GEOVAN: THE MOBILE MAPPING SYSTEM FROM THE ICC

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ABSTRACT:

Since 2000 the Cartographic Institut of Catalonia (ICC), within the frame of the GEOVAN project, is developing its own Mobile Mapping system. The GEOVAN project includes the integration in a van of all the sensors needed for acquiring digital stereopairs of images and its direct georeferencing. In this paper all the subsystems integrating the GEOVAN will be described: the imaging subsystem consisting in a pair of digital cameras; the orientation subsystem based on GPS/INS integration; the synchronization subsystem; the data storage subsystem; the power subsystem and finally the control subsystem. The interaction between the subsystems, operational procedures and calibration of the subsystems will also be explained in detail. The first steps for integrating a terrestrial laser in the vehicle and georeference directly its data by using a GPS/INS system will be also presented.

1. INTRODUCTION

Since the first LB-MMS (Land Based Mobile Mapping Systems) developments early 90's [1] this systems have successfully demonstrated how they could improve the efficiency of GIS and cartographic data collection. During this period the positioning and orientation systems have been improved having better GPS coverage and receivers, increasing the dead reckoning sensors but specially the evolution on GPS/IMU (Inertial Measurements Units) integration for determining position and orientation in a global three-axis reference frame. Direct sensor orientation is mandatory due to the large amount of photographs taken (≈20.000 photos for a 100km survey).

2. GEOVAN SYSTEM

With the objective to develop its own LB-MMS flexible enough to integrate several sensors for acquiring data of cartographic interest, the ICC started the GEOVAN project that integrates in this first stage the positioning and orientation subsystems, algorithms and sensors required to determine observed elements coordinates 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. The initial realization of this project comprises two digital cameras that form stereoscopic models in the zone of interest. The zone of interest is defined to be at a distance of 10 meters of the vehicle along track and 10 meters wide across track with the intention of acquiring all the elements present in the photographs such as horizontal and vertical road signs. The integration platform is mounted in a vehicle that equips other auxiliary subsystems for the continuous operation of the system, as air conditioning, electrical power and other subsystems including operator security and attenuation of the disturbing vibrations present in mobile environments.

Figure 1. GEOVAN System.

The GEOVAN system has been divided in the following subsystems:

- *Orientation:* Handles the absolute reference frames, temporal and geometric.
- *Integration Platform:* Creation of a rigid physical base for the transference of the geometric reference frame of all the installed sensors.
- *Image sensor:* Scene configuration, sensors geometry , focal.
- *Image Acquisition:* Exposure synchronization and control, image acquisition and storage.
- *Synchronization:* Creation of temporal reference frame coherent transferable to all the sensors.
- *Power and environment control:* Guarantee the power supply and stabilize the operational environment conditions to the sensors.

2.1 Orientation subsystem

The orientation subsystem is responsible for georeferencing the photographs taken by GEOVAN. So it provides the coordinates (position) and the angles (attitude) of their projection centers. The subsystem is based in an Applanix system, designed specifically for land vehicle applications, that is integrated to the GEOVAN. This system is basically composed by:

- An IMU (Inertial Measurement Unit), sensor that provides measurements of the accelerations and angular velocities.
- Two sets of GPS antenna-receiver, one of them of double frequency that will provide observations of the position and velocity, and another one of single frequency that will be used to improve the heading angle determination. This system of two GPS antennas is called GAMS (GPS Azimuth Measurement System).
- One DMI (Distance Measurement Indicator), sensor installed directly in one of the vehicle’s rear wheels that provides information of the distance traveled.
- POS Computer System, that contains the core of the system, IMU and DMI interfaces, two GPS receivers and a removable PC-card disk drive where the data is stored.
- POSPac, software to process the GPS data and to integrate the GPS solution with the observations of the other sensors.

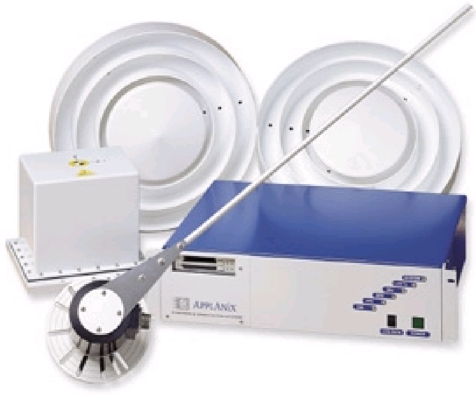
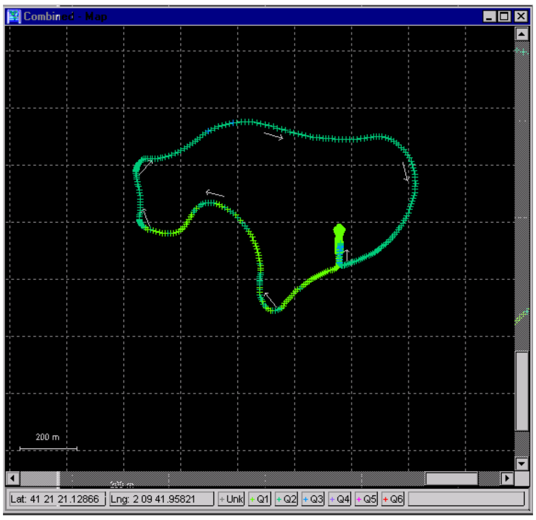


Figure 2: Applanix POS LV 420 (courtesy of Applanix)



Lat: 41 21 21.12866 Lng: 2 09 41.95821

Figure 3: Ex. of trajectory processed by POSPac

Like any system that combines inertial and GPS observations in a high level integration, GPS derived trajectories are used to correct and calibrate the drifts of the IMU gyros and accelerometers, so that the position and velocity errors derived from the inertial sensors are minimized. But the main drawbacks for terrestrial navigation are the presence of obstacles in the road, like bridges or tunnels, that interrupt totally or partially the acquisition of GPS observations during some time interval, and the existence of areas where most of the GPS satellites signals are blocked by terrain conditions, like urban areas with high buildings, forest zones, etc. In these areas without GPS coverage or with a very poor constellation, position and velocity are calculated from IMU observations, whose errors, with the help of the observations provided by the DMI, don’t grow according to the duration of the GPS signal outage but depending on the distance traveled.

In order to obtain, from the position and angles provided by the orientation subsystem, the position and attitude of the photographs an important issue is to fix the relation between all reference frames present in the orientation process,. For this reason it must be guaranteed that inertial, cameras and GPS have a strong stability between them.

2.2 Integration Platform

The integration platform is the structure where the different sensors are mounted for their operation. In addition it has to be sufficiently stable for the precise transference of reference frames. There are two basic requirements to consider, first it must have a maximum physical space in the top of the van and second 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 in the platform. This implies a great immunity to deformations. A study of design of the platform was carried out [3] and diverse options where analyzed resulting that the optimal solution was based on a irregular mesh system reinforced in its diagonals as it is shown in figure 4. This structure is equipped with equidistant anchorage points so that different sensors distributions can be done easily.

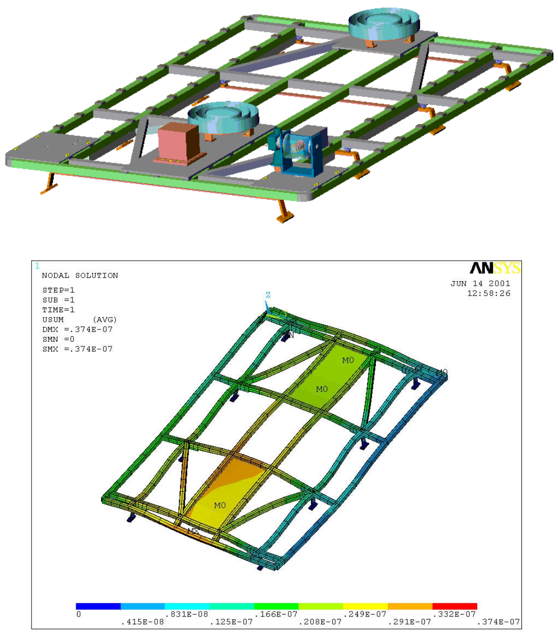


Figure 4: Integration Platform and deformation simulation with the reinforcements diagonals [3].

As explained above the highest constrain in the design of the platform and the anchorage system for the sensors have 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 arcseg in rotation.

2.3 Image Sensors subsystem

The subsystem design has been driven by two main requirements: acquire at least 1Mpix images and get 10 m stereoscopic overlap at 10 m distance of the van (about 100 m^2). The selected image size is a compromise between image resolution an data storage and management. 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 (see figure5). Table 1 summarizes the image sensor subsystem characteristics.

No. pixels	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.

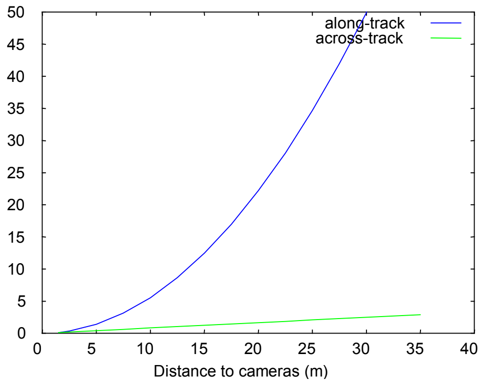


Figure 5: Relationship between distance (units in m) and fotogrammetric precision (units in cm) across and along-track. Along-track precision depends on B/D ratio.

2.4 Image Acquisition subsystem

A pair of digital cameras generates stereoscopic models of the scene in front of the cameras, the selection of the photo parameters, the generation of the trigger pulse and the data handling composes the Image Acquisition Subsystem. 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 that generates a pulse train (trigger) with a frequency depending on the travelled distance or at a given constant frequency.

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

The hardware components of Image Acquisition Subsystem consist in two Frame Grabbers, one Counter/Timer and two removable disks, all these components are managed by a Control PC. A Frame Grabber is required to control the digital cameras being the interface between the cameras and the acquisition software. The Counter/Timer is a device for generating train pulses used to trigger the camera (*Trigger* signal) and to synchronize a time board (*Resync* signal.) The software components of the Image Acquisition Subsystem are integrated into the general GEOVAN software application that is in charge of the hardware equipment configuration, acquisition control, GPS time synchronization process and system status displaying.

The data storage capacity of the system has been evaluated to be bigger than 100 Gbytes. Considering that a GEOVAN survey session can last seven hours, at 1 Mbyte image size, driving at 72 Km/h vehicle speed and with a spatial acquisition frequency of 10 meters/image; a minimum amount of 101 Gbytes storage capacity per session is needed. Therefore, the system storage capacity is composed of two 73.4 Gbytes removable disks. If it is needed the disks can be exchanged for increasing the storage capacity. According to current hardware configuration and the write to disk data rate a maximum of four pair of images per second can be taken by the system. This number is enough for covering the requirements of the system.

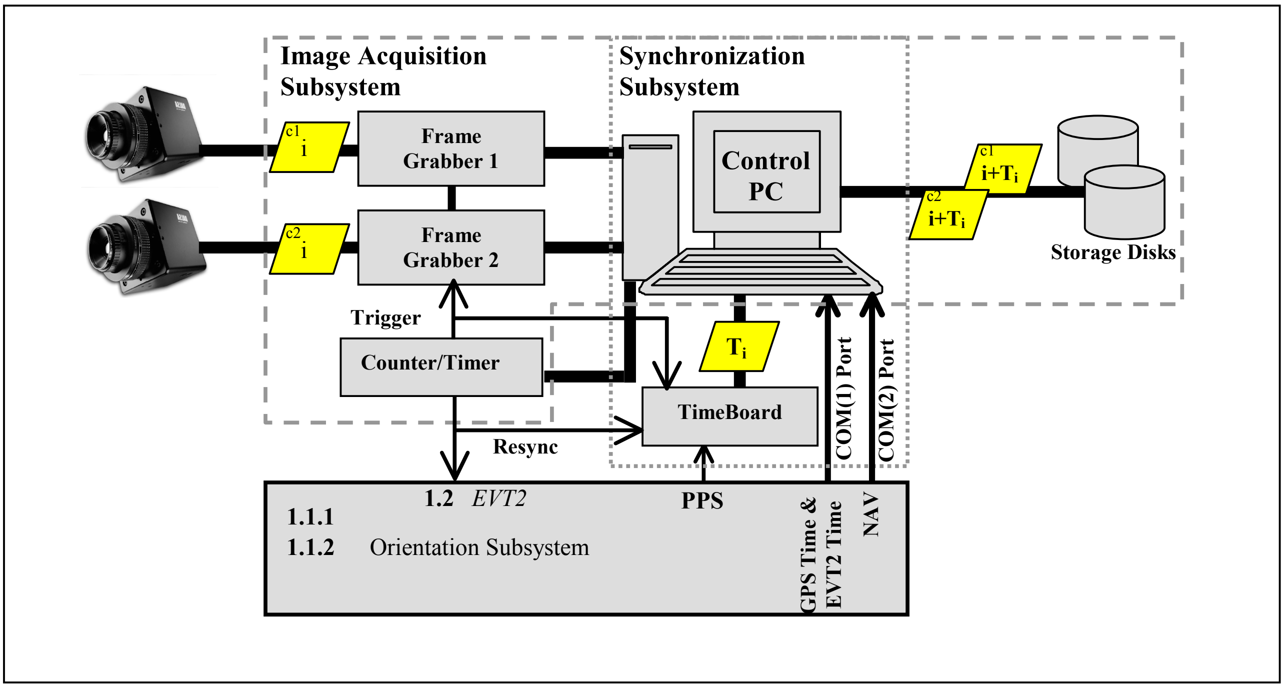


Figure 6: Geovan Hardware Configuration.

In order to have a good image histogram distribution the exposure time depends on the exterior brightness considering only the pixels of the predefined region of interest (ROI) shown in figure 7. The estimation of the scene brightness (p_m), is done by calculating the mean gray level of the pixels that belong to the predefined ROI. Assuming that there is a linear relation between the exposure time (t_{exp}) and the ROI brightness (p_m) the exposure time can be expressed by means of the following linear relationship (1):

$$t_{\exp} = k \cdot p_m \qquad (1)$$

The linear constant k depends on environmental conditions and scene features. Therefore, when image brightness quality is the desired, the factor k is also estimated from camera exposure time and ROI brightness. The adaptation speed can be improved if extra images are taken and the image acquisition rate is higher than the writing to disk image rate. With that implementation faster convergence speeds to desired brightness values have been obtained.

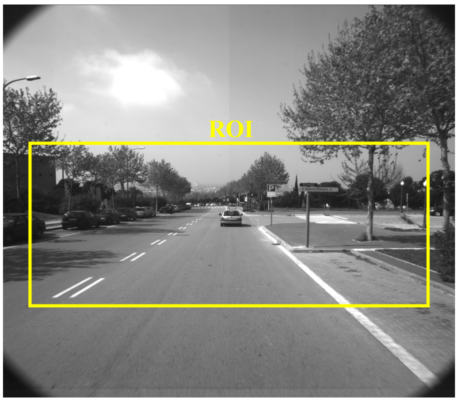


Figura 7: Region of Interest (ROI).

Figure 8 shows the ROI mean gray level and the camera exposure time evolution, both parameters are related to each other by expression (1). This graphic was obtained using data corresponding to a Geovan test done at 30 km/h, a maximum of 6 ms exposure time was set to avoid bluring effects in images and the brightness optimum value were configured at 120 to 140 gray level. Figure 8 also shows that the algorithm successfully maintains the mean gray level of the image within the predefined values. Moreover, if the mean gray level of the ROI falls outside the allowed boundaries the algorithm need 1 to 4 images (depending on test conditions) to return the image brightness within the required values.

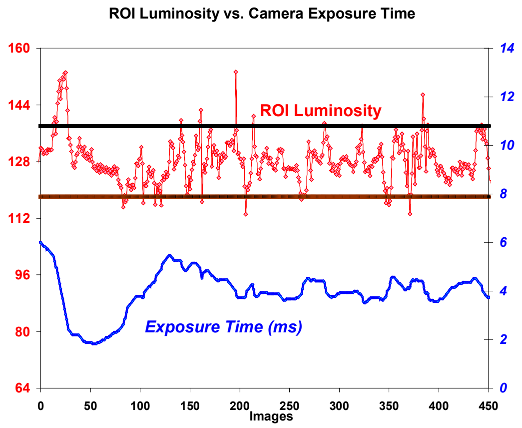


Figure 8: ROI luminosity evolution

2.5 Synchronization subsystem

The Synchronization Subsystem has the objective to synchronize in a common temporal reference (GPS time) all the sensors integrated in the GEOVAN (GPS/IMU/Image sensors/laser). This subsystem integrates a timeboard and handles different synchronism signals: PPS, Trigger and Resync (see figure 6).

The timeboard is a device that allows the timetagging of the received TTL signals with 20 ns resolution. Therefore 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 in two steps, initialization and data synchronization.

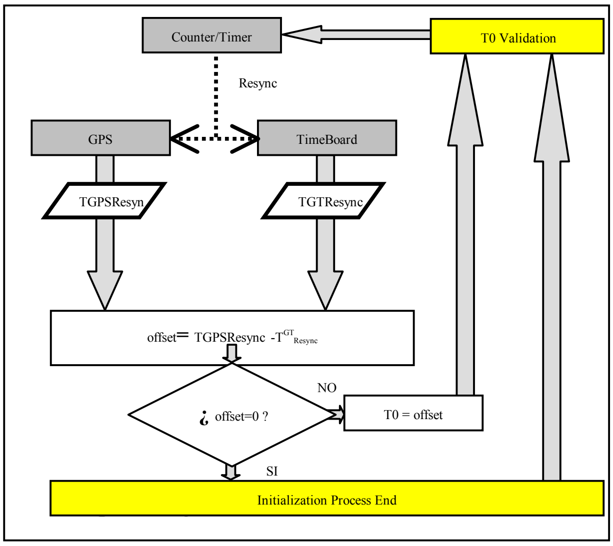
The goal of the initialization process is to establish the difference between GPS time and timeboard time (figure 9). Let T^{GPS} be a timetag referenced to GPS time and let T^{GT} be the same timetag referenced to timeboard time; then the following expression relates both temporal references:

$$T^{GPS} = T^{GT} + T_0 \qquad (2)$$

where T_0 is the timeboard GPS start time, in other words, it is the instant when the timeboard resets its intern time to zero and starts working; therefore, T_0 is the timing differnece between GPS and timeboard time reference.

$$T_0 = T^{GPS}_{Resync} - T^{GT}_{Resync} \qquad (3)$$

In this first initialization step, T_0 is set to the result of subtraction between synchronism or *Resync* pulse GPS-timetaged by the GPS receiver (T^{GPS}_{Resync}) and the same pulse but timetaged by timeboard (T^{GT}_{Resync}) (3). During the subsystem operation the drift of the timeboard internal clock is also monitored and corrected.



2.6 Power supply and environment

The power supply and environment subsystems include those equipment and facilities to support the operation of the subsystem in productive operation (orientation, image sensors, central PC). The required power supply is provided by a generator of 4000 KVA installed in the van. It has been taken in account the acoustic noise level of the equipment and its installation has been reinforced with passive acoustic and vibration attenuators in order to improve the system operator's comfort. This generator provides energy to a UPS system from which the equipment takes provision. Thus a good quality and continuous electrical provision to the equipment is guaranteed. The GEOVAN has also an external power input to run the system in stationary when necessary.

The environmental control has the goal to stabilize the operational conditions of the external and internal equipment. With this purpose protectors of glass fiber have been designed to isolate the external equipment from atmospheric conditions [4]. Finally air conditioning equipment blow air to the sensors containers to stabilize the temperature and to absorb the humidity that could be present in order to avoid condensations.

Figure 11: Environment protectors and evaporator part of the climate system..

3. DIRECT ORIENTATION AND CALIBRATION

Direct orientation of each sensor require the transference of the orientation given by the orientation sub-system in the inertial reference frame to each of the on-board sensor reference system. So it is mandatory to know *a priori* the eccentricity vectors (offset) of each sensor to the inertial reference frame and the misalignment matrix (rotation between the involved reference systems) between the inertial reference system and the sensor. Direct orientation also requires a good knowledge of the sensor (cameras) geometry. The determination of these parameters is carried out in a calibration process.

Image sensor sub-system calibration is done in two steps. The first step is calibrate the geometric distorsion of each camera (optics included). The second step is the determination of eccentricity vectors and misalignment matrix between the cameras (relative orientation) and the cameras and the inertial reference frame.

The first step is carried out at the ICC facilities (see figure 12). Six ground points and five different positions of the cameras (in the ICC map library balcony) have been computed using surveying methods. Additionally, 471 tie points have been also automatically measured leading to a total of 4096 photogrammetric measurements. A bundle block adjustment has been carried out with these data set. The photogrammetric residuals had an rms of 0.90 pixels and showed a systematic behavior (see figure 13). A polynomial was adjusted to the photogrammetric residuals in order to model the lens distortion, after the polynomial fit the value of the photogrammetric residuals dropped to a rms of 0.50 pixels.


Figure 12: Picture of the optics calibration process.

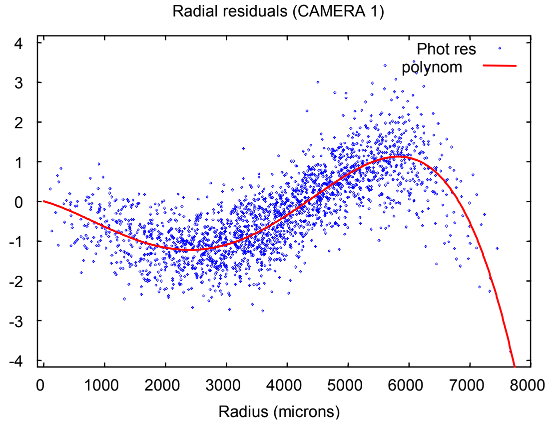


Figure 13: Radial component of photogrammetric residuals (in pixels) vs. Radius (in microns) and adjusted polynomial.

Relative orientation, eccentricity vectors and misalignment matrices determination was carried out in the neighbourhood of ICC facilities. In the calibration field 60 control points on the surface of a wall were surveyed with an accuracy of 1-2 cm. Static images and images in movement were acquired in the calibration field (see figures 14 and 15). Control points have been identified in several stereo-pairs and a bundle block adjustment have been carried out. Adjusted relative orientation reached accuracies of 1 cm for position and 60-80 arcseconds for attitude (misalignment matrix). Adjusted eccentricity vectors (between cameras and inertial reference frame) got accuracies of 1-2 cm and the adjusted attitude of the misalignment matrices got accuracies of 120-150 arcseconds.


Figure 14: Picture of the GEOVAN during the acquisition of images for the calibration process.

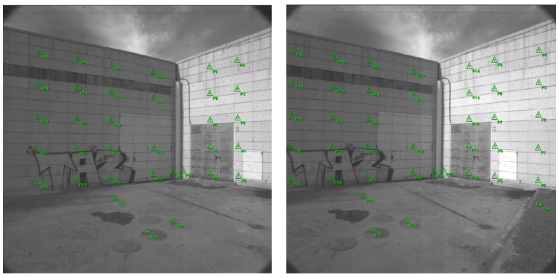


Figure 15: Stereo-pair with identified control points.

Once eccentricity vectors and misalignment matrices have been computed it is possible to transfer the GPS/IMU sub-system orientation parameters to the photogrammetric model. Preliminary results on the empiric accuracy of the system using direct orientation are summarized in table 2. Up to 39 objects have been identified in photogrammetric models when the van was moving and its coordinates computed using direct orientation techniques. The coordinates have been compared to the coordinates computed using surveying methods. Notice that Y is approximately along-track direction, and X and H are across-track. Notice as well that these empiric accuracies are coherent with the theoretic accuracies shown in figure 5.

	Stand. Dev.
X	0.05 m
Y	0.13 m
H	0.03 m

Table 2: Empiric accuracies

4. INTEGRATION OF A TERRESTRIAL LASER SCANNER

In September 2003 a terrestrial laser scanner has been integrated in the GEOVAN system. The laser has been rigidly mounted in the platform in order to allow the transference of the orientation from the GPS/IMU subsystems to the laser system (see figure 16). A synchronization TTL pulse is sent to the laser to reset the laser internal clock that timetags the laser lines.

Figure 16: Integration of a terrestrial laser scanner in the GEOVAN

The laser is fixed at a determined angle and scans the façade of the buildings while the van is moving along the street. Figure 17 shows an intensity image of a survey with the laser looking at the right site of the van. First results are very promising and confirm that a great improvement in the productivity of the terrestrial laser surveys can obtained.

Figure 17: Intensity image of a dynamic laser survey

5. CONCLUSIONS

In the framework of the GEOVAN project ICC has integrated all the required hardware and software subsystems in order to obtain an oriented platform mounted in a van. The oriented platform allows the dynamic georeferentiation of any sensor rigidly mounted on it.

In the first stage two digital cameras have been integrated with the purpose of obtaining stereoscopic models of images. The accuracies obtained in surveyed points observed in the photographs with good GPS coverage are 3-5 cm in the directions perpendicular to the vehicle and 13 cm in the direction of the vehicle.
Those results are coherent with the theoretic accuracies of the system.

A terrestrial laser scanner has been integrated in the platform. Preliminary results for orienting directly a dynamic scanner mission are very promising.

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