals of each mission. In particular, the laser can be set in two main configurations scanning direction upside-down or scanning direction right-to-left. Each configuration requires its own calibration.

It is used the same calibration scenario that the used for the CCD camera bore-sight calibration. On the CCD camera calibration wall 15 of the 60 measured points were signalized with reflecting targets. The laser from different positions and azimuths scans the calibration wall. Targeted points are identified automatically on each scan of the wall. A Bundle Block Adjustment is performed taken into account the laser observations of targeted points at each laser location, the coordinates measured of the 15 targeted points and the positions and attitudes computed by the orientation subsystem. In the adjustment there are determined the eccentricity vector and misalignment matrix (bore-sight parameters, an amount of 6 parameters), which defines de relationship between the inertial reference frame (the one of the orientation subsystem) and the laser scanner reference frame.

Data Extraction Software

The data extraction software assists the interactive digitization of features for creating, updating or revising georeferenced data. The system allows the point measurement on the images obtained with the GEOMÒBIL, and the classification of the feature attributes according their semantic contents.

The original idea, to use a stereo environment that allowed superimposition of vector data, based in the photogrammetric model obtained from the orientation data of two images, was considered too expensive and the actual system is not stereo. For each pair, each image is visualized in a view and the operator should identify the point to be measured in both images. Vector data can be superimposed on top of the images.

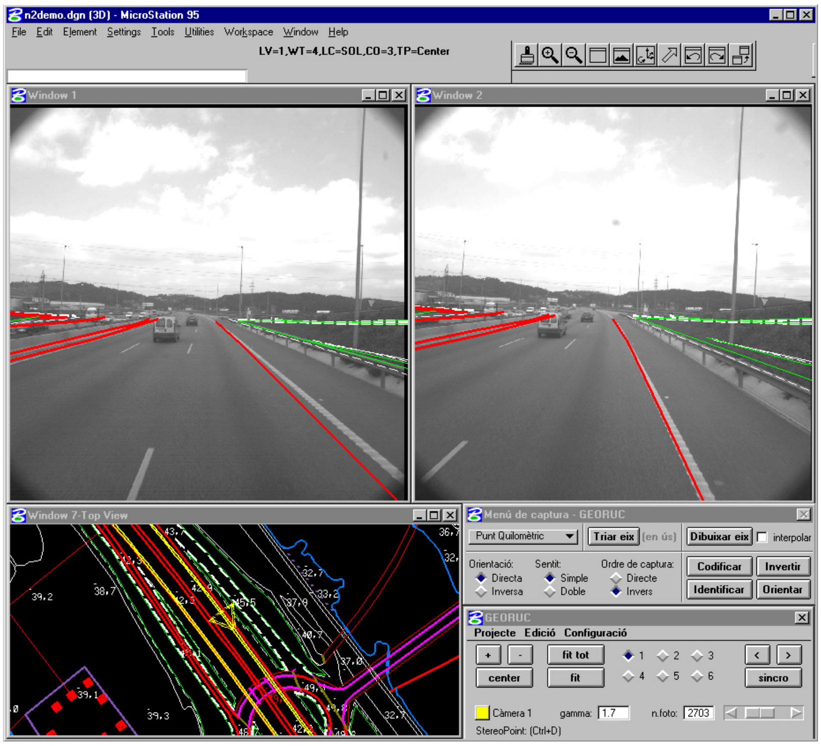

Figure 3: Screen shot of the GEOMÒBIL data extraction software.

The system is based in MicroStation 95 and the customization has been developed using MDL language. The system functionality for image and vector visualization, data digitalization and editing or data storing takes advantage of the MicroStation basic tools. As the same tools are used in data compilation, editing and storing for other topographic databases created at the Institut Cartogràfic de Catalunya, data integration can be achieved without any data transformation.

The application allows the reproduction of the path covered by the GEOMÒBIL, visualizing the sequence of images collected by each camera. The path information is obtained from a file with the position (geographic coordinates in a given reference system) and attitude of the projection center for every photo. Another file provides information about the parameters for the cameras (focal length, principal point coordinates, radial distortion and internal orientation).

Each image sequence is visualized in a MicroStation view. The view is configured according to the camera (coordinates and angles of the projection center, coordinates of the principal point, and focal length), and the image is placed in the perpendicular plane to the camera axis at a selected distance of the projection center. This method allows the visualization of georeferenced data on top of the image.

Two views of MicroStation can be used to show the path, the projection centers and the orientation of the visualized images. Vector data and raster images can be also displayed in these views. As no more than eight views can be used in MicroStation, a maximum of six sequences can be visualized during a session.

The tools for image management allow to advance and to go backwards one image in one or more views, to select one image in one view, to synchronize the images for all the views, and to go to the nearest image to a georeferenced point. The visualization tools, as zoom in, zoom out, center the view to a given point, or fitting the image in the view, have been specially developed for this application, because MicroStation standard visualization tools do not preserve the camera configuration.

The point coordinates are calculated resolving the collinear equations from the position identified in two images. The images can be amplified to facilitate the point identification, and the epipolar line can be visualized, after giving the point in the first image, to identify the same point in the second image. The collinear equations solution is computed in geocentric coordinates to increase the accuracy, and then it is converted to the work reference system.

The coordinates of the calculated point are sent to MicroStation to be processed by the active command as a standard input. Microstation commands and other specific tools can be used to capture new data or to modify existing information. A set of tools has been created to gather elements tied in the roads. They allow to capture the axis of the route, to attribute it with some characteristics (number of rails, tunnel, street...) and to capture attached elements to the road as kilometric points, traffic signs, gas stations or bus stops.

EMPIRICAL RESULTS

Some missions have been carried out under different environmental conditions. In prior works urban data sets were analyzed see (Alamús et al. 2004). Such data set had the inconvenient of the urban environment where computation of GPS/INS trajectory has problems due to GPS occlusions and the expected difficulties in a urban environment with narrow streets and high buildings. In the current study an open road application have been investigated.

Using GEOMÒBIL image data has been collected in a 6-Km piece of the B-24 road, which runs from Sant Vicenç dels Horts to Vallirana southern Barcelona. The aim is to measure position of road signs. Notice that the environment of acquisition has good conditions to compute a good solution for the GPS/INS trajectory.

On the road, 12 mileposts have been surveyed on the field with GPS. Those mileposts have been identified and measured in all possible image pairs of the GEOMÒBIL data using the GEOMÒBIL extraction software. Up to 45 measures of those points have been performed in GEOMÒBIL images at distances of the van ranging from 11 to 80 meters. In figure 4, it is plotted the empirical accuracy computed using the 45 observations of the 12 mileposts against along-track distance to the van.

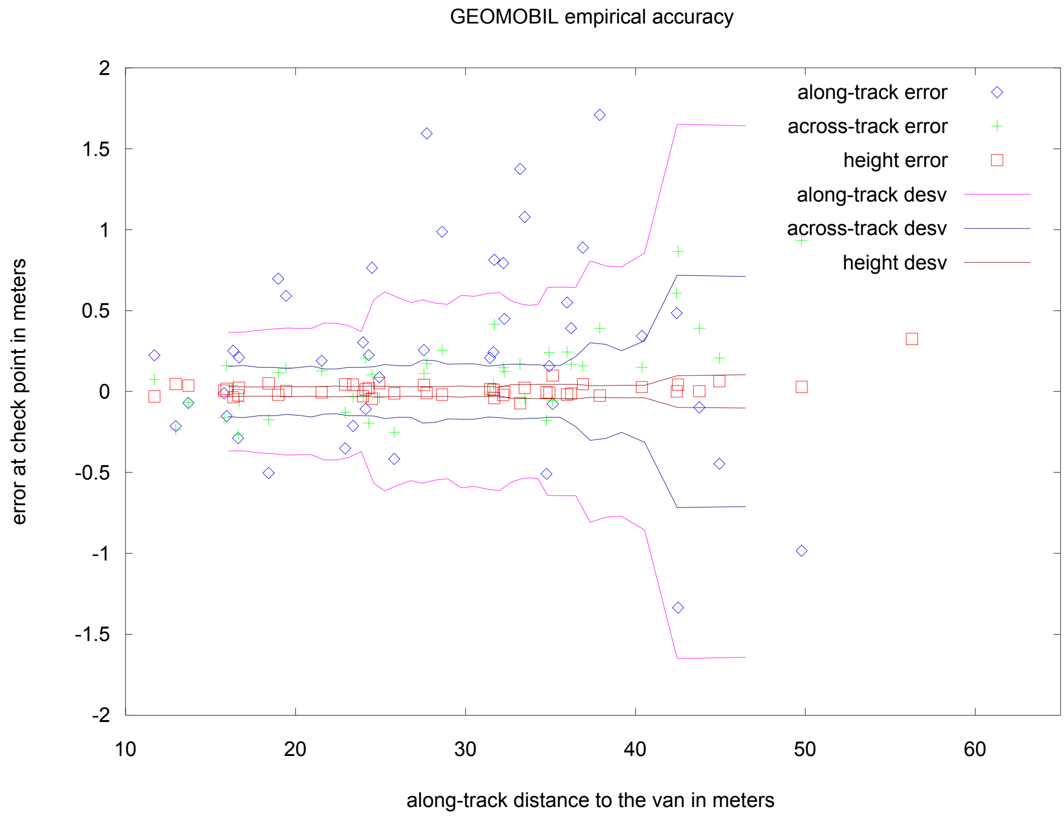

Figure 4: Residuals of measured mileposts and empirical accuracy in terms of along, across-track and height.

In figure 4 a systematic shift on the trajectory has been removed in order to compute internal accuracy of the system. Standard deviation has been computed using 11 residuals, sorted by distance to the van, and assigned to the mean of their distances to the van (lines corresponding to the along-track, across-track and height). It has to be notice that empirical accuracy is in the order 0.3 meters at distances lower than 20 meters for all the components and it is below 1 meter at distances up to 40 meters. Accuracy is getting poorer as larger is the distance to the van, which implies that the ratio base-distance is worse as it is depicted in figure 1.

	Along-track	Across-track	Height
R.M.S.	0.95 m	0.46 m	0.06 m

Table 2: Accuracy of GEOMÒBIL

Overall accuracy of the system is summarized in table 2. In this table distance to van has not been considered, that is the reason for larger accuracies than in figure 4.

FUTURE DEVELOPMENTS

Further developments focus on two issues. The first one is the integration of new digital color cameras pointing forward and backwards. The second is to improve trajectory determination. In general, this improvement may be achieved by integrating new sensors (as barometers), which can help in the computation of trajectory. In urban environments with existing maps and/or aerial photography, some objects may be extracted and used as "ground control". These points will be used to improve trajectory computation.

CONCLUSIONS

GEOMÒBIL development has been successful integrating and operating simultaneously two digital CCD cameras and a terrestrial laser range system. The ICC development consists of sensor integration, calibration and data extraction software.

Current experiences prove that the GEOMÒBIL system exhibits an excellent photogrammetric behavior; nowadays GEOMÒBIL configuration reaches accuracies below 30 cm (1-σ) at distances to the van of 20 meters and shorter. Despite accuracy goes poor with distance it is in the l meter level at distances up to 40 meters.

Nevertheless, total precision of the GEOMÒBIL system depends on trajectory precision. In the current investigation only good environment (which means good GPS visibility) have taken into account. In other environment like urban projects or roads as mountain or forest roads with low GPS visibility GEOMÒBIL precision will be affected by trajectory errors.

It has also been proved that the calibration protocol obtains expected accuracy so that obtain the best performance of the image subsystem can be achieved.

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