VRS concept using NWP and Mod_Ion_FK: Preliminary Results in Brazil

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SUMMARY

Nowadays, the use of multiple reference stations has had a great growth, mainly because this kind of procedure overcomes the limitations of standard real time kinematic (RTK) systems. Using multiple reference stations it is possible to model the atmospheric effects (troposphere refraction and ionosphere effect) and to reduce the satellite orbit errors. Another important question concerning this topic is related to the transmission of the network corrections to the users. There are some possibilities for this and an efficient one is the Virtual Reference Station (VRS) concept. In the VRS concept, a base station is generated near to the rover receiver (user). The preliminary results obtained from an in-house software which has been developed at São Paulo State University (UNESP), Brazil, are presented in this paper. In this software, it was used multiple reference stations data and atmosphere models developed by Brazilian researches to generate the VRS. In relation to the troposphere, it was used zenithal tropospheric delay (Z_{TD}) predicted from a model of Numerical Weather Prediction (NWP) and the Niell mapping function. In relation to the satellite orbit, IGU precise ephemeredes provided by IGS were used to reduce orbit errors. Concerning the ionospheric effects, the Mod_Ion_FK model, developed at UNESP, has been used. Mod_Ion_FK and Z_{TD} from NWP performance for network RTK using the VRS concept are the main topics of this paper. So far, no attempt was done for solving the ambiguities as fixed among the reference stations. The preliminary results provided accuracy of the order of 7.5 cm in the resultant processing the generated VRS in Precise Point Positioning (PPP) and 25 cm considering relative positioning between the VRS and the real file collected at the same position.

Network RTK: Preliminary Results in Brazil

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1. INTRODUCTION

Several positioning techniques have been developed to explore the GPS capability to provide precise coordinates in real time, such as RTK method. However, this kind of positioning is restricted by the de-correlation of the ionospheric effect, tropospheric refraction, and satellite orbit errors. In order to solve this problem, the concept of network RTK has been extensively used.

Using the network RTK concept it is possible to obtain more availability, accuracy and reliability in the positioning if compared with conventional RTK method (ALVES et al., 2003, FOTOPOULOS, 2000). Besides, using network RTK positioning, it is possible to model the distance dependent errors, such as ionosphere effect (WANNINGER, 1999; COLOMBO et al., 2002; ODIJK, 2000b) and troposphere refraction (SEEBER, 2003). The errors derived from satellite orbits can be minimized using precise orbit provided by International GNSS Service (IGS).

Several methods have been developed to formulate corrections from network stations data: Partial Derivative Algorithms (WÜBBENA, 1996; FOTOPOULOS, 2000; VARNER, 2000), Interpolation Algorithms (GAO and LI, 1998; ODIJK, 2000a), Condition Adjustment Algorithm (RAQUET, 1998; FORTES, 2002; FOTOPOULOS and CANNON, 2000) and Virtual Reference Station (VRS) (ZHANG and ROBERTS, 2003; van der MAREL, 1998; HU et al., 2003; RETSCHER, 2002). The first three methods concentrate in correction generation, which require changes of rover (user) receiver software, while the last one generates a virtual station near the user, which is compatible with the rover existing software. Therefore, in this research, it was decided to use the VRS concept, which may be quite useful in Brazil.

The VRS data are not provided by a real receiver, but its data are generated from real GPS observations collected by an active multiple reference station network. The idea is that the VRS data resemble as much as possible a real receiver data at the same location. Therefore, the user has the possibility of using the VRS as if it were a real reference station in your proximities, and to accomplish the relative positioning with a single frequency receiver (ALVES, 2006).

In this paper, preliminary results obtained from an in-house software which has been developed at São Paulo State University (UNESP), Brazil, are presented. In this software, multiple reference stations data, Mod_Ion_FK (section 2.1) and ZTD from NWP (section 2.2) were used to generate the VRS data. So far, no attempt was done to solve the ambiguities and compute the residual errors from the network. This will be tackled in a next step, in which the cited models will also be used to try to improve the ambiguity solution.

2. ATMOSPHERE MODELS

In this section, the ionosphere and troposphere models used in this research will be presented. In relation to the ionosphere model, aspects related to Mod_Ion_FK will be discussed. Otherwise, concerning the troposphere, the NWP model will be treated.

2.1 Ionosphere Model

In the absence of the limitation imposed to the civil users by the United State Department of Defense, through the adoption of the Selective Availability (SA), the ionosphere is the largest error source in the positioning for single frequency GPS users. It affects directly the point positioning technique, while in the relative positioning of short baselines, this degradation is practically eliminated. The errors due to the temporary behavior of the ionosphere, which depends on several variables, such as: time of day, season, solar cycle, geographical location of the observer and geomagnetic field of the Earth, are difficult of being corrected.

A general description of ionosphere models for correcting data collected from single frequency GPS receiver, of global, regional or local scale, can be found in Camargo (1999). Most of these models have as input the pseudoranges or the carrier phase measurements collected by dual frequency receivers.

In the derivation of a model, errors due to the non-synchronism between the satellite and receiver clocks, ephemerides and tropospheric refraction won't be considered. These errors contaminate the measurements made in both frequencies in same way and do not affect the development of the model. It is based on the difference between the two original pseudoranges ($P^s_{1_r}, P^s_{2_r}$) or pseudoranges filtered by the carrier phase. It is expressed by (CAMARGO, 1999; CAMARGO et al., 2000):

$$F(P^s_{2r} - P^s_{1r}) = I^s_{1r} + F[(S^s_{p2} - S^s_{p1}) + (R_{p2} - R_{p1})_r] + F\varepsilon_{P_{21}}, \quad (1)$$

with $F = f_2^2/(f_1^2 - f_2^2)$, *s* representing the satellites and *r* the receivers.

Equation (1) is used to estimate the ionospheric slant delay (I^s_{1r}) in the L_1 carrier. The differences ($S^s_{p2} - S^s_{p1}$) and $(R_{p2} - R_{p1})_r$ represent, respectively, the L_1-L_2 satellites and receivers interfrequency biases and the $\varepsilon_{P_{21}}$ represents differential unmodeled errors. The ionospheric delay along the path linking the satellite and receptor can be obtained as function of the vertical ionospheric delay (I_1^v), using an geometric mapping function, thus:

$$F(P_{2r}^s - P_{1r}^s) = \frac{I_1^v}{\cos(z'^s)_r} + F\,[(S_{p2}^s - S_{p1}^s) + (R_{p2} - R_{p1})_r] + F\varepsilon_{P21}, \qquad (2)$$

where z'^S is the zenital angle of the satellite signal path, in relation to a simple ionospheric layer.

Mod_Ion_FK was implemented in FORTRAN Lahey 95, with the objective of estimating the unknown parameters of the model and provides corrections to the L_1 carrier observables in real time. These parameters consist of the coefficients of the series and the L_1-L_2 interfrequencies of the L_1 carrier from the satellites and receivers. They are estimated through the Kalman Filter (KALMAN, 1960) and the Gauss-Markov process (GELB et al., 1974) for prediction. As a modeling function, a 19 coefficient Fourier series is used (AGUIAR, 2005). This model presented good results for a simulated real time Precise Point Positioning (PPP) test. So, its efficiency will be tested in RTK Network positioning.

2.2 Troposphere Model

Nowadays, the use of Zenithal Tropospheric Delay (Z_{TD}) prediction from models of Numeric Weather Prediction (NWP) (KINTER et al., 1997) is a good alternative to minimize the effects of the troposphere in the radio frequency signs for real time applications. This process is denominated Z_{TD} Dynamic Modeling (SAPUCCI et al., 2006). Center for Weather Forecasting and Climate Studies of the National Institute for Space Research (CPTEC/INPE) has made available operationally Z_{TD} prediction for South American region (available in: http://satelite.cptec.inpe.br/htmldocs/ztd/zenital.htm). This modeling technique has already been explored by others researcher and good results were found (JENSEN et al., 2003; JUPP et al., 2003; SCHULER et al., 2000).

The ZTD is divided in two components: wet (Z_{WD} - Zenithal Wet Delay) generated by influence of water vapor, and hydrostatic (Z_{HD} - Zenithal Hydrostatic Delay), generated by influence of the other atmospheric gases. The Z_{HD} values depend of atmospheric air density and can be given by the equation (SPILKER, 1994):

$$Z_{HD} = 10^{-6} \int_{h_0}^{\infty} k_1\, R_h \rho\, dh \qquad (3)$$

in which R_h = 287,0538 J kg-1 K -1 is specific constant of hydrostatic air and ρ is air density varying in function of altitude (h). The Z_{WD} values can be obtained using the following expression (SPILKER, 1994):

$$Z_{WD} = 10^{-6} \int_{h_0}^{\infty} (k_2' \frac{e}{T} Z_w^{-1} + k_3 \frac{e}{T^2} Z_w^{-1}) dh \, , \tag{4}$$

where e is partial pressure of water vapor and T is temperature values, both varying in function of altitude (h), Z_w^{-1} is inverse compressibility factor of the water vapor, k_1 = 77,60 K hPa^{-1}, k_2' = 22,10 $K\ hPa^{-1}$ and k_3=373900 K^2 hPa^{-1} are atmospheric refractive constants.

The Z_{HD} prediction are obtained applying the atmospheric temperature and pressure profile predict by NWP model (for some "A" point from model grid) in a numeric integration in the equation (3). In a similar form, the Z_{WD} values can be obtained applying temperature and humidity profiles generated by NWP model for the same point in the equation (4). The Z_{TD} predicted for this "A" point is obtained adding the values of both components and applying the same process to all points of the grid is obtained a surface with information about the space distribution of that variable. Using interpolation process is possible to obtain Z_{TD} predict values to any other internal point of the grid.

3. IMPLEMENTATION

This section presents the main steps (Figure 1) of the in-house network RTK software, which has been developed at São Paulo State University (UNESP) at Presidente Prudente, São Paulo, Brazil, as part of a Ph.D. thesis.

Observing Figure 1 one can see that using the reference stations and VRS coordinates a base station is selected. Since the VRS data will be generated from base station data, it is necessary to read the base station data. The carrier phase and pseudorange observations from the base station are altered by applying the geometric corrections (HU et al., 2003) to displace these data from the base station to the VRS position. But, it is still necessary to correct the data from atmospheric effects. So, there is the possibility to correct the observations from ionosphere effect using Mod_Ion_FK (section 2.1), and/or troposphere refraction using the NWP model (section 2.2) or Hopfield model (SEEBER, 2003). Another point that must be emphasized is related to ambiguity resolution. No attempt was done to solve the ambiguities in this implementation.

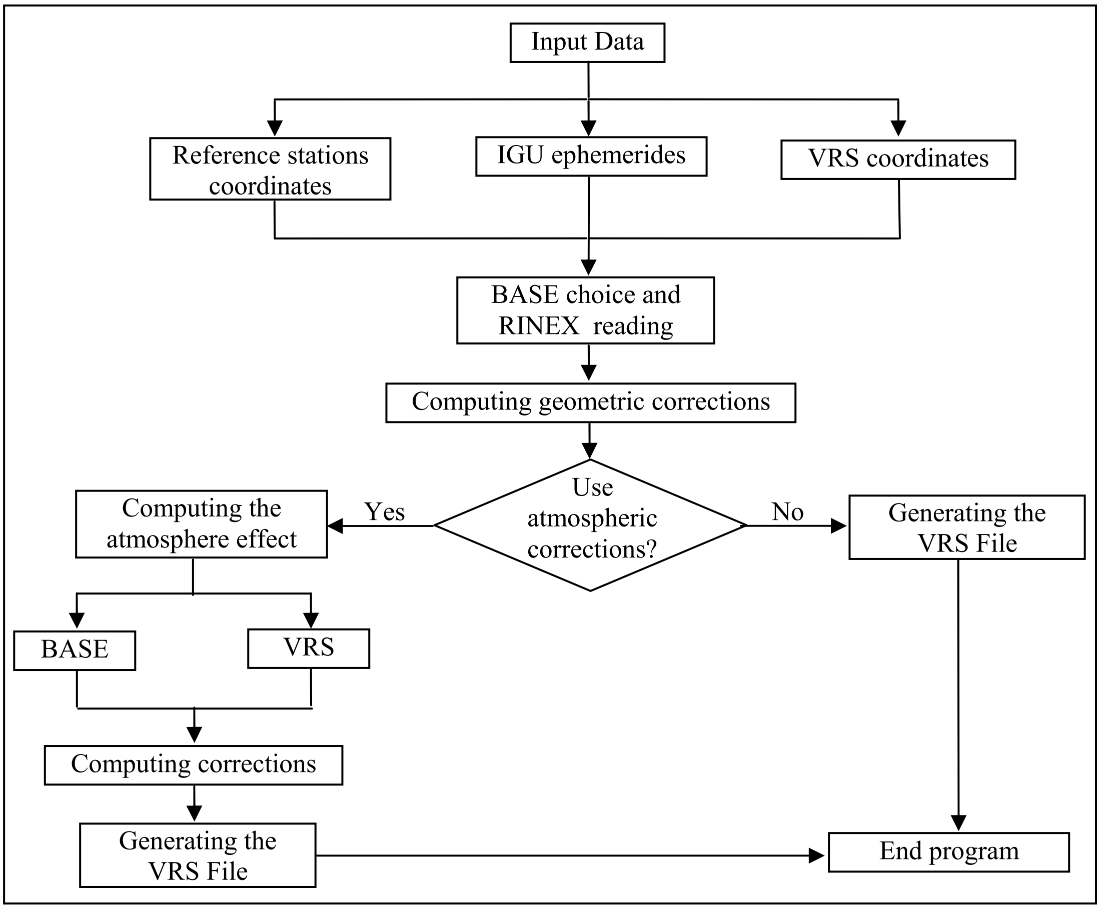

Figure 1. Main steps of the software implementation

4. EXPERIMENTS AND ANALYSIS

In order to accomplish the experiments to verify the performance of the method discussed in section 3, it is necessary to use the data of a network of reference stations. In Brazil, there is the Brazilian Continuous GPS Network (Rede Brasileira de Monitoramento Contínuo - RBMC) (FORTES, 1997). However, the distances among the reference stations are very long. So, it was also used extra-stations as it is shown in Figure 2. CUIB, NEIA, PARA and UEPP are stations from RBMC. PIRA, QUAT and MARI are the extra-stations. The data were collected from 16 to 25 May 2005 around 11h to15h local time. The VRS was generated on QUAT position, and this station was used just for comparison.

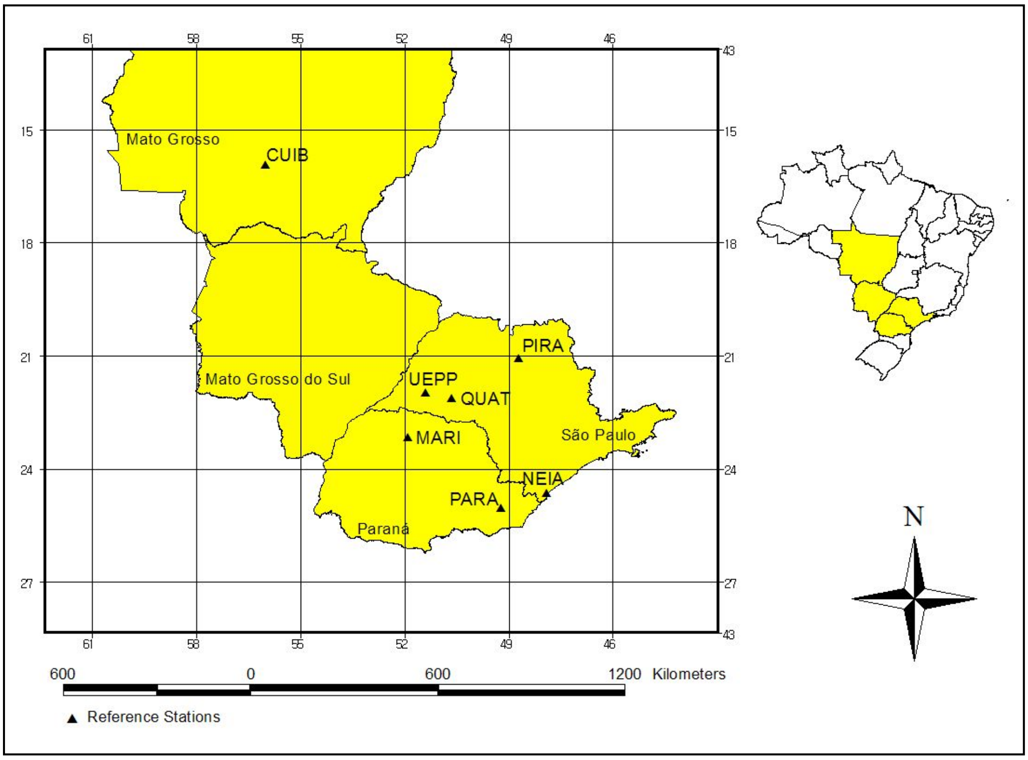

Figure 2. Reference stations used in the experiments

In order to analyse the generated VRS, two procedures were tested. It was performed the Precise Point Positioning (PPP) and the Relative Positioning. In relation to PPP, the software available online by the Natural Resources Canada (NRCan) (<http://www.geod.nrcan.gc.ca/online_data_e.php>) was used for processing the VRS data. For analysing the results, the resulting discrepancies in relation to the ground truth coordinates $\left(\Delta E^2 + \Delta N^2 + \Delta h^2\right)^{1/2}$ were computed. Concerning the relative positioning, the Trimble Geomatics Office (TGO) version 1.62 was used. It was realized the relative positioning between the real data from QUAT station and the generated one from the VRS station.

The results from the generated VRS with different methods are considered. They are: just geometric corrections (GC); geometric corrections plus NWP (GC+NWP); geometric corrections plus Hopfield (GC+Hop); geometric corrections plus Mod_Ion_FK (GC+Mod); and geometric corrections plus NWP plus Mod_Ion_FK (GC+NWP+Mod).

4.1 NWP versus Hopfield

In this section are presented the results obtained using PPP (Figure 3) and relative positioning (Figure 4) using the NWP and Hopfield models.

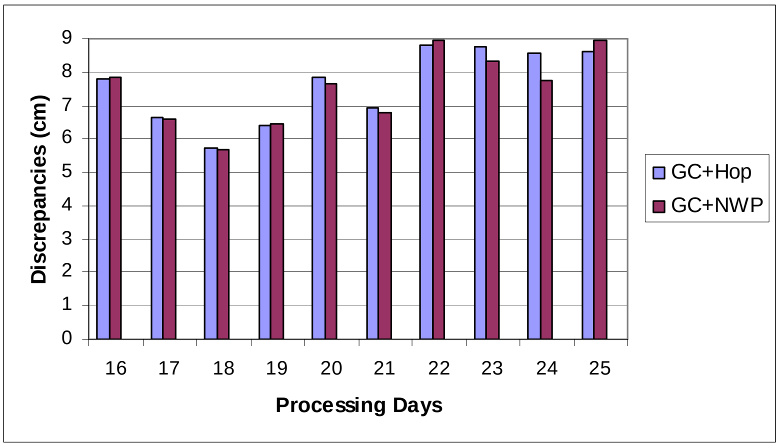

Figure 3. Discrepancies obtained in PPP with different troposphere models

In Figure 3 one can observe that the discrepancies between the VRS generated by CG+NWP and CG+Hop are practically the same; on average, 7.5 cm and 7.6 cm respectively. This similar result was expected, mainly because in PPP method the troposphere term is estimated during the adjustment process. Another point concerning this experiment is related to the discrepancy magnitude. The obtained values are smaller than expected. The reason for that may be due to the use of Ion Free observable in PPP. With this kind of observable the first order ionosphere effects are eliminated.

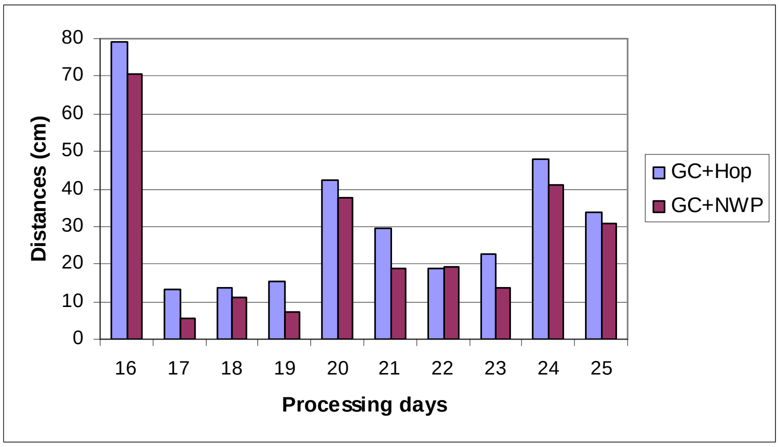

Figure 4. Distance obtained in relative positioning with different troposphere models

Observing Figure 4 it is possible to verify that the distances between QUAT and VRS are, on average, 25.5 cm using CG+NWP and 31,5 cm using CG+Hop. This shows a considerable improvement when the NWP model is used.

4.2 Generating VRS with different methods

In this section, the methods GC, GC+NWP, GC+Mod and GC+NWP+Mod used to generate the VRS will be analysed. Table 1 shows the average of the resulting discrepancies in relation to the ground truth coordinates and the Standard Deviation (SD) obtained by PPP.

Table 1 – Discrepancies average obtained in PPP with different models

Intervals	**GC** (cm)		**GC+Mod** (cm)		**GC+NWP** (cm)		**GC+NWP+Mod** (cm)	
	Average	**SD**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**
11h-12h	50.46	40.44	50.18	40.45	9.34	4.70	9.63	4.86
12h-13h	71.73	14.63	70.76	14.42	9.78	4.15	9.47	4.50
13h-14h	52.06	16.10	50.67	14.59	12.11	3.51	13.87	3.63
14h-15h	54.40	13.10	52.64	13.42	18.74	8.50	15.75	5.98
11h-15h	39.13	8.11	38.84	7.60	7.50	1.10	7.50	1.10

From Table 1 one can observe that the best results are obtained by GC+NWP and GC+NWP+Mod. However, the model GC+NWP+Mod is more efficient on 14h-15h interval. This may happen because during this interval the ionosphere effect is more relevant. However, in the PPP approach it is difficult to analyze the ionosphere model adopted, mainly because the Ion Free observable is used. To overcome this problem, Table 2 shows the results obtained by relative positioning on 11h-15h interval.

Table 2 – Discrepancies average obtained in PPP with different models

	GC	**GC+Mod**	**GC+NWP**	**GC+NWP+Mod**
Average (cm)	33.41	45.82	25.56	30.27
SD(cm)	20.52	20.00	20.02	20.61

Observing Table 2 it is possible to verify that the CG+NWP presented the best results. But something that must be discussed is related to the ionosphere model. The results with GC+Mod were worse than those obtained by GC+NWP. This happened mainly because the inadequacy of the reference network configuration. But at this moment, it was the only reference station network available to test the proposed method. In few months, it will be available a reference stations network at São Paulo State, Brazil, which will have better geometry. Data of this network will be used to accomplish new tests.

5. CONCLUSIONS

In this paper was presented the preliminary results obtained from an in-house software which has been developed at São Paulo State University (UNESP), Brazil. Using this software it is possible to generate a VRS station to a specific position with different atmosphere models, among them the ones developed at UNESP. So far, no attempt was done to solve the ambiguities. This will be tackled in a next step, in which the cited models will also be used.

The preliminary tests accomplished were very promising. Using NWP and Mod_Ion_FK models to create the VRS with four hours of data, it was obtained, on average, using PPP, a discrepancy (in relation to the ground truth coordinates) of about 7.5 cm in the resultant. Besides, the results obtained by NWP model were better than those obtained by a Hopfield standard model. Another test was accomplished, considering relative positioning between the VRS and the real file collected at the same position. It was obtained, on average, discrepancies of about 25 cm considering the NWP model. It may be approximately what one could expect for accuracy using the presented RTK Network concept.

A problem that should be tackled is related to ionosphere modeling. The results obtained with Mod_Ion_FK model were not very good probably due to the reference stations configuration. More experiments will be accomplished in the future with another reference station network to investigate the Mod_Ion_FK performance in the proposed method.

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BIOGRAPHICAL NOTES

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