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GNSS-Free Geo-Referencing System Using Multiple LEO Cube-Sat Formation

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CubeSats are ideal transponder carriers to integrate a new GNSS-free geo-referencing system. The system concept might be viewed as an “inverted GPS” configuration, utilizing four ground-based reference stations and a number of repeaters in space. A time signal transmitted by one of the reference bases is retransmitted by transponders in space, received back at the bases, producing four ranging measurements for each satellite. The measurements are corrected for time delays in every time coded retransmission caused by three main sources: the transit time at the transponders, the path delays, and delays at the ground-based transmitter and receivers antennas, cables and electronics. An algorithm compares the repeaters’ positions for at least two groups of three reference bases, minimizing unknown signal delays, providing the accurate position for each repeater. Once the repeaters’ coordinates are known, the other determinations and applications become straightforward. It is demonstrated by simulations, based on the system performance algorithms, that with a formation of at least four repeaters, the position of a remote target is determined for a single coded time signal transmission. A formation of multiple CubeSats in low earth orbits (LEO) is particularly suitable to accomplish the new geo-referencing system. Simulations are presented, exhibiting accuracies which may become comparable to other space-based systems. This system has various strategic and economic applications in remote clock synchronism, navigation and target geo-positioning. It may be used as a backup to GNSS location systems in critical applications, or when such systems are not available,

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Introduction

Current space geo-positioning techniques are part of Global Navigation Satellite Systems (GNSS). They include the first systems based on ranging and Doppler effect of radio transmitters at low orbit satellites, used until to-day [1,2] and the global positioning systems, based on a constellation of slow moving high altitude satellites such as GPS and equivalents [3,4]. An alternate GNSS-free system has been proposed The concept might be viewed as an “inverted GPS”, utilizing four ground-based reference stations and a number of repeaters in space. A time signal transmitted from one base is re-transmitted by transponders in space, received back at the bases and target, producing ranging measurements for each satellite (see Fig. 1) [5-7].

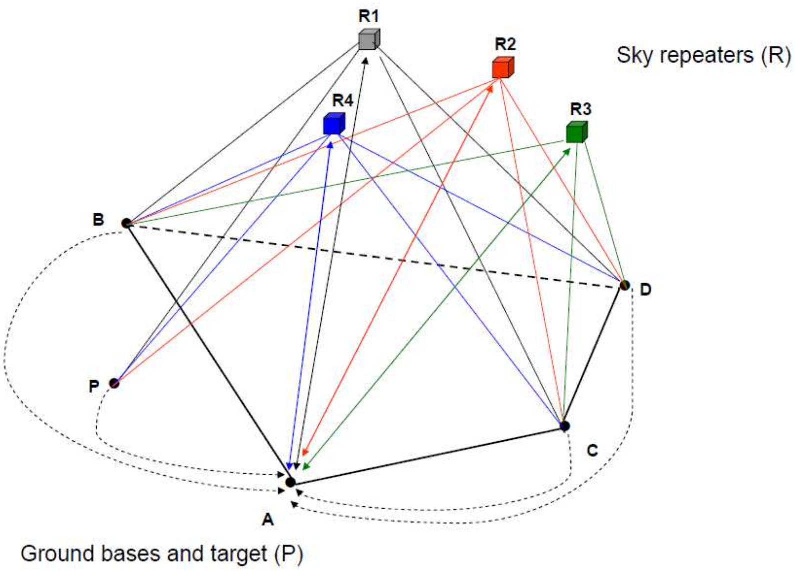

Fig. 1. Schematic diagram of the system. A coded time signal is transmitted from base A, retransmitted by the transponders in the sky and received by the four reference bases and by the remote target P.

The clock time differences measured at the bases and the target are forwarded by any means to a processing center, which may be at base A. The accurate time differences needed to define the repeaters’ to bases and target segments become critically dependent on corrections for time delays caused primarily by signal transit time at the remote transponder and by signal propagation the medium. It has been shown that these time delays can be minimized by comparing the positions of the repeater referred to at least two distinct sets of three of the four reference bases on the ground [5-7] calculated using known algorithm [8-9] for distinct sets of three bases, using one software developed to simulate the new system applications in repeater's positioning, navigation, remote clock synchronization and target coordinates determination [10].

Coordinates Determinations Using Multiple Repeaters

We extended to the original system performance simulation [1], using multiple repeaters carried by satellites at about 500 km orbits, visible from the four ground bases and the target; and adopting path time delays δ_{TEC} given by the total electron content (TEC) [11]:

$$\delta_{TEC} = S \times 1.343\ (TEC/f^2) \times 10^{-7}$$

with TEC in e/m^2, f is the transmission frequency in MHz, and S is the slant factor for the respective elevation angles E the repeaters are observed from the bases and target [12-13]:

$$S = 1/\cos\ \{\arcsin\ [(R/(R+h)) \times \cos E]\}$$

where R is the Earth radius and h ionosphere reference altitude. S equals 1 to 2.5 for elevation angles of 90 to 15 degrees. The system geometry is shown in Fig. 2, with four reference bases with known coordinates, one target at arbitrary coordinates assigned for simulation purposes, and four Cube Sats sat-carrying transponders at low orbits (500 km), separated by 240 km.

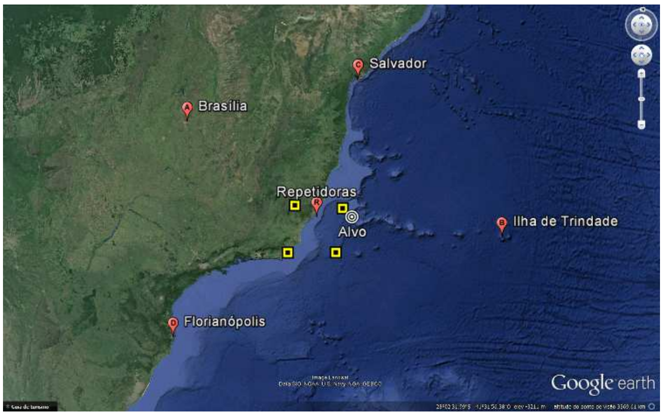

Fig. 2. System geometry used for simulations. Ground reference bases are on continental Brazil and one at Trindade island, target at an arbitrary position, four repeaters carried by low orbit (500 km) CubeSats.

Simulations were carried out using the algorithms and software referred before [5], simultaneously for four repeaters. To confirm the algorithms correctness he calculations were first performed assuming all parameters previously known, including the bases and target coordinates. The results exhibited errors close to zero, as expected.

Simulations assumed the same value of TEC for all the area occupied by the bases and target. An intermediate TEC = 10^{17} e/m^2 was adopted in calculations for the frequency band of 2000 MHz. The approximate elevation angles and respective slant factors the repeaters and target are viewed from the bases are recalculated and estimated for each iteration of the minimization process. We obtain elevation values close to the real ones. The satellites were placed in the sky at an altitude of 500 km displaced by about 2^o (i.e. about 240 km) from each other. It has been assumed an overall system random clock synchronism uncertainty of 3.3 nanoseconds. The preliminary results provide typical uncertainties of 20-100 m for the repeaters (satellites) positions; 5-80 m for target positions and 1-90 nanoseconds for remote clock synchronism (when assuming the target at known coordinates).

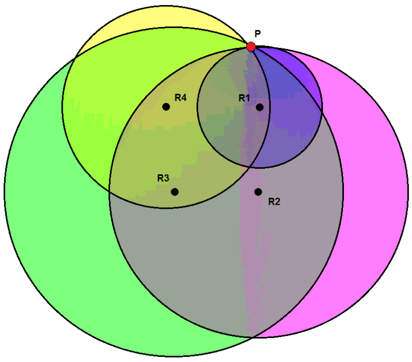

Fig.3. Projected 3 D graphic representation of simulated calculations showing the target P position coordinates obtained at the interception of four spheres centered at the four repeaters carried by CubeSats.

Concluding remarks

The new geo-referencing system performance using four satellite repeaters is highly encouraging, even assuming gross approximations. Delays due to signal transit times at the transponders and to radio propagation are efficiently minimized by the algorithms utilized. The obtained accuracies remain about the same for TEC changes within one order of magnitude. Assuming a gaussian 3.3 ns uncertainty distribution in system clocks synchronism and residual time delays, we obtain typical uncertainties of 5-80 m for target coordinates; 20-100 m for repeaters positions, and 1-90 ns for remote clock synchronism. System improvements are currently investigated, including enhancing accuracies by statistical treatment, the development of new mathematical solutions, and the use of two radio frequencies links to allow actual TEC estimates.

CubeSats are ideal transponder carriers. There are no critical on-board requirements. The power requirements for the transponder are of the order of 20 W, which are attainable by CubeSats. The implementation of one operational pilot system using CubeSats as the repeaters' carriers is being considered.

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