New System and Process for Geo-Referencing

P. Kaufmann[1,2], P.L. Kaufmann[3], S.V.D, Pamboukian[1,4], R. Vilhena de Moraes[5]
[1] Escola de Engenharia, CRAAM, Universidade Presbiteriana Mackenzie, São Paulo, SP, Brasil
[2] Centro de Componentes Semicondutores, Universidade Estadual de Campinas, Campinas, SP, Brasil
[3] Instituto de Matemática e Estatística, Universidade de São Paulo, SP, Brasil
[4] Escola de Engenharia, Laboratório de Geotecnologias, Universidade Presbiteriana Mackenzie, São Paulo, SP, Brasil
[5] Dinamica Orbital e Planetologia, Universidade Federal do Estado de São Paulo, São José dos Campos, SP, Brasil

***Abstract* — We present a new process and method of geo-referencing. The system takes into account corrections for delays caused by signals transit times in remote transponder and by propagation effects. The principal applications of the system are for navigation, time synchronization of remote clocks, and location of targets. The delay corrections are an essential requirement to obtain accurate ranging measurements. The new system utilizes four ground-based reference stations, synchronized in time, installed at well known geodesic coordinates and a repeater in space, carried by a satellite, balloon, aircraft, etc. Signal transmitted by one of the reference bases is retransmitted by the transponder, received back by the four bases, producing four ranging measurements which are corrected for the time delays undergone in every retransmission. A minimization function was derived to compare the repeater's positions referred to at least two groups of three reference bases, providing the signal transit time at the repeater and propagation delays, and consequently providing the accurate repeater position. The system and process performance has been demonstrated by simulations adopting a practical example with the transponder carried by an aircraft moving over bases on the ground.**

***Keywords* — geo-referencing, space geodesy, remote ranging transponder transit times, path delays**

I. INTRODUCTION

A very well known principle to determine indirectly the distance of a remote object utilizes the echo of a retransmitted signal. A remote repeater position can be geometrically determined in relation to three transmitters at known position. This principle led to the concept of a geo-referencing system [1]. However in practical applications, and when applied to electromagnetic signals, the feasibility of the concept depends entirely on the knowledge of temporal effects due to four principal causes: (a) the signal speed propagation the medium causing path length variations; (b) propagation time at instruments, cables and connectors at the transmission; (c) propagation time at instruments, cables and connectors at the final reception; and (d) time of signal transit at the remote transponder, which distance is to be determined.

The cause (a) is generally well described by models for propagation in various media (ionosphere, troposphere) as well as in space (see for example [2-7] and references therein). The path length variations, however, depends on the elevation angle the object (carrying a repeater) is seen from the bases, which needs to be determined. Causes (b) and (c) are measured directly, with high accuracy depending on the quality of the instruments that are utilized. The cause (d) however is undetermined since the remote object, carrying the transponder, is inaccessible for direct measurements. It undergoes changes in its internal signal propagation physical characteristics, which can change with time, or for each sequence of signals used to determine its distance. There are various long distance wireless transmission options using electromagnetic waves, such as the radio waves. The signals are sent to great distances using retransmission repeating links. At these links the signals are received, they may or may not be stored or processed, be amplified, and then retransmitted at a frequency which may be the same, or different from the incoming frequency. As mentioned before, the signal transit time at the transponder is affected by several sources.

Other known time changes on fast moving transponders, carried by satellites for example, may be neglected for velocities << the speed of light, because they produce effects much smaller in comparison to propagation and delays at the repeater. We refer to Doppler path change caused by frequency shifts in the direction of the repeater [7-8] and to relativistic effects relative to the reference system containing the sites to which the distances are to be determined, which become further accentuated when the satellites move over distinct gravity potentials relative to the geoid [9].

On the other hand, passive transponders, such as the signal scattering reflection by meteor trails in the upper terrestrial atmosphere in the VHF frequency band [10], may undergo significant phase delays which need to be taken into account for distance measurements.

The precise knowledge of the time changes at each signal interaction at the transponder is an essential requirement for accurate ranging measurements, and applications in remote positioning, navigation, and time synchronization.

2. THE SYSTEM AND METHOD

The new system consists in four reference bases on the ground at know geodesic position, synchronized among themselves, and a repeater in space. The method to determine delays compares the positions of the repeater referred to at least two distinct sets of three of the four reference bases on the ground [11,12] (see Figure 1). A set of tentative possible delay values is established in advance. For a given single time-coded transmitted signal, the calculations of the repeater's positions are performed for different values assigned to the delays for each set of three reference bases on the ground (ABC, ACD and ABD).

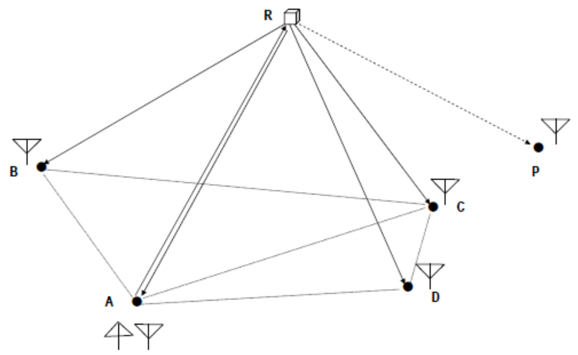

Figure 1 – The four ground based geodetic reference bases, A,B,C and D, the repeater in the sky R, and a remote site P. Time signals are emitted by one reference base (A), retransmitted by R and received by all ground bases and the target where time differences are measured[11,12].

We show that the delays become determined as the repeater's positions converge to the same value in relation to at least two distinct sets of three out of four ground based reference bases, for every single time-coded transmitted pulse.

The delays are inferred from the convergence of a minimization function for the difference in repeater's position for distinct sets of three ground-based reference stations, obtained by applying a known algorithm [13] for each set of three reference ground bases.

3. SIMULATIONS

a) The accuracy of the new system and process. A new software has been developed to perform simulations using the minimization algorithm developed here [14]. We used the programming language of MATLAB software, version R2010a [15]. As an example of application, to represent the ground-based reference bases we have selected four cities in São Paulo state, Brazil. Another city in the same state has been selected to simulate the target. It has been conceived a transponder carried by an aircraft flying at an altitude of about 6 km being seen by all four bases and the target.

The minimization of the repeater position discrepancy process has been done starting with an initial value for transit time and setting an upper and lower range for its variation. The correct time delay at the repeater is found at the end of the minimization process.

The whole process has been repeated for three more positions of the repeater, to allow the target position determination. The results obtained were very close to the real pre-established values, exhibiting position errors of about 0.001mm. This first step was a necessary to demonstrate the functionality of the method.

b) Estimate of path delays. The time delays due to the signal propagation in the medium were introduced in the following step, and assuming a propagation model. The calculations of delays at the repeater, of the repeater's position, and propagation path delays relative to each base were simulated by simultaneous iterations since these variables are interdependent. The path delay lengths were then added to obtain a new position for the repeater. The process has been repeated until obtaining the convergence of values. Comparing the values found in this phase with the pre-established values we find that the approximations remained excellent, with discrepancies in the repeater's position and in the target position less than 0.001 mm.

c) Clock synchronism. The time of arrival of the transmitted time coded signal at a target with known coordinates permits the synchronization of the clock at that location. The time elapsed for the coded time signal to travel from the instant of transmission to the target at a known position can be calculated. The obtained time difference can be used to synchronize the target's clock to the clock at the transmitting base. The results obtained from simulations are excellent. Assuming the clocks of the system perfectly synchronized, the ideal error at the receiving location is practically zero.

d) Estimate of uncertainties. The practical source of uncertainties of the determinations is primarily related to errors in clocks and/or in delays miscalculations. The two sources can be added together within a certain range of uncertainty.

To perform simulations of the error effects caused by the clocks (and/or delays) uncertainties, we have generated random values for clock/delay errors at the four reference bases and at the target, within a plausible time interval. The propagation of errors due to the clock synchronism uncertainties on the repeater's position, on the target location and on the clock synchronism, are shown in Figure 2. We set arbitrarily clock plus path delays uncertainties of ± 5 ns. For each delay it was determined the repeater's position, the target position and the clock synchronization accuracy. The most typical errors found are of less than 2 meters in the repeater's position, of tens of meters for the target location, and of few ns on clock synchronization.

4. APPLICATIONS

This new method has a wide range of applications in geo-referencing, which do not depend on other space-based positioning systems (such as GPS and Doppler-based Doris, etc.). We may give the following examples:

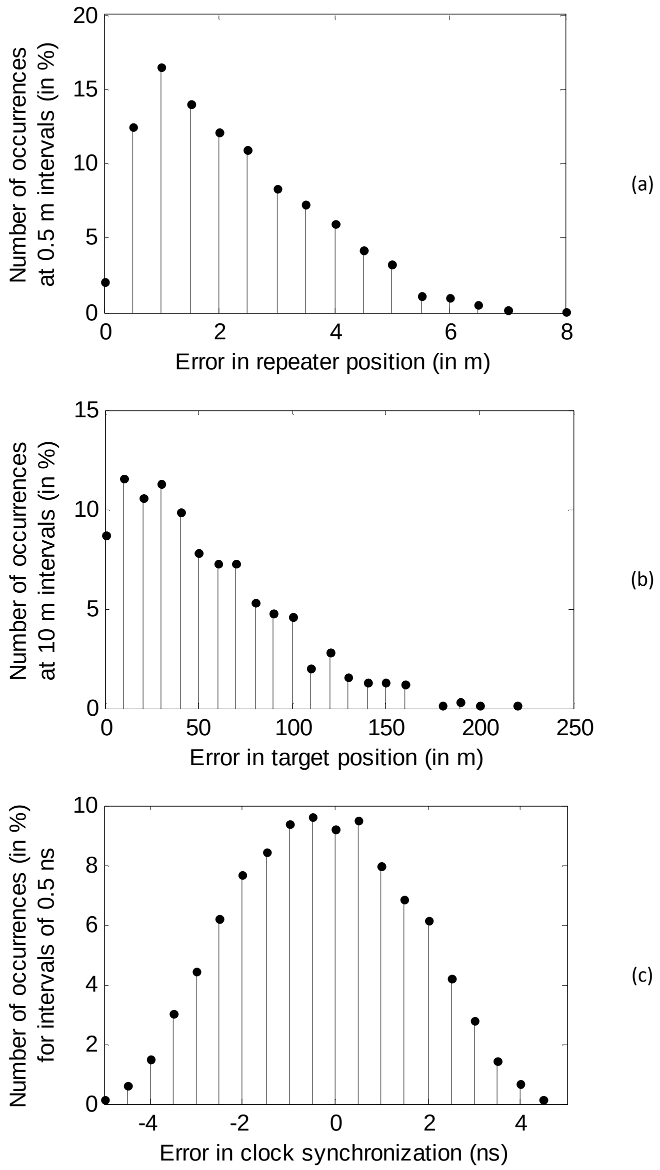

Figure 2 – Example of errors caused by clock uncertainties, which may include the path delays errors, for a range of ± 5 ns. In (a) the effect in the repeater position; (b) the error on the target location; and (c) the error in clock synchronization [12].

a) Repeater's navigation. The method is readily used to obtain the repeater's actual coordinates, for each coded time interaction. The navigation of the platform is immediately derived from successive repeater's positions determinations.

b) Synchronism of a remote clock. At locations where the coordinates are known, the discrepancy between the local clock at P (Figure 1) and the time received from the clock at the transmitter A can be readily determined, and time become synchronized.

c) Remote target location. The coordinates of an unknown target position can be found univocally by obtaining four different measurements of its distance to the repeater R, at four distinct instants, provided that the respective repeaters´ positions are not part of a straight line. The calculations are repeated referring to one set of three reference bases, including A where the time code transmitter is located (i.e., A,B,C or A,B,D or A,C,D), which are a requirement to determine the transit times at the transponder and the path delays due to propagation. After corrections are added, we obtain the equations for four spheres which intersections give the coordinates of the target.

5. CONCLUDING REMARKS

The new geo-referencing system and method of calculations, using four reference bases at known locations on the ground and a remote transponder in space, permits the calculations of time delays of signals transiting by the repeater, and other caused by the signal propagation in the medium. The method allows the navigation of the repeater, remote target positioning and remote clock synchronization with very high accuracy. The simulations demonstrate the analytical performance of proposed algorithm on practical application with a transponder carried by an aircraft. The main sources of uncertainties are the clocks synchronism at the reference bases and the target.

Another relevant application for this new system is a new approach for the determination of satellite orbits. Assuming a repeater placed in an artificial satellite and a favorable geometry its position can be determined for every time mark interaction with the same errors or uncertainties found for repeaters at lower altitudes, shown here. A study on satellite orbital applications is currently being developed for future publication

Acknowledgements. This research was partially supported by Brazil agencies CNPq, CAPES and FAPESP.

REFERENCES

[1] P. Kaufmann/Universidade de São Paulo, “Sistema e processo de posicionamento geográfico e navegação”, Brazil Patent of Invention, PI9101270-8,1997.
[2] A. J. Anderson, “Path length variations due to changes in tropospheric refraction”, Proc. IAU Symposium nr. 89, “Refractional influences in astrometry and geodesy” (ed. By E. Tengstrom, G. Teleki and I. Ohlsson), D. Reidel, Dordrecht, NL, 1979, pp. 157-162.
[3] M. Honma, Y. Tamura and M.J. Reid, 2008, “Tropospheric delay calibrations for VERA”, Publ.Astron.Soc.Japan, 60, 2008, pp. 951-960.
[4] S.M. Hunt, S. Close, A.J. Coster, E. Stevens, L.M. Schuett and A. Vardaro, “Equatorial atmospheric and

ionospheric modeling at Kwajalein missile range", Lincoln Laboratory Journal, 12, 2000, pp. 45-64.

[5] J. A. Klobuchar, Design and characteristics of the GPS ionospheric time delay algorithm for single frequency users, in PLANS'86 – Position Location and Navigation Symposium, Las Vegas, NV, USA, Nov. 4-7 (1986), Record (A87-41351 18-17), IEEE New York, pp. 280-286.

[6] J.W. Marini, Correction of satellite tracking data for an arbitrary tropospheric profile, Radio Sci., 7, 1974, pp. 223-231.

[7] T.S. Radovanovic, Adjustment of satellite-based ranging observations and deformation monitoring, PhD dissertation, Dept. of Geomatics Engineering, University of Calgary, Canada, 2002, Rept. Nr. 20166.

[8] M.I. Skolnick, Introduction to radar systems, McGraw-Hill, 1962.

[9] K.M. Larson, An assessment of relativistic effects for low Earth orbiters: the GRACE satellites, Metrologia, 44, 2007, pp. 484-490.

[10] J.-M. Wislez, Forward scattering of radio waves in meteor trails, Proc. Int. Meteor Conf., Brandenburg, Germany, 1995, pp. 99-117.

[11] P. Kaufmann, and P. Levit Kaufmann/Instituto Presbiteriano Mackenzie, 2012, "Process and system to determine temporal changes in retransmission and propagation of signals used to measure distances, synchronize actuators and georeference applications", Patent of Invention PI03003968-4, filed in Brazil on 19 March 2012, international PCT, application filed on 17 April 2012.

[12] P. Kaufmann, P.L. Kaufmann, S.V.D. Pamboukian, and R. Vilhena de Moraes, "Signal transreceiver transit times and propagation delay corrections for rangiung and geo-referencing applications", Math. Problems in Engineering, pp. 1-15, 2012, article id 595823, doi:10.1155/2012/595823.

[13] P. Levit Kaufmann, R. Vilhena de Moraes, H.K. Kuga, L.A. Beraldo, C.N. Motta Marins and P.Kaufmann, "Non recursive algorithm for remote geolocation using ranging measurements", Math. Problems in Engineering, 2006, pp. 1-9, article id79389, doi:10.1155/mpe/2006/79389.

[14] S.V.D. Pamboukian/Instituto Presbiteriano Mackenzie, "Novo processo de georeferenciamento: determinação de posição de transponder romoto e aplicações no posicionamento de alvos e disseminação de tempos", Software registered in Brazil, protocol 020120032225, April 13, 2012.

[15] Mathworks. matlab – "The language of technical computing", 2012. Available at: http://www.mathworks.com/products/matlab/.