GPS CONTROL FOR DIGITAL MAPPING

Joseph Forrai

Chief, Research Division and Department of Photogrammetry
Survey of Israel

ISPRS Commission IV

ABSTRACT

With the improvement of productivity and the accuracy of analytical photogrammetry, new tasks have arisen. Large volume of very accurate, large scale, digital maps, are demanded by architects and civil engineers, and the geographic and land information systems require creation of up-to-date data bases. Consequently, photogrammetric mapping requires accurate, rapid and economic ground control more than ever before.

The GPS gives a very satisfactory answer for the increasing control demands. The author feels, that there are a number of coincidences between the GPS - and the photogrammetric philosophies. The analogies are reviewed in the paper.

For illustrating the wide range of applications, two photogrammetric GPS control networks are presented. One was designed for large-scale urban mapping for engineering purposes; the other is pilot project of a global, homogeneous control network for medium- and small-scale mapping and remote sensing, mainly aimed at the establishment of the topographic data base of our National Geographic Information System. The results achieved are briefly analyzed and discussed.

KEY WORDS: GPS, Ground Control, Digital Mapping, Photogrammetry.

1. INTRODUCTION

The increase of GPS applications is quite surprising. A few years ago GPS was considered a revolutionary (but rather expensive!) means for high order geodetic network densification, and - perhaps - for solving some difficult problems of different geoscience ramifications. Few of us thought seriously, that within a few years, GPS would dramatically break the bounds of higher geodesy and unhinderedly enter into the most usual, day-to-day surveying practice (Adler, 1985).

The ground control for photogrammetry is one of the most successful GPS surveying applications. Let's try to give some reasons why.

2. PHOTOGRAMMETRY AND GPS - KINSHIP IN FIGURATIONS

The "central receiver" of the photogrammetric procedure is the aerial camera. The aerial base vector ($\bar{b}$) is determined by the relative and "absolute" camera positions in two exposure moments. Two ground located GPS receivers are in a similar mutual position. The so-called position (or base) vector ($\bar{d}$) is a result of the relative and "absolute" position fix of the two GPS receivers.

The spatial configuration is somewhat alike in both cases (Figure 1). The disparity is, that in photogrammetry the control points are located on the ground and the base vector is "in the sky"; in GPS, inversely, the base vector is situated on the ground and the control points -the satellites- are located "in the sky". In both systems there is a relative motion between the "central receiver" and "control points". (As forward motion in photogrammetry, the consequent doppler effect is also compensated for in GPS!)

The theoretical ground for base vector determination, both in photogrammetry and GPS, is spatial resection, demanding certain additional mathematical manipulations for complete solution.

3. PHOTOGRAMMETRY AND GPS - FIELD REQUIREMENT SIMILARITIES

When choosing control points for photogrammetry, measured by any traditional method, the following requirements must be fulfilled:

a. Appropriate configuration from photogrammetric point of view (control for model, strip or block).

b. Appropriate configuration from geodetic point of view (intervisibility with other geodetic control points).

c. Well identifiable site for photogrammetric measurements (exact three dimensional reading in a photogrammetric instrument).

d. Suitable situation from aerial photographic point of view ("open sky").

The simultaneous fulfillment of the above postulates makes the field activity complicated by any classical way of measurements. But not by GPS! As no intervisibility is required between ground points (paragraph 'b' can be omitted), the choice of the suitable site becomes incredibly flexible including the very important requirement of paragraph 'c'. The requirement of the "open sky" stays relevant, as a trivial demand both for photo and GPS techniques.

4. GEODETIC CONSIDERATIONS

After fulfilling the field requirements, what are the further geodetic aspects of a good photogrammetric control ?

a. Sufficient geometry for the horizontal geodetic - photogrammetric control point configuration.

b. Very good inner agreement for horizontal and vertical photogrammetric control.

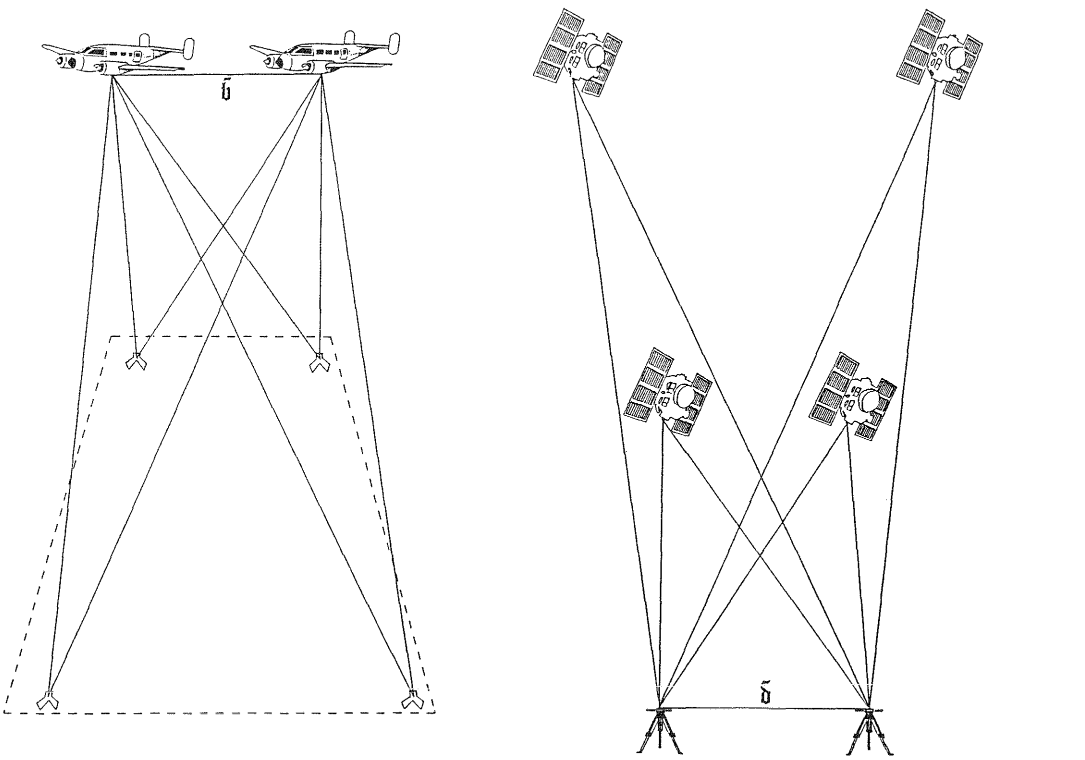

Figure 1. Photogrammetry and GPS - kinship in figuration

c. Harmony between the photogrammetric and geodetic (horizontal and vertical) control.

In classical methods, both the inner agreement and the "outer" harmony can be ensured by the national geodetic control network. Generally, direct measurements can not be completed between photo control points, therefore, the "inner accuracy" of the photogrammetric control will depend on the homogeneity of the supporting geodetic frame. However, the homogeneity of a national network in different regions is, many times, more than doubtful. Historical reasons partook in it, as well as professional - technical ones. The conventional partition of the national horizontal and vertical control nets is more definite! As a result, the recorded heights of the horizontal control points are, in general, definitely less accurate then their Y and X coordinates. For appropriate vertical control, photo points must be in addition, connected by levelling to the surrounding benchmarks. **Only GPS is able to treat the complex problem of the geodetic control for photogrammetry in a global, three dimensional and homogeneous manner.**

5. ECONOMY AND ACCURACY

It is impossible to give some generally valid formula for precise and economical computation. Practically every project is individual, and economy depends on the local circumstances and special conditions. Nevertheless, one can say, that GPS control for photogrammetry is, in almost every case, cheaper than any other geodetic method (Hajela, 1989). The larger and more complex a special project is, the higher saving is to be expected in time and money.

In respect of accuracy, GPS - superiority is unquestionable. In position 3-5 ppm inner accuracy for photo control points is usual, and achievable by a very customary and simple manner. This accuracy likely exceeds the photogrammetric requirements. As mentioned in paragraph 4, the agreement between photo control and the national geodetic network depends, mainly, on the accuracy and homogeneity of the latter. Very good results can be achieved, for instance, by a least square fitting of the adjusted and unchanged photo control configuration to the national horizontal control points.

In height, the GPS generally is slightly less accurate than in position, mainly because of the uncertainties of the geoid undulations. However, connecting with precisely levelled benchmarks and applying an appropriate and simple estimate for undulations (Melzer, 1990), even in large photogrammetric control networks, the absolute height accuracy will remain in the range of centimeters.

6. TWO PRACTICAL EXAMPLES

6.1 Engineering

In Haifa bay region, over an approximately 6X3 km site, 1:500 scale photogrammetric mapping was required for planning a new highway system. The accuracy standards of this engineering project would require carrying out an aerial triangulation based on 3rd order horizontal points. However, the special geographical situation and the limitation of the classical geodetic methods caused, historically, the total absence of high order control points over the complete planning area. Therefore, as solution, the whole geodetic control frame for the aerial triangulation (26 points in all) was measured by GPS based on three third order control points and four benchmarks (Figure 2). The average mean

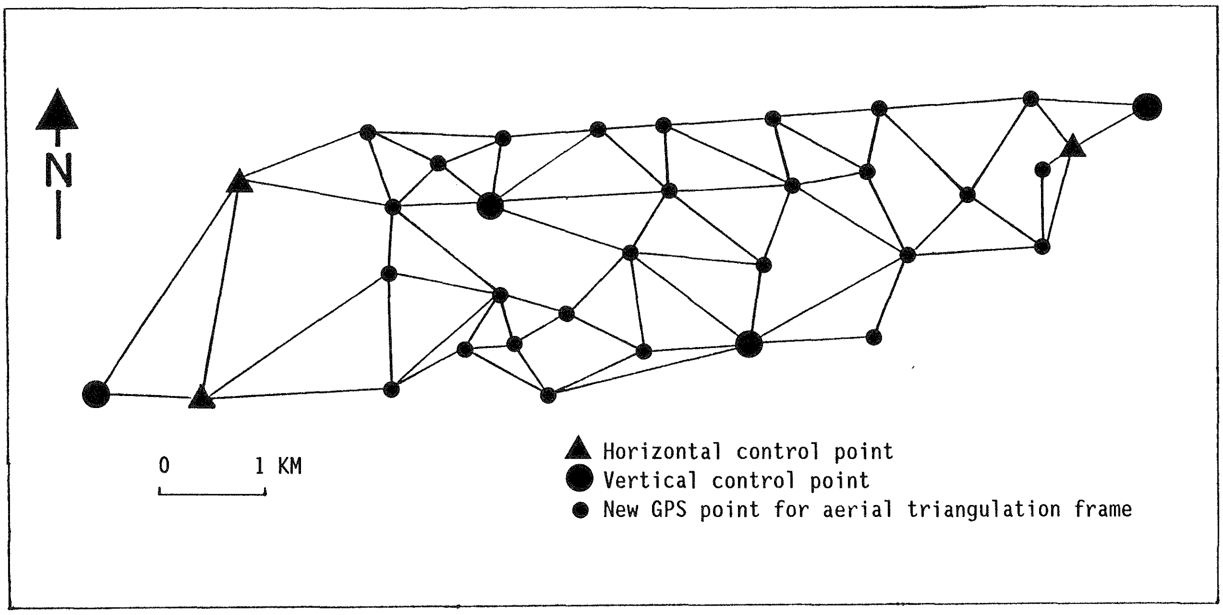

Figure 2. GPS frame for aerial triangulation, controlling an engineering project.

square error, including the eight control points within a one point fixed adjustment, is ±0.025 m in total position and ±0.021 m in height. (The maximum m.s.e. in position is ±0.041 m, and in height is ±0.034 m).

After completing an aerial triangulation for 40 models, situated in 4 strips (average scale is 1:6,000), one model was chosen - randomly - for a test. Nine premarked signals and fourteen, well identified details were measured in the field by the combination of GPS and total station, based on the GPS frame of the aerial triangulation. Subsequently, the measured signals and details were read by five different operators in five different stereoplotters (Wild SD-2000 and ADAM ASP-2000), when the orientation of the model was based on the appropriate model control (pricked on diapositives) previously determined by aerial triangulation. The comparison between field measurements and single readings in stereoplotters is given in tables 1 and 2. The differences between geodesy and photogrammetry, in absolute sense, both for premarked signals and identified details are smaller then 0.045 m in position and 0.08 m in height, (with clear systematic character). The accuracies (m.s.e. of a single geodesy-photogrammetry difference) are: for premarked signals ±0.06 m in position and ±0.07 m in height, for identified details ±0.12 m in position and ±0.08 m in height. Presumable, that the general accuracy of the field geodetic measurements were, both in position and height, on a ±0.03-0.05 meter level.

6.2 National GIS - Topographic Data Base

In 1991 a meaningful decision was made at the Survey of Israel to create the topographic data base of the national geographic information system by digital photogrammetric remapping of the country (Peled et al., 1991). The chosen photo scale is 1:40,000 for most of the regions. The pilot - the digital mapping of a nearly 40X40 km area - is just being in execution. The absolute accuracy standards for the well identifiable mapped details are rather rigorous: 2 meters in position and 2 meters in height for the mapped details. Aerial triangulation was carried out for the block, composed of 81 models in 8 strips. From geodetic point of view, the aerial triangulation was controlled, mainly, by existing and identified third (or higher) order classical triangulation points and benchmarks. The first results show, that horizontal accuracy is sufficient - but not the vertical one. The height accuracy is regionally inhomogeneous and differences between geodetic and photogrammetric heights exceed the standard, sometimes by 30-50%. The clear consequence is that the control frame for aerial triangulation must be completely measured by GPS. This method will ensure both local and global accuracy and harmony along this important, national dimensioned project.

7. SUMMARY AND CONCLUSION

GPS is the best tool today for geodetic control of digital photogrammetric mapping. It is fully digital in its nature, efficient, sure, rapid, accurate and relatively inexpensive. Until the subdecimeter accurate airborne GPS receiver, combined with some kind of cheep inertial system, will reduce or totally cancel the need of ground control (Baustert et al., 1991; Cannon et al., 1991; Dorrer and Schwiertz, 1990), GPS will be undoubtedly dominant in this activity.

8. ACKNOWLEDGMENTS

The assistance of the personnel of the Research, Photogrammetry and Field Divisions of the Survey of Israel is appreciated. Particular thanks to Ron Adler, Yossi Melzer and Sari Grossman for their support. Thanks to Mapping Technologies LTD., Armi Grinstein Geodetic Engineering LTD., and other private firms for their contribution to the paragraph 6.1.

Operator	Instrument	Number of premarked signals measured for X, Y and H	Average diff. between geodesy and photogrammetry and its standard deviation in meters		
			Y	X	H
1	SD - 2000	9	-0.01±0.05	0.00±0.06	-0.12±0.07
2	SD - 2000	9	-0.03±0.02	-0.02±0.03	-0.06±0.07
3	SD - 2000	9	-0.03±0.03	0.00±0.04	-0.12±0.05
4	ASP - 2000	9	0.00±0.03	-0.07±0.06	-0.01±0.04
5	ASP - 2000	9	-0.04±0.03	-0.09±0.06	-0.07±0.12
		Mean:	-0.02±0.03	-0.04±0.05	-0.08±0.07

Table 1. Comparison between field measurements (geodesy) and photogrammetry - **premarked signals**

Operator	Instrument	No. of details measured		Average diff. between geodesy and photogrammetry and its standard deviation in meters		
		for X,Y	for H	Y	X	H
1	SD - 2000	12	14	+0.04±0.11	0.00±0.11	-0.11±0.07
2	SD - 2000	12	14	-0.03±0.05	-0.03±0.08	-0.03±0.07
3	SD - 2000	12	14	-0.04±0.08	+0.03±0.06	-0.11±0.06
4	ASP - 2000	12	13	+0.02±0.09	-0.04±0.08	-0.04±0.07
5	ASP - 2000	12	14	+0.03±0.01	-0.05±0.06	-0.10±0.11
			Mean:	0.00±0.09	-0.02±0.08	-0.08±0.08

Table 2. Comparison between field measurements (geodesy) and photogrammetry - **identified details**

9. REFERENCES

Adler, R., 1985. A hybrid method of mapping and photogeodetic control network densification. Surveying and Mapping, 45(1):33-44.

Baustert, G., Hein, G.W. and Landau, H., 1991. Applying GPS to airborne Photogrammetry - determination of camera positions and flight navigation. In: IUGG - IAG XX General Assembly, Wien.

Cannon, M.E., Schwartz, K.P., Wei, M. and Delika-Raoglou, D., 1991. A consistency test of airborne GPS using multiple monitor stations. In: IUGG - IAG XX General Assembly, Wien.

Dorrer, E. and Schwiertz, C., 1990. Kinematic GPS and aerial triangulation - a comparative study. In: ISPRS Comm. III Symp. Progress in Data Analysis. Wuhan, China.

Hajela, D., 1989. Horizontal and vertical control for aerial triangulation for large scale mapping by GPS. Geodetical Info. Magazine, June, pp. 40-41

Melzer, Y., 1990. Orthometric Heights by GPS. Proceeding of GPS'90 International Symposium, Ottawa.

Peled, A., Adler, R. and Forrai, J., 1991. Accuracy considerations in creating a topographic data base. In: ACSM/ASPRS Fall Convention, Atlanta GA.