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Instituto de Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brasil

Geodetic Reference System and the Accuracy Estimates of the Brazilian GPS Network

JOÃO FRANCISCO GALERA MONICO¹, VIDAL ASHKENAZI²
AND TERRY MOORE²

¹Faculdade de Ciências e Tecnologia UNESP : Campus de Pres.Prudente - Rua Roberto Simonsen 305, CP 957, CEP 19060.900 - Presidente Prudente, SP, Brasil.

²Institute of Engineering Surveying and Space Geodesy (IESSG) - University of Nottingham, University Park, - NG7-2RD - Nottingham - UK

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Abstract - The solutions adopted in some countries for the provision of geodetic network suitable to GPS users are described. They have been found either by establishing an array of new passive control network or by the so-called Active Control System (ACS). Special attention focused on the Brazilian proposed solution, which is a GPS network of continuous satellite tracking. Within this concept, an user equipped with only one receiver can perform relative positioning. Tests were carried out in order to assess the precision that such an user can obtain, once the proposed network becomes operational. Results have showed relative precision in the range of 2 to 0.1 parts per million (ppm) for the height difference component and 1.3 to 0.05 ppm horizontally.

Resumo - As soluções adotadas em alguns países com a finalidade de adequar o sistema de referência com as atividades geodésicas efetuadas com GPS são descritas. Tais soluções têm sido o estabelecimento de uma nova rede passiva de pontos ou um Sistema de Controle Ativo (SCA). Atenção especial tem sido direcionada na proposição brasileira, a qual é uma rede com rastreamento contínuo dos satélites GPS, apresentando algumas características de um SCA. Alguns testes foram efetuados para verificar a precisão factível de ser obtida com a rede proposta. Resultados tem mostrado precisão relativa na ordem de 2 a 0,1 partes por milhão (ppm) para a diferença em altitude e 1.3 a 0.05 ppm para as diferenças nas componentes horizontais.

INTRODUCTION

The Global Positioning System (GPS) has revolutionised the positioning industry (surveying, mapping and navigation) and changed the concept of a geodetic control network mainly because of the high accuracy (relative positioning) and cost-effectiveness of the system. Surveys performed by GPS have provided precision of the order of 1 part per million (ppm) within a relatively short period of time. For longer periods, precision of a few parts per billion (ppb) has been reported (Dong and Bock, 1989; Monico, 1994). It is also conceivable that as the cost of GPS receivers reduce, almost all future geodetic (horizontal) surveys will be performed by GPS. However, the traditional geodetic networks, which have been extensively used so far, are inadequate for GPS users. This is not only with respect to precision but also because most of the horizontal control points are normally located on the highest point in the area and often are not easily occupied by GPS. It is therefore important that the organisations responsible for the maintenance of these networks provide a suitable solution to this problem.

The solution has been found either by establishing an array of new (passive) control points or by the so-called Active Control System (ACS). In Brazil, a GPS network of continuous satellite tracking stations, which has some characteristics of an ACS has been proposed (Fortes, 1991).

This paper outlines the solutions adopted in some countries for the provision of geodetic networks suitable for GPS users, with a special attention given to the Brazilian solution. This is preceded by a review of the basic concepts of GPS positioning. The tests carried out to assess the expected accuracy of the Brazilian network are also outlined, considering the observable, the use of either

precise or broadcast ephemerides for baselines ranging from 9 to 1000 Km.

GPS POSITIONING

GPS positioning can be performed either absolutely (only one receiver) or relatively (more than one receiver). In the former case, the user can generally almost freely choose the location of the station to be positioned whereas in relative positioning, one of the stations must be known and occupied. Access to the known station may be in some cases, a difficult and time consuming task.

Point (absolute) positioning is commonly processed using only the code (pseudorange) observable. The navigation accuracy achievable with GPS is of the order of 10 to 15 m using the restricted Precise Positioning Service and 100 m (95% probability) under the freely available Standard Positioning Service (SPS). Even after several days of observation the achievable absolute accuracy is not better than ± 5 m (Seeber, 1993). The high accuracy obtainable with GPS can not be achieved with "stand-alone" GPS, i.e. by point positioning.

To achieve better positioning accuracy with GPS, the satellite signals collected by two or more receivers must be combined and differenced (relative positioning). This approach greatly reduces the systematic errors present in the data. It should be pointed out that in relative positioning, any uncertainty in the base station position will transfer to the new stations. The use of the pseudorange in the differential approach is referred to as differential GPS (DGPS). In this case, one receiver is located at a known position providing means to compute corrections in the observations or position. These corrections are then broadcast to remote users for application to their observations or positions. Relative

navigational accuracy of approximately 2 to 3 m is successfully achieved (Seeber, 1993). It is, however restricted to a relatively small area. A more sophisticated approach is the Wide Area Differential GPS (WAGPS) (Ochieng 1993), in which a sparse network of GPS reference stations can provide real-time network DGPS corrections to users over a large region, or even globally.

High accuracy GPS positioning (geodetic accuracy) is achieved in the relative positioning mode using the phase measurements. In the static mode, relative accuracy of 10 cm has been achieved, depending on the time span of the observation, observable used, strategy applied and the reference system adopted. Results obtained by GPS similar to those of Very Long Baseline Interferometry (VLBI) have been reported in the literature (Heflin *et al*, 1992).

Other powerful relative positioning techniques exploring the capability of GPS are the Rapid Methods (Seeber, 1993) providing accuracy levels of the order of 10 cm within a few minutes. The carrier phase data are used as the basic observable with the code observables sometimes used to aid in the resolution of the integer ambiguity. These techniques, where the distance from the base station does not exceed 30 km, are very suitable for detailed surveying.

This short description of the GPS positioning shows the possibility of performing high accuracy surveying within a few minutes. Considering that the accuracy of the conventional geodetic networks (triangulation) is approximately 10 to 20 times worse (Hofman *et al*, 1992) than that obtained by GPS and that the stations are sometimes located on sites not easily accessible, the clear conclusion is that a new concept for the provision of geodetic networks should emerge. This should focus on the traditional as well as on the potential users. The next chapter describes the solutions to the provision of geodetic networks adopted by some countries.

GPS CONTROL NETWORKS

Conventional and GPS Control Networks

The conventional geodetic networks were generally surveyed by triangulation, traverse (or a combination of both) and by spirit levelling. The horizontal control network is normally separated from the vertical one with some common points. From the mid seventies, Doppler observations were used in the densification and control of these geodetic control networks. An example of network densification by Doppler observations, is the Brazilian Amazon where the coordinates were first estimated in the satellite datum and then converted to the particular national datum, with well known transformation formulas. In the United Kingdom and Republic of Ireland, distances derived from Doppler observations (translocation) were incorporated in the adjustment of the triangulation. This solution became known as OS(SN)80 (Ashkenazi, 1980). Similar solutions were adopted in other countries.

The conventional geodetic networks have been used to scale and orient maps to provide a unified reference frame for large scale projects and to provide a common datum for property surveys. As already stated, these networks in addition to being less accurate than required by GPS users, their points are normally located on hilltops or church and water towers and are often not easily occupied by GPS. Since almost all future geodetic surveys will be performed by GPS, the existing networks are inadequate.

It should be pointed out that GPS provides solutions on

a three-dimensional system with roughly the same degree of accuracy in the three components. However, the height differences measured by GPS are referenced to an ellipsoid and not to the geoid to which conventional levelled heights refer. Therefore, the potential use of GPS as a levelling tool requires additional solution, which is related to a local or regional geoid model.

The solution to the problems briefly outlined was found either by establishing an array of new (passive) control points or by the so-called Active Control System (ACS).

Passive Control Network

The concept of a passive control network, involves the installation of a completely new network within a global geocentric reference datum, compatible with the World Geodetic System 84 (WGS-84), defined with an accuracy of about 1 to 2 m. As the station coordinates of the International Terrestrial Reference Frame (ITRF) sites are accurate to about 0.1 m or better, it is advisable to use the ITRF reference frame instead of WGS-84. At a continental or sub-continental GPS network level, the fiducial concept is used (Ashkenazi *et al*, 1989). The inter station distance should be between 300 and 500 Km, with about one week of observation carried out by dual frequency receivers. An example is the EUREF (EUropean REference Frame) project, with about 90 stations, performed with about 60 dual-frequency receivers in 1989. In 1990, 30 stations were added during the EUREF North Campaign. At a national GPS network level, the stations in the network are installed with a spacing of 25 to 100 Km, depending of the size of the country and objectives. In the processing of the national network, the stations of the continental level may be held fixed as fiducial points.

In Great Britain, where six EUREF sites are located, an intermediate network between the continental and national networks is being installed, referred to as Scientific Network. It consists of 27 stations spaced at approximately 100 to 150 Km and includes the local EUREF stations (Wilson & Christie, 1992). The National GPS Network comprises 538 stations, spaced at 20 to 25 km around urban centres and more relaxed in rural areas. Many existing primary and secondary triangulation stations have been incorporated into the GPS network in order to provide transformation between the WGS-84 and the UK national mapping datum (OSGB36). In order to provide vertical control, some stations of the National GPS network are being directly connected to the levelling network. This will provide control for the geoid model enabling height changes to be monitored using GPS observations alone (Christie, 1992). The network stations were selected such that they will make ideal sites for GPS occupation. Thus, they should be accessible 24 hours a day by two wheel drive vehicles in all weather conditions.

In Germany, 109 stations with a mean spacing of 70 to 100 Km were observed with 83 dual frequency receivers. Some 20 stations are EUREF sites (Seeber, 1993). Another similar network is the Tennessee Geodetic Reference System Network (Zeigler, 1988), consisting of 60 control stations. It has been designed such that no location in the state would be farther than 25 km from a control station.

This new concept of a geodetic network will consist mainly of Continental and National networks and the division of geodetic networks into first to fourth order within a country will disappear.

A solution to the existing terrestrial network is the combination with new GPS observations. The existing network datum is maintained but the complete network is

readjusted and strengthened with the inclusion of GPS measurements. New points can also be introduced into the existing network. The Readjustment of the Triangulation of the United Kingdom and the Republic of Ireland in 1980 used a similar approach, but with Doppler observations (Ashkenazi *et al*, 1980).

Active Control System

The main drawback of the passive control networks is that users have to occupy one or more stations in order to determine the position of the new ones. The user has therefore to have access to at least two receivers. An Active Control System (ACS) is a GPS-based system of fixed receivers continuously tracking all visible satellites and relaying the information via a communication link to a central Master Active Control Station (MACS). The GPS tracking stations are called Active Control Points (ACP), in which all operations should be performed automatically. Figure 1 illustrates the major components of an ACS. The user showed in Figure 1 can access the information from the ACP, either via a communication link (communication satellites) or off line via floppy disks. The former case refers to a real-time user (navigation) and the last one a static one, which essentially post process the data. Information available from MACS can be accessed by the users using telephone and Internet links. The principal elements of each ACP are depicted in Figure 2. An ACP unit would mainly consist of one dual frequency receiver capable of tracking all satellites in view and a microcomputer to control the functions of the system. Meteorological sensors, communication interface and a continuous power supply are essential as well.

The MACS controls the operation of the ACPs, processes the information obtained from the ACPs, performs data management and monitors the integrity of the GPS constellation. Besides this, it computes satellite orbit and provides real-time and post mission GPS related information to the user community via a communication link.

It is clear from the description of the system that a user with only one receiver can perform relative positioning and estimate the coordinates related to the reference frame of the ACS. As such, there is no need to occupy an existing control point. The coordinates of the ACPs may be computed using the fiducial concept. The International GPS Service for Geodynamics (IGS) network (Neilan and Noll, 1993) can be thought as a global ACS.

Figure 1 - Active Control System Concept

Figure 2 - Active Control Point Components

The Canadian ACS provides an example of a national ACS, the details of which have been reported by Delikaraoglou *et al* (1989). At the national level the ACPs are spaced at about 500 Km (approximately 20 ACPs), providing the framework for the country. The provincial component will be more dense, with approximately 250 Km spacing. In British Columbia, the proposed ACS has an average station spacing of the order of 450 Km and is expected to satisfy all positioning requirements (Underhill *et al*, 1992).

BRAZILIAN GEODETIC SYSTEM

Present status

The Brazilian Geodetic System (SGB) has been developed and maintained by the Brazilian Institute of Geography and Statistics (IBGE). The levelling network of approximately 60,000 points has recently been readjusted. The horizontal network is composed of 6,209 points (3,498 triangulation points, 1,158 traverse points, 26 Hiran points, 384 Laplace points and 1,143 satellite (Doppler) points). It is currently being readjusted using the software GHOST (Geodetic adjustment using Helmert blocking Of Space and Terrestrial data). This software is composed of a series of programs developed to adjust three-dimensional geodetic networks by the least-squares method, using the decomposition of the network into blocks (Helmert blocks). Measurements derived from GPS are planned to be introduced in the readjustment of the conventional horizontal network. They will aid in the realisation of the Brazilian Geodetic System whose origin is the same as that of the South American Datum 1969 (SAD-69). This solution represents a preliminary answer to the Brazilian geodetic community (Costa and Pereira, 1994; Costa and Fortes, 1991).

The transformation from SAD-69 to World Geodetic System of 1984 (WGS-84) and vice-versa adopted in Brazil is realised only by 3 translation parameters (X, Y and Z). They were estimated from 24-days of Doppler data collected at the origin of the SAD-69 (Station CHUA) using precise ephemerides (Fortes *et al*, 1989). Recent assessment of the WGS-84 coordinates of CHUA has shown an agreement of the order of 0.4 m with respect to the corresponding ITRF coordinates (Monico *et al*, 1994). This result agrees with the expected accuracy of the WGS-84. However, these parameters are expected to degrade as a function of distance from the origin. Considering that the conventional network provides relative precision of the order of 10 ppm, the expected discrepancy at a point located 1,000 Km from the origin is about 10 m. An error of this order of magnitude in the absolute position of a station in the WGS-84 may cause an error in the ellipsoid height difference of up to 2 ppm (Breach, 1990). Therefore, the Brazilian geodetic

community should be aware and expect errors of this order or even worse when applying these transformation parameters at stations located far from the origin of the SAD-69. Once the readjustment of the SGB has been completed, better results might be obtained, depending on the precision of the realisation of the new system.

Future Developments

It is clear from the previous section that for a more powerful use of GPS, additional solutions should take place in Brazil. IBGE has proposed the development of a Brazilian Network for continuous tracking of the GPS satellites. This network will consist of 9 tracking stations (Fig. 3). It is intended that this network will, in the future, replace the conventional one. Details of the network reported by Fortes & Godoy (1991) show that the network will have some characteristics of an ACS. From the configuration of the network, GPS users will place their receivers at a spacing of up to 500 Km from the nearest station. Exceptions occur in the Amazon region and Southern of Brazil, where they can reach about 1,700 and 900 Km respectively. This situation can be improved by the inclusion of some IGS stations located in South America, whose data are available to the users at different IGS centres (Neilan and Noll, 1993). In such cases, only static users can take advantage of this situation, because IGS data is not available in real-time. Figure 3 also includes the six IGS stations, besides those belonging to the proposed Brazilian GPS network. The station Fortaleza, located in the Brazilian territory, belongs to the Brazilian and IGS networks. The inclusion of stations Kourou, Arequipa, Bogota and La Plata may be useful because some regions in Brazil are closer to these stations than those of the Brazilian GPS network. In such a case, the maximum distance from the nearest station is about 900 km.

The description of the present situation and future developments of the SGB shows that the solutions which have been carried out in Brazil might give support to the Brazilian GPS users. Once the Brazilian network becomes operational, it will represent the culmination of the Brazilian geodetic system. An ideal situation by that time would be to have the mapping system of Brazil and its National Grid transformed on the satellite datum (WGS-84 or ITRF). This is a long term possibility, which requires to have all maps in digital form and then to carry out a massive transformation of all data involved. Therefore, the estimation of precise and reliable transformation parameters between the reference systems involved is essential to obtain the maximum benefits of this crucial task.

ASSESSMENT OF THE EXPECTED ACCURACY OF THE BRAZILIAN GPS NETWORK

The main goal of the Brazilian GPS network of continuous satellite tracking is to serve as a base and framework to support static relative positioning to an accuracy of the order of 0.1 ppm. Studies documented in GPS literature have shown relative accuracy better than 0.1 ppm (Anderson *et al*, 1993; Ashkenazi and Ffoulkes-Jones, 1990; Dong and Bock, 1989). To achieve this level of accuracy, the fiducial GPS technique has to be used. It involves the simultaneous determination of high precision satellite orbits and other bias parameters, as well as the required inter-station coordinate differences. The data processing requires state-of-the-art software, such as, GPS Analysis Software (GAS) developed at Nottingham University (Stewart *et al*, 1994) or GPS Inferred Positioning System (GIPSY) of Jet Propulsion Laboratory (JPL) (Blewitt, 1989).

Figure 3 - Proposed Brazilian GPS Network and some IGS Stations

Most of the ordinary users in Brazil will not have access to state-of-the-art software for data processing and will therefore rely on the use of software supplied by the manufactures. It was therefore necessary that some tests were carried to try to simulate the future situation in Brazil. The main objective was to assess results obtainable by GPS users, with only one receiver, once the Brazilian GPS network becomes operational. The assumption is that the user will have access to GPS data of the (nearest) stations of the network, either via a communication link or off line via floppy disk (Figs. 1 and 2). In both cases, only static positioning has been assessed.

Data Sets and Processing Strategies

An ideal situation to perform the tests would require GPS data from Brazil. As this was not possible at the time, data from Europe, available at Nottingham University was used.

The data sets refer to the 1991 and 1992 GPS Campaign of the UK Tide Gauge GPS Project. It comprises 7 fiducial stations in Europe and 15 regional stations in the United Kingdom. Observations were taken during an 8-hour window, for 5 consecutive days with 20 dual frequency receivers. Tests showed that these GPS data set are of very high quality (Ashkenazi *et al*, 1993a).

The processing of the 1991 data set was carried out using the fiducial technique and the estimated coordinates of the stations were considered as the 'true' values. The result of this processing agrees quite well with the ITRF91N (Ashkenazi *et al*, 1993b). Baselines ranging from 7 to 1000 Km of the 1992 data set were processed with different strategies and compared with the 'true' values. The differences between the 'true' and estimated values represent the strength of the recovery of each strategy. The processing was carried out with the GPS Analysis Software (GAS) developed at Nottingham University (Stewart *et al*, 1994). Only the baseline processing option was used.

Table 1 gives details of the scenarios used for different strategies. In scenarios (a) and (b) the Jet Propulsion Laboratory (JPL) precise ephemerides were used. In the former case, the observable used was the ionospheric free observable and in the last case, the L1 carrier phase was used.

Scenarios (c) and (d) were carried out with ionospherically free and L1 carrier phase observables respectively, in conjunction with broadcast ephemerides. For each test, data processing covering observation time spans of one, two and five hours was carried out.

Scenarios	Ephemerides	Observable
(a)	JPL precise	Ion-free
(b)	JPL precise	L1 carrier
(c)	broadcast	Ion-free
(d)	broadcast	L1 carrier

Table 1- Scenarios Tested

Results and Discussion

The baseline recoveries for the test using the JPL precise ephemerides and ionospherically free observable, which represents scenario (a) are illustrated in Figure 4. It can be seen (as expected) that better recoveries are obtained as more GPS data is involved in the data processing. The height component recoveries show the poorest results, followed by the east component.

The worst recoveries were of the order of 22 and 30 cm for the east and height baseline components respectively. In the former case such value was obtained with 2 hours of GPS data and in the latter, 1 hour of data was involved. With 2 and 5 hours of data, the recoveries of the height component were better than 15 cm for most of the baseline lengths. For

all data span, the recoveries of the north component (better than 10 cm) were better than the east component (up to 22 cm). This is probably due to the fact that the GPS satellite provided a better geometry for the determination of the north component. The length component provided recoveries always better than 12 cm, for all data span and baseline lengths.

For the other tests carried out in order to try other user scenarios in Brazil, only the recoveries for the length and height components are presented. The former gives an indication of the quality in the three cartesian coordinates, and the latter generally represents the worst case of the three components. Therefore, if the recoveries derived from the tests taking into account these two components are acceptable, they are likely to be for the north and east components as well.

The recoveries for the processing with JPL precise ephemerides and the L1 carrier phase observable are given in Figure 5. It can be seen that for shorter periods of observation, the recoveries for baselines longer than 50 km deteriorate. For longer baselines, the recoveries for one and two hours of data are very inconsistent. It is due to the effects of the ionosphere which were not taken into account and do not cancel out over long baselines, neither they average out over short period of observations. For a longer period of observation (5 hours), the height component recoveries reduce from 2.5 m to about 50 cm and from 2.0 m to about 80 cm for the length component. The recoveries of the latter were on average 40 cm.

Figure 4 - Recoveries for JPL ephemerides and Ionospherically free observable

Figure 5 - Recoveries for JPL ephemerides and L1 observable

Figure 6 - Recoveries for broadcast ephemerides and Ionospheric free observable

Figure 7 - Recoveries for broadcast ephemerides and L1 observable

The results of the tests carried out with broadcast ephemerides in conjunction with ionospheric free and L1 carrier phase observable are illustrated in Figures 6 and 7, respectively. As expected, the recoveries of the tests with broadcast ephemerides are worse than those with the precise ephemerides, since the same observable is taken into account.

The effects on the recoveries are more significant for baselines longer than 100 Km, in which the errors of the broadcast ephemerides are not cancelled out. The height component recoveries for scenario (c), (see Fig. 7) reach about 80 cm in the data processing with 5 hours of data. The length component recoveries reach at maximum 20 cm. One can

observe that with data span of 1 and 2 hours, the height component recoveries are generally better than those of 5 hours. It is due to the fact that the broadcast ephemerides were used beyond the ‘valid’ interval (2 hours) in the longer data span.

The test of scenario (d), ie broadcast ephemerides and the L1 carrier phase (Fig. 7) demonstrated that considering 1 hour of data the recoveries of the height component can reach, for the longer baselines, almost 3 m. They reduce to better than 1 m for data span of 5 hours. The recoveries of the height components for the shorter intervals do not behave as in the previous scenario (ie shorter interval with better recoveries than those of longer intervals), because the ionospheric effects, which were not taking into account in this scenario, are more significant than the errors of the broadcast ephemerides beyond the ‘valid’ interval. The ionospheric effects do not average out over short intervals. For the length component, the recoveries reach 2 m for 1 hour of data and reduce to better than 1.50 m and 50 cm for 2 and 5 hours respectively.

In order to obtain a more convenient description of the results, a linear fit through the recoveries of length and height components obtained from all the tests was carried out. The resulting values, which are given in Table 2, provide an average value of the repeatabilities as function of the baseline length.

Strategies	Length component			Height component		
	1 Hour	2 Hours	5 Hours	1 Hour	2 Hours	5 Hours
ION-FREE and Precise Ephem.	0.1 ppm	0.1 ppm	0.04 ppm	0.22 ppm	0.17 ppm	0.13 ppm
L1 and Precise Ephem.	1.0 ppm	0.8 ppm	0.6 ppm	1.5 ppm	1.5ppm	0.5 ppm
ION-FREE and Broad. Ephem.	0.3 ppm	0.2 ppm	0.1 ppm	0.4 ppm	0.4 ppm	0.6 ppm
L1 and Broad. Ephem.	1.3 ppm	1.0 ppm	0.5 ppm	1.8 ppm	1.9 ppm	0.7 ppm

Table 2 - Linear Fit of the Baseline Recoveries for the Tested Scenarios

The values given in Table 2 show recoveries in the range of 1.3 to 0.1 ppm and 2 to 0.1 ppm for the length and height components respectively. With a single frequency receiver collecting 1 hour of data, precision better than 2 ppm is expected for height, and 1.3 ppm for length, independently of using either broadcast or precise ephemerides. With 5 hours of data, such values reduce to about 1 ppm. Once 1 hour of data of a dual frequency receiver is used in conjunction with the precise ephemerides, precision better than 0.2 ppm for the length and height components has been demonstrated. Both components do not improve significantly by increasing the interval of data collection. Dual frequency receiver, broadcast ephemerides and 1 hour of data collection have shown results better than 0.4 ppm for the length and height components. The latter become worse for longer intervals due to the fact that the broadcast ephemerides were being used beyond the valid interval.

The values given in Table 2 show the expected accuracies that can be obtained by a GPS user equipped with only one receiver in a region with an ACS, taking into account four different scenarios. Once the Brazilian GPS network becomes operational, relative positioning accuracies at these levels are expected for baseline data processing. However, as the tests were carried out using data from Europe, it would be advisable to repeat some of these tests using data from Brazil, once data are available. The data collected during the

recent SIRGAS campaign (May-June 1995) may be used.

It has to be pointed out that although the results of the data processing using only a single baseline have provided very high precision, they are not very reliable. Therefore, the concept of reliability within the context of an ACS must be further investigated.

CONCLUSIONS

The solutions adopted by some countries in the provision of geodetic networks for using GPS as the main positioning system have been described. The general tendency has been the establishment of new passive networks, retaining some stations of the conventional network, in order to provide a set of parameters to realise the transformation between the two systems. However, the state-of-the-art geodetic network is the so-called Active Control System (ACS). Within such system, users equipped with only one receiver can perform relative positioning without occupying any control point. The proposed Brazilian GPS network has some characteristics of an ACS and is expected to give total support to the demands of the Brazilian GPS users.

Tests carried out to assess the expected precision obtainable by a GPS user in Brazil equipped with only one receiver have shown that results in the range of 2 to 0.1 ppm can be obtained for the height component. For the first case (2 ppm), a single frequency receiver and broadcast ephemerides are the requirements. In order to obtain precision of the order of 0.1 ppm, a dual frequency receiver is required and the satellite positions must be computed from precise ephemerides. The results of the North and East components are slightly better than the Length and Height component, respectively.

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REFERENCES

Andersen P. H., Hauge S. & Kristiansen O. 1993. GPS Relative Positioning at a Precision Level of one Part Per Billion, *Bulletin Géodésique*, 67 (2) : 91-106.

Ashkenazi V., Crane S. A., W. J. & Williams J. W. 1980. The 1980 Readjustment of the triangulation of the United Kingdom and the Republic of Ireland OS(SN)80. *Ordnance Survey Professional Paper New Series*, 31, p. 45

_____, Moore, T., Ffoulkes-Jones, G.H., Whalley, S. & Aquino M. 1989. High Precision GPS Positioning by Fiducial Technique. In : Bock Y, Leppar N (eds) : *Global Positioning System: an overview*. Springer, London. p. 195-202.

_____, & Ffoulkes-Jones G.H. 1990. Millimeters Over Hundred of Kilometres by GPS, *GPS World*, 1, (6): 44-47.

_____, Bingley R. M. & Whitmore G. M. 1993a. *Reference Framework for Fiducial GPS*, IESSG Publication, University of Nottingham, Nottingham, p.30.

_____, Bingley R. M.; Whitmore G. M. & Baker T. F. 1993b. Monitoring Changes in Mean-Sea Level to Millimeters Using GPS, *Geophysical Research Letters*, 20 (18): 1951-1954.

Breach M. C. 1990. The importance of accurate coordinates of a known station in precise relative positioning, *Survey Review*, 30: 398-403.

Blewitt, G. 1989. Carrier Phase Ambiguity Resolution for the Global Positioning System Applied to Geodetic Baselines up to 2000 Km, *Journal of Geophysical Research*, 94 (B8): 10187-10203.

Christie R. R. 1992. *Pillars in the sky*, (Paper presented at Civil Engineering Surveying Conference, Keele University, April 1992.)

- Costa S. M. A & Pereira K. D. 1994. *Processamento da Rede GPS Brasileira e Ajustamento Combinado com a Rede Classica*, Departamento de Geodésia, IBGE, Rio de Janeiro, p. 11.
- _____. & Fortes 1991. *Ajustamento da Rede Planimétrica do Sistema Geodésico Brasileiro*, Departamento de Geodésia, IBGE, Rio de Janeiro, p. 7.
- Delikaraglou D.; Steeves R.R. & Beck N. 1986. Development of a Canadian Active Control System Using GPS, In: *Proceeding, 4th International Geodetic Symposium on Satellite Positioning*, Austin, Texas, p. 15.
- Dong D. & Bock Y. 1989. Global Positioning System Network Analysis with Phase Ambiguity Resolution Applied to Crustal Deformation Studies in California, *Journal of Geophysical Research*, **94** (B4): 3949-3966.
- Ffoukes-Jones G.H. 1990. *High Precision GPS by Fiducial Techniques*, PhD Thesis, University of Nottingham. 189 p.
- Fortes L.P.S. 1991. Brazilian Network for Continuous Monitoring of the Global Positioning System - RBMC In: Mader, G. L. *Permanent Satellite Tracking Network for Geodesy and Geodynamics*, Springer Verlag, Wien, p. 95-101.
- _____.; Cagnin I.F. & Godoy R.A.Z. 1989. Determinação dos Parâmetros de Transformação entre os Sistemas NWL-10D, NSW-92Z, WGS-84 e o SAD-69. *Anais, 14^o Congresso Brasileiro de Cartografia*, Gramado, 1: 157-165.
- _____. & Godoy R.A.Z. 1991. *Rede Brasileira de Monitoramento Contínuo do Sistema de Posicionamento Global-GPS*, Departamento de Geodésia, Diretoria de Geociências, IBGE, Rio de Janeiro, p. 8.
- Heflin M.; Bertiger W.; Blewitt G.; Freedman A.; Hurst K.; Lichter S.; Lindqwister V.; Vigue Y.; Weeb F.; Yurck T. & Zumberge J. 1992. Global Geodesy Using GPS without Fiducial Sites, *Geophysical Research Letters*, **19**, (2): 131-134.
- Hofmann-Wellenhof B.; Lichtenegger H. & Collins J. 1992. *GPS Theory and Practice*, Springer-Verlag, Wien, 326 p.
- Neilan R. E. & Noll C.E. 1993. The IGS Core and Fiducial Networks: Current Status and Future Plans. *Proceeding, IGS Workshop Berne*, University of Berne, Berne, p.32-41.
- Monico J. F. G. 1994. *High Precision Inter-continental GPS Network*, PhD Thesis, University of Nottingham, 205 p.
- _____.; Moore T & Ashkenazi V. 1994. Preliminary results of the IGS Epoch '92 Campaign in Brazil, *IAG Courier for Development*, Newsletter (3): 3-5.
- Ochieng W. Y. 1993. *Wide Area DGPS And Fiducial Network Design*, PhD Thesis, University of Nottingham. 246 p.
- Seeber G. 1993 *Satellite Geodesy: foundations, methods and applications*, Gruyter, Berlin, New-York. 531 p.
- Stewart M. P.; Ffoukes-Jones G. H. & Ochieng W. Y. 1994. *GPS Analysis Software (GAS) Version 2.2 User Manual*, IESSG Publication, University of Nottingham, UK. p. 130.
- Underhill and Underhill, Usher Canada Limited & UGC Consulting Ltd. (1992). *British Columbia active control sytem application, definition and feasibility study*, British Columbia Ministry of Environment and Parks- Survey & Resource Mapping Branch. 163 p.
- Zeigler H. J. (1988) GPS Geodetic Reference System in Tennessee, *Journal of Surveying Engineering*, **111** (4): 156-164.