A STREET MAP BUILT BY A MOBILE MAPPING SYSTEM

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ABSTRACT

Mobile mapping systems (MMS) integrate sensors and methods to deliver an accurate spatial position of details on or near the topographic surface. This means an expensive hardware configuration where CCD cameras, GPS receivers, INS platforms, wheel sensors, gyroscopes, laser rangers and others are linked together to produce georeferenced images and spatial coordinates of attributes. A sequence of terrestrial images is formed by consecutive digital images taken from bases that are moved forward along the main axis of a road. This happens when a pair of video cameras is mounted on the top of a MMS vehicle to take frontal images of a street. In general, sensor orientation is provided directly by means of GPS and INS data integration. In a few situations, INS equipment is hard to purchase mainly for the high prices. When no INS equipment is provided bundle triangulation can then be used for camera orientation. Object details can be positioned by photogrammetric intersection. The prototype is composed of a van, two digital video cameras, a GPS receiver, and a laptop. An experimental street test was conducted and the results revealed that bundle method provides average positional accuracy of less than 1.5m for the perspective centers. A 1:2000 street map was made based on topographic surveying by the photogrammetric traverse, which concatenates a sequence of terrestrial stereo pairs. Statistic tests show that the map accuracy succeeded and the standard error is 1.0mm in map scale.

1 INTRODUCTION

There are situations when recent released technology is not easily reachable both for the high costs and for the political issues related to the acquisition of new technologic equipment. Particularly, INS (Inertial Navigation System) technology has gained the attention of more and more geospatial scientists and researchers since one or two decades ago. INS combined with GPS (Global Positioning System) is a very powerful technique to orient imaging sensors specially when in kinematics applications like aerial photogrammetric or terrestrial mobile mapping projects.

Starting the development of a mobile mapping prototype is a very hard task in countries that are not high technology producers and then the importation is the only way to have the technological goods. The difficulties to be overcome are mainly funding and importation process when it comes to a complete configuration which means then imaging sensors, GPS and INS integration. Individually, INS module is the most expensive. So bundle block adjustment is a less expensive and reasonable method applied in the mainstream to overcome the sensor orientation problem.

Prior to the development of the mobile mapping prototype, a situation of collecting data on streets in order to make maps was simulated using an alternative methodology called photogrammetric traverse. The idea behind that project was to provide the understanding of the map making process to a group of undergraduate students (capstone project). Despite of being an unconventional method for topographic mapping, the project also brought contributions to learn the relationship between the stages that connect the main phases of the data and information when it comes to the application of photogrammetric traverse. Details are given in Silva et al. (1999).

This article presents the prototype called *Unidade Móvel de Mapeamento Digital* (UMMD) composed of a van, two digital video cameras (Sony DSR200A) mounted as a stereo camera on the top of the vehicle, two GPS receivers (Ashtech Reliance and Garmin 12 XL), a notebook (Fujitsu Pentium 266MHz), and a sound frame synchronization system (fig. 1). Besides the mobile unit, in the Mobile Mapping Laboratory, there are computers used to download and process the digital images recorded in appropriate tapes. Other software makes the rest of the job to perform the photogrammetric and the cartographic phases. This set of equipment and methods provides the opportunity to merge distinct techniques to make topographic maps and also to give researchers the different technique application results under a modern and alternative approach to make maps of street and road environment.

Figure 1 - Mobile Mapping Unit.

The results attracted the attention of public work engineers who envision the benefits of this technology to inspect street and road pavement, to map the horizontal and vertical traffic signs, electric energy poles, telephone booths, and many other applications quite important to the people's safety and welfare.

2 STREET SURVEYING AND PHOTOGRAMMETRIC TRAVERSE

Reasons for surveying the streets

Most people live in urban areas. Along the streets facility companies lay their networks say water and sewer, electric power, telecommunication, and many others. Poles and trees are quite common in typical urban scenes. They do help but at some extent they disturb people when walking on the sidewalks. Pedestrians and drivers (these representing a large collection of different vehicles) need a language to communicate to each other in favor of traffic security, which is expressed in signs and warnings, both horizontal and vertical. Not only architects and urbanologists argue for a comfortable urban environment where humans can live with dignity and happiness. A long list of nice words could be continued to justify the need for the street and road mapping. Briefly, from a technical point of view, an image database and digital maps will help the urban administrators to reach the standards of a better quality of life. Particularly, MMS seem to play an important role in collecting street and road data for mapping and GIS purposes.

Photogrammetric traverse

Suppose a sequence of stereo images taken by a pair of cameras from the top of a vehicle that moves along a street or road. In a MMS, the images are usually positioned by GPS and oriented by an INS (Inertial Navigation System). When GPS data are not available (and this is quite common in urban areas), INS data fills in the blank positions. And when one does not have the INS to do it, orientation is given by a bundle block adjustment. This is what has been called photogrammetric traverse (Silva & Oliveira, 1998).

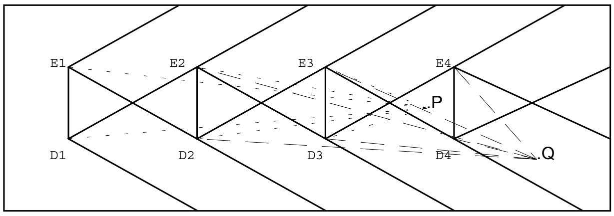


Figure 2 - Mapping the object points in a sequence of image pairs.

Figure 2 shows that an object point or detail on the street, for example, may be clearly seen in two or three stereo bases and then in four or six images. Simple, double or even multiple photogrammetric intersection can compute the spatial object coordinates. Theoretically, the closest stereo base delivers the highest accuracy and the far base the lowest accuracy for an object point when the photogrammetric intersection is computed separately for each base. When the computation takes in account multiple intersections the final accuracy is diminished mostly by the far bases data due to unfavorable geometry and minor quality observations. Among many others, Silva (1996) has treated sequences of digital images. As the photocoordinates are obtained in a manual (visual) measurement process, of course, this is restricted to a non real time system.

3 THE MMS MAP MAKING PROCESS

Inner Orientation

Before going to the survey site, a camera calibration project was designed and performed with both cameras mounted on the frame fixed on the top of the vehicle. Two digital video cameras (Sony DSR200A) were set together like a stereo camera in the normal case facing ahead with horizontal and parallel optical axes. This type of camera is not intended for photogrammetric projects and their inner geometry is extremely unstable. Although set to manual and wide mode, when the camera is turned on it automatically goes to the shortest focal length (nominal 5.9mm). Of course, this length varies around the nominal value every time the camera is turned on. A calibration field was built with 54 targets on a wall. The targets had their coordinates computed by intersection after a base and the horizontal and vertical angles determined using a total station (Sokkia SET5F). The vehicle, and so the cameras, were positioned in front of the wall to take six images, being two at the left, two straight in front, and two at the right. Other way of saying it is that six images mean three with the left camera and three with the right one in three different positions (fig. 3).

Figure 3 - Convergent calibration method.

The images were downloaded to a computer equipped with two hard disks: one IDE for the operating system and application software and the other (SCSI) for the non linear edition (miroVIDEO DVTolls for image capture and Adobe Première LE for image selection). One frame for each position was selected from a short strip (AVI) and transformed to a bitmap image (BMP). FOTOCIC is the software developed with Borland Builder C/C++ 3.0 to measure image coordinates which were then transformed to photocoordinates. The sensor size is 4.8 mm (h) x 3.6 mm (v) or 720 (h) x 480 (v) pixels, which means a pixel size equivalent to 6.7 μm (h) x 7.5 μm (v). Appropriate treatment was done to consider the aspect ratio. Table 1 shows three distinct inner parameter determinations, namely (I), (II), and (III), done in different days. The third refers to the project described in this article (the others refer to two other projects).

Table 1 - Three inner parameter determination projects by FOTRAC.

Sony DSR200A	Project I		Project II		Project III	
L: left - R: right	parameter	std. dev.	parameter	std. dev.	parameter	std. dev.
L f (mm)	5.891	0.002	6.058	0.078	6.873	0.098
L x_0 (mm)	-0.132	0.002	0.008	0.031	0.553	0.002
L y_0 (mm)	-0.001	0.002	0.004	0.030	0.077	0.036
L k1 (mm^{-2})	-0.00297	0.00016	-0.00398	0.00185	0.050	0.003
R f (mm)	6.041	0.002	6.000	0.056	6.406	0.069
R x_0 (mm)	0.035	0.002	0.172	0.082	0.215	0.099
R y_0 (mm)	0.055	0.002	0.155	0.055	0.010	0.099
R k1 (mm^{-2})	-0.00615	0.000244	-0.00708	0.00231	0.005	0.003

The variation is considerable significant and then it demands a calibration for every new project. The stereo base measurement was done using an invar tape that showed 0.94 m and this result was constrained to the self calibration bundle block adjustment. FOTRAC (*FOToTRiangulação com Auto Calibração*) is the software that computed the photo triangulation adjustment. Only four parameters were considered as the lens diameter is only 52 mm.

Field Surveying and Data Processing

The antenna of the rover receiver (Ashtech Reliance: carrier L1, code C/A) were put on the top of the vehicle at the half distance between the two cameras. The antenna of the Ashtech Z-XII receiver (carriers L1, L2; codes C/A, P, Y) was fixed on the reference station. The GPS signal acquisition rate was set to 1 second for both receivers.

The synchronization of the video cameras was started with the image acquisition by remote control. The cameras' synch to the GPS signal was done using a sound signal emitted by a Fujitsu laptop (Pentium 266 MHz) when a special designed C language software (Hasegawa, 1999) recorded the position (geographic coordinates) signal emitted by a Garmin 12XL receiver every two seconds and the corresponding laptop clock time. The sound signal was sent to both cameras using a sound box from where two cables were introduced in both camera's microphone jacks (mic). This apparatus produces frames marked with a noise pick in the sound track corresponding to the laptop time that had been aligned to the Reliance clock (in order to have the same time base) that, in conclusion, means the geographic location given by the Garmin receiver.

The stereo base advances was planned to be around 20 m at maximum in the middle of the block and about 5 m when turning around the corners. This constrained the vehicle speed from about 36 km/h to 9 km/h (table 2), respectively. Stereo base advances are the distances traveled by the vehicle along the streets during the time interval (2 sec then) to get the next GPS location signal (given by Garmin 12XL in the application). They are schematically illustrated in fig. 2 (E_1D_1, E_2D_2, ...).

Table 2 - Vehicle speed according to the stereo base advances and signal rate.

Stereo bases advances (m)	5	10	15	20	25	30
Vehicle speed (km / h)	9	18	27	36	45	54

The selected site for the mobile surveying and mapping project was composed of three urban blocks in the suburban area of the city of Presidente Prudente (fig. 4). The total time spent in acquiring images and GPS signals in the selected area was less than five minutes. However, it took around 20 minutes since the beginning of the section in order to solve the ambiguities. WGS84 (World Geodetic System 1984) coordinates were transformed to SAD69 (South American Datum 1969) and then to UTM (Universal Transverse Mercator, λ = 51° W). The GPS data was post processed using Reliance software based on the kinematics GPS method and it released the following standard deviations for UTM coordinates of 57 stations: 1.7cm (E), 2.0cm (N), and 5.1cm (h). The computed positions of the 57 stations (P_1 and P_2 in fig. 5) were extended to the 114 perspective centers (CP_1 and CP_2, fig. 5) that correspond to the 57 stereo pairs, that cover the streets around the three blocks.

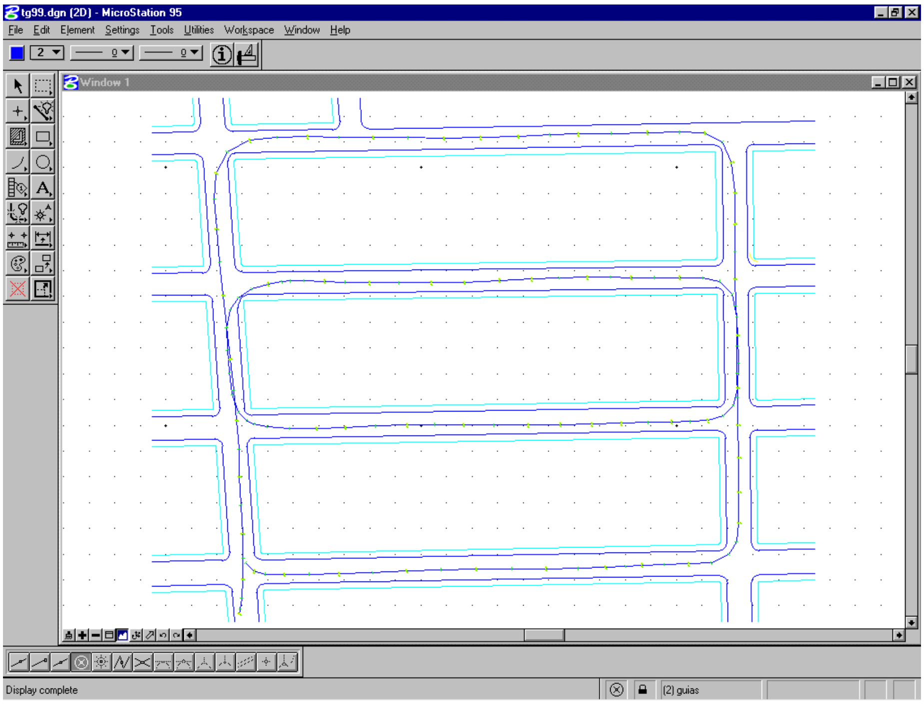


Figure 4 - The preliminary site map generated from the GPS and photogrammetric data.

The height information was derived from the GPS data which were transformed to orthometric heights using a local surface transformation model (Oliveira, 1998). All the antenna stations and the point and line coordinates were positioned in a hybrid system formed by UTM (E,N) coordinates and orthometric heights (H). The altimetric coordinates were computed based on the local geoidal model. The hybrid system was considered orthogonal because of the small size of the field area and then the approximated object coordinates were introduced directly in the collinearity equations (see section of photo triangulation ahead) without any coordinate system transformation.

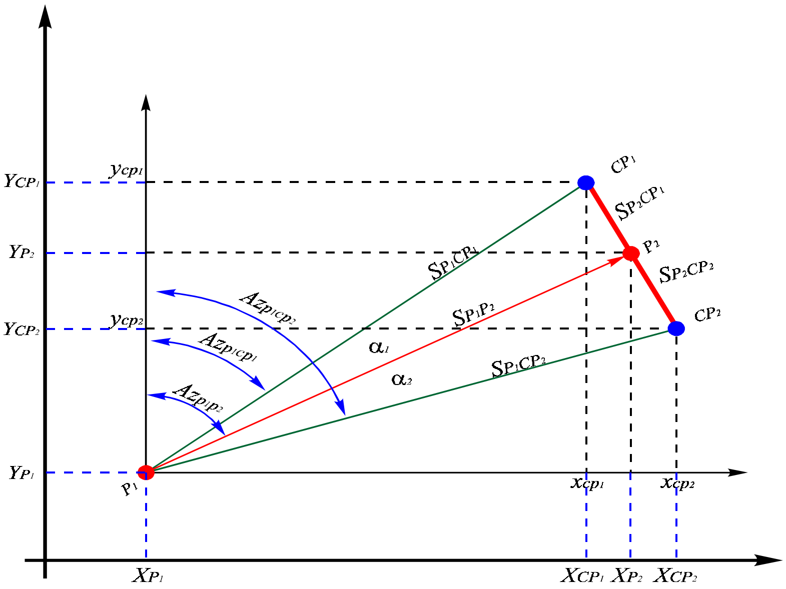


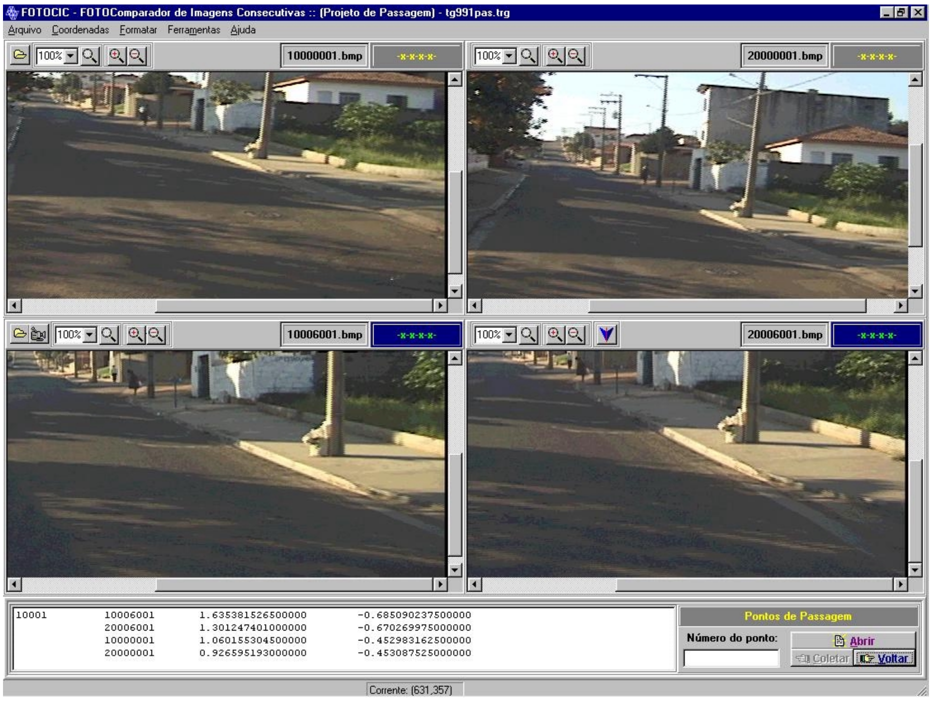
Figure 5 - Two consecutive GPS antenna positions and the two perspective centers.

Considering fig. 5, the two perspective center coordinates are determined from two consecutive GPS antenna positions by assuming that the stereo base advance (P_1P_2) is a straight line, the antenna center (P_2) and the two perspective centers (CP_1, CP_2) are collinear with P_2 in the middle, and both straight lines are orthogonal at P_2. The distance P_1P_2 and the azimuth AzP_1P_2 are derived from the computed GPS coordinates P_1 and P_2. The corresponding covariance matrices are also computed by applying the covariance propagation law.

Photo Triangulation

A bundle block adjustment was computed by TFTC (*Triangulação de Fotos Terrestres por Caminhamento Fotogramétrico*) in order to estimate the attitude for both cameras at each station. The photocoordinates were measured by clicking the mouse, which means visually, with an estimated error about 3 pixels. FOTOCIC is the software written for this purpose (*FOTOComparador de Imagens Consecutivas*). Besides the photo coordinate measurement, point and linear features were also collected concomitantly and their codes and labels were recorded in distinct layers to be represented in the final product (the street map). A few of those points were used as pass points. Figure 6 illustrates the measurement procedure with two pairs. When the pair at the bottom is finished it gives place to the pair above in which place the next pair of the sequence is loaded and so on.

In fact, the whole project was split into six distinct smaller blocks. Figure 4 shows that there were two blocks running north-south direction and four blocks east-west. There were 19 images in average in the six split photo triangulation adjustments. With the perspective center coordinates constrained to a weight of 10,000 (equivalent to a standard deviation equal to 0.01m), the released average of the standard deviations was around 2' for omega (ω) and phi (φ) and 2° for kappa (κ) —sexagesimal minutes and degrees —; the estimated standard deviations for the pass point object coordinates were about 1.5m. These results appear to be far from those given by classical aerial and terrestrial triangulation blocks but a direct comparison is not worthwhile because the network designs are pretty different. Despite of this difference, reasons are arisen to explain the results, as it follows: the weak geometry of the photogrammetric traverse and the difficulties to choose pass points, both already mentioned recently (Silva & Oliveira, 1998; Silva et al., 1999), and also the absence of automatic methods for point and line measurements.



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10001       10006001      1.635381526500000      -0.685090237500000
            20006001      1.301247401000000      -0.670269975000000
            10000001      1.060155304500000      -0.452983162500000
            20000001      0.926595193000000      -0.453087525000000
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Figure 6 - Interface to measure point and linear features both for bundle block and mapping.

Photogrammetric Intersection

The street scene components like poles, trees, telephone booths, mail boxes, garbage cans, bus stops, the construction and sidewalk lines, and the land parcel limits had their spatial coordinates in UTM system computed by photogrammetric intersection. The corresponding object point coordinates were computed from the twelve outer orientation parameters and the four collinearity equations without any adjustment. That was possible because some parameters were grouped together after some algebraic manipulation so that it resulted in a linear system of four equations and three unknowns (E, N, h). INTERFOTO (*INTERseção FOTOgramétrica*) did all the intersection computations.

Cartographic Drawing

With MicroStation SE, all the point and line features that had been recorded in layers were edited and represented in a street map which includes contour lines interpolated from the orthometric heights. The alignment points were constrained by a straight line equation. In the street corners an arc equation constrained the alignment points. A topographic surface was interpolated to generate contour lines using Surfer software based on the 57 mobile stations. Figure 7 shows the final street map at the scale 1:2000 entirely made from image and position data collected by the UMMD and processed in the Mobile Mapping Laboratory. In fact, the cartographic original was made on a A3 size paper so that fig. 7 is only a reduction of it.

4 CARTOGRAPHIC ACCURACY ANALYSIS

The accuracy of the final product was estimated by comparison of the UTM map coordinates and GPS ground coordinates (transformed to UTM) of the 29 check points. The average discrepancies (Δ) were -0.064m and -0.212m for the E and N coordinates respectively. The corresponding root mean square errors (rmse or σ_Δ) were 0.938m and 0.811m. A trend and accuracy analysis, based on the methodology proposed by Galo & Camargo (1994), was performed with the computed E and N discrepancies and standard deviations. Table 3 shows a summary of the figures involved. The trend analysis is based on the null hypothesis (H_o: Δ average = 0; H_1: Δ average $\neq$ 0) whose not rejection is given by the computed Student t statistics: 0.36 (E) and 1.41 (N) both are lesser than 1.7, the theoretical $t_{28;5\%}$.

Table 3 - Trend analysis and accuracy statistics

Parameter	*Δ (m)*	*σ_Δ (m)*	*t_{sample}*	*t(28;5%)*	χ^2_A	χ^2_B	χ^2_C	χ^2*(28;10%)*
E	-0.064	0.938	0.36	1.7	136.95	49.3	34.23	37.92
N	-0.212	0.811	1.41	1.7	102.21	36.79	25.55	37.92

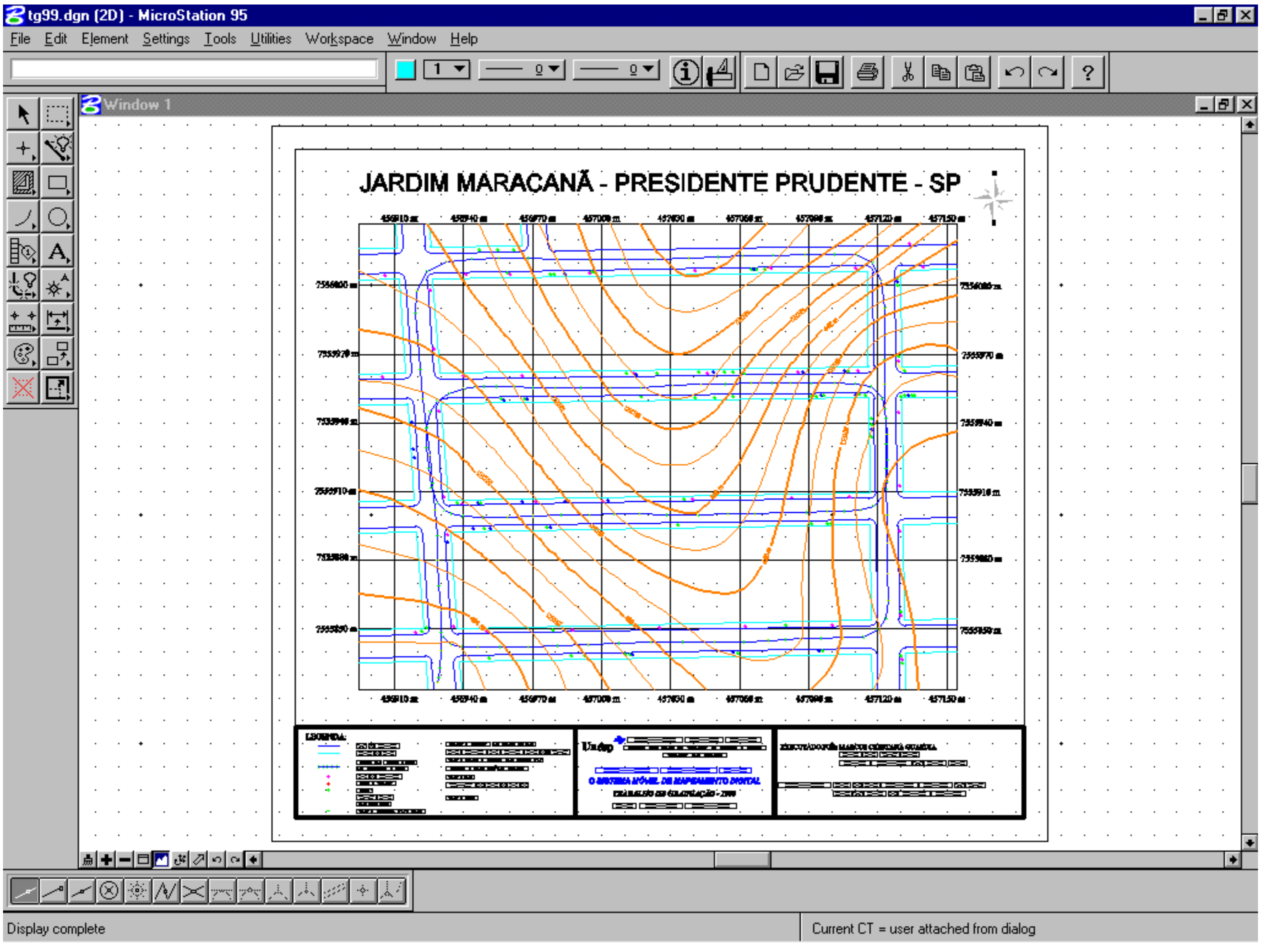

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Figure 7 - 1:2000 street map (reduced) built with data acquired by UMMD.

According to the Brazilian cartographic law, the standard error (SE) in class A maps is equal to 0.3mmM (M is the modulus or map scale factor), in class B SE is 0.5mmM, and in class C SE is 0.6mmM. Considering these map accuracy classes, the null hypothesis ($\chi^2_{comp} \le \chi^2_{(28;10\%)}$) is not rejected for class C maps at 10% statistical confidence level. In other words, 90% of all point coordinates extracted from the map are expected to have a planimetric error lesser than 2.0m (1.0mmM).

5 CONCLUSION

The project showed the potential of the mobile mapping technology to map urban streets. Photogrammetric traverse is an option to circumvent the absence of inertial systems in order to orient the images. The mainstream is hardly dependent on manual and visual operating work. This means a short time stay in the field and a much longer time in the lab. In the near future, new projects will rely on automated data acquisition both in the mobile unit or in the lab segment. The expected consequence is an improvement in data quality and faster processing and then a better accuracy of final product, which can be either a digital map or an image database or both.

In the educational domain, the observed result was the students' enthusiasm caused by the challenge of integrating different technologies to make a digital and line map. Their participation was highly motivated during the whole process. Although a MMS is not designed to make maps, the students had the opportunity to design and execute the project whose main characteristic was the integration of distinct technologies to make a map.

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