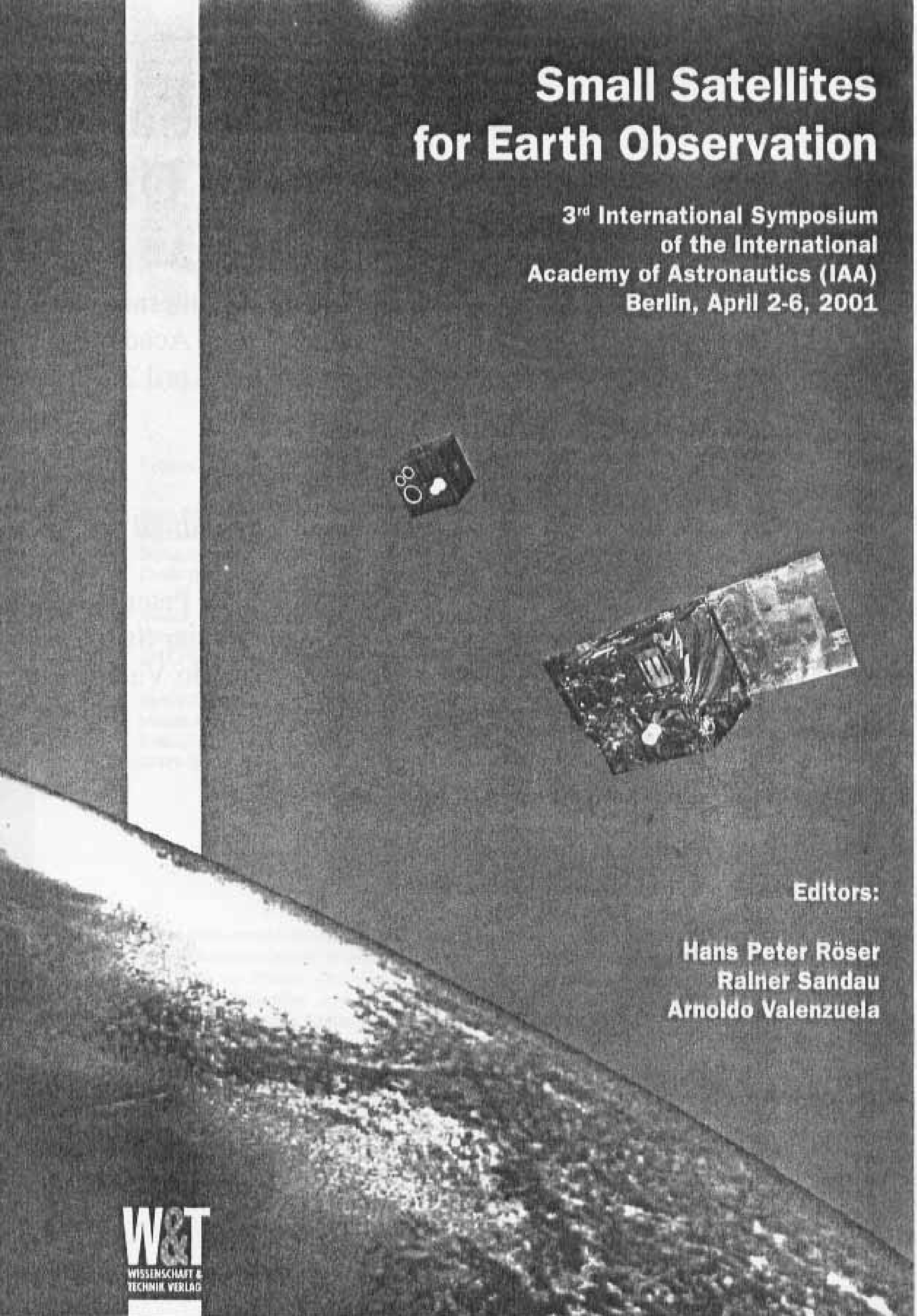

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GEO-LOCATION OF TRANSMITTERS USING REAL DATA, DOPPLER SHIFTS AND LEAST SQUARES

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ABSTRACT

In this paper we descibe a new method implemented at INPE (Brazilian Institute for Space Research) for obtaining the geographic location of transmitters, using Doppler shifts and a batch estimator based on least-squares technique. Near real-time geographical location of transmitters through satellite is used to monitor and rescue people in remote areas, or to track animals and oceanographic buoys for scientific research. A representative data set used for the tests was collected by means of a portable reception station located in the Antarctic Brazilian Station (Antarctica), using the NOAA-12 satellite as data relay, and a transmitter placed in the nearby Elephant Island. In addition, we obtained data collected in Cuiabá Satellite Reception Station (central Brazil) using the Brazilian satellite SCD-2 and a nearby Data Collecting Platform. The paper addresses the modeling of the Doppler shift measurements, the satellite dynamic motion, and the non-linear least squares technique applied to the problem. The results and analysis of the geographic method are shown and depicted here, demonstrating the location accuracy of 3.97±2.30 km and 3.13±1.51 Km respectively, achieved by such a near real-time system.

1. INTRODUCTION

In Brazil, geographic location of transmitters is applied in the following areas: in biology research, by fixing mini-transmitters in wild animals, to monitor their displacements and habits [1]; in oceanography research, launching drift buoys to study oceanic streams [2]; in emergency location and rescue of aircrafts and ships [3]; in field location and support to researchers of the Brazilian Antartic Program – PROANTAR in Antarctica [4]. Up to now, the location of these mobile targets were achieved through the purchasing of data from the French system Argos [5], using the NOOA satellites. The geo-location software, which preliminary test results are discussed here, will make possible to obtain geo-location data independently and using as well Brazilian satellites and reception stations. This method of near real-time (right after data reception) geographic location of transmitters and data collecting platforms (PCDs) through satellite is based on recently developed work [6].

In the following sections we summarize the modeling of the geo-location problem, using the Doppler shift measurements, the satellite dynamic motion, and the non-linear least squares technique. Then we show the results and analysis for two different transmitters in a typical condition, where transmitter and ground reception station are close to each other.

2. BASIC MODEL: TRANSMITTER LOCATION

The transmitter geographic location can be determined by means of the Doppler shift of the transmitted frequency due to the relative velocity between the satellite and the transmitter. When the transmitter and the reception station are inside the satellite visibility circle of around 5000km diameter for 5° minimum elevation angle, the nominal UHF frequency signals periodically sent by the transmitter are received by the satellite and sent down to the reception station. In a typical condition, where both are close enough, this period can last up to 10 minutes. The received data is then processed to generate the transmitter position information.

The satellite velocity relative to the transmitter ($v \cos \alpha$) in vacuum conditions, denoted by $\dot{\rho}$ is given by the Doppler effect equation [7] as follows:

$$\dot{\rho} = \frac{(f_r - f_t)}{f_t} c \tag{2.1}$$

where f_r is the frequency value as received by the satellite; f_t is the reference frequency sent by the transmitter; $(f_r - f_t)$ is the Doppler shift due to the relative velocity satellite-transmitter; c is the speed of light; α is the angle between the satellite velocity vector v and the transmitter position relative to the satellite. Given the observations modeled by:

$$y = h(x) + v \tag{2.2}$$

where y is the set of Doppler shifts measured; $h(x)$ is the non-linear function relating the measurements to the location parameters and function of the satellite ephemeris; and v a noise vector, the non-linear least squares solution [8] is:

$$H_1 \delta\hat{x} = \delta y_1, \tag{2.3}$$

where $\delta\hat{x} = \hat{x} - \bar{x}$, H_1 is a triangular matrix, and therefore the solution $\delta\hat{x}$ is obtained straightforwardly. The method turns out to be iterative as we take the estimated value $\hat{x}$ as the new value of the reference $\bar{x}$ successively until $\delta\hat{x}$ goes to zero. The H_1 matrix is the result of the Householder [9] orthogonal transformation T such that:

$$\begin{bmatrix} H_1 \\ \hline 0 \end{bmatrix} = T \begin{bmatrix} S_0^{1/2} \\ \hline W^{1/2} H \end{bmatrix}, \tag{2.4}$$

where H is the partial derivatives matrix $[\partial h / \partial x]_{x=\bar{x}}$ of the observations relative to the state parameters (latitude, longitude, altitude, bias, bias rate) around the reference values; $W^{1/2}$ is the square root of the measurements weight matrix; and $S_0^{1/2}$ is the square root of the information matrix. The δy_1 is such that:

$$\begin{bmatrix} \delta y_1 \\ \hline \delta y_2 \end{bmatrix} = T \begin{bmatrix} S_0^{1/2} \delta\hat{x}_0 \\ \hline W^{1/2} \delta y \end{bmatrix} \tag{2.5}$$

where δy is the residuals vector. The final cost function can be written:

$$J = \| y_1 - H_1 \hat{x} \|^2 + \| y_2 \|^2 \tag{2.6}$$

with $\|\delta y_2\|^2 = J_{min}$, where J_{min} is the minimum cost.

3. RESULTS

The results and analysis of the geographic location method developed are shown, demonstrating the location accuracy achieved by this near real-time system. We gathered representative data sets of two different transmitters collected in typical conditions, transmitter and ground reception station nearby: i) Transmitter #23840 fixed in the Elephant Island (Antarctica) sending data through the NOAA-12 (National Oceanic and Atmospheric Administration) satellite to a portable reception station placed in the Antarctic Brazilian Station - EACF; ii) Fixed Data Collecting Platform (PCD) with transmitter ID #32544, relaying data through the SCD-2 (Brazilian Data Collecting Satellite-2) to the nearby Cuiabá Reception Station (center of Brazil). The following criteria were established for the analysis and validation of the results: i) when the standard deviation of the Doppler shift residuals is greater than 10Hz the location estimate is rejected. The initial standard deviation is set to 5Hz, and a result twice bigger may indicate excessive interference or noise in the measured Doppler shift values; ii) data for satellite elevation lower than 5° may suffer considerable effects of the atmospheric refraction and noise due to transmitter power attenuation, and also are discarded; iii) if in a single satellite pass we obtain frequency samples covering only one side of the Doppler curve, i. e. either only positive or negative values, the geographic location is obtained with degraded precision and also must be discarded. Finally, if we know a former position of slowly moving transmitters, we can compare it to the obtained geo-location for cross-validation.

3.1. Transmitter - PCD #32544, SCD-2 Satellite, Cuiabá Reception Station

The sampling rate for this PCD is one transmission burst every 45 seconds, which leads to at most 13 possible Doppler data samples for a 10 minutes duration LEO (Low Earth Orbit) satellite pass. From July to August 2000 we collected 23 SCD-2 (750km altitude) satellite passes with Doppler data for the #32544 transmitter which, after facing the above criteria, ended up with 8 valid geo-location results as shown in Table 3.1.

TABLE 3.1 – Valid Geo-Locations for Transmitter - PCD #32544

Date	Time	Samples(+/-)	Location Error (km)	Longitude(°)	Latitude (°)
Jul/16/00	03:06	5/3	3.64	303.964	-15.558
Jul/16/00	04:52	1/5	1.95	303.938	-15.539
Jul/19/00	00:47	4/1	2.31	303.909	-15.553
Jul/21/00	02:52	3/4	4.21	303.893	-15.544
Jul/23/00	01:21	3/4	3.98	303.967	-15.558
Jul/24/00	00:37	3/2	5.45	303.981	-15.560
Jul/28/00	11:56	4/2	0.62	303.935	-15.552
Aug/10/00	06:40	4/3	2.93	303.957	-15.561
		Mean	3.13±1.51	303.929±0.03	15.551±0.01
		Reference	0	**303.9302**	**-15.555**

The mean of location error was 3.13km and its standard deviation was 1.51km, meaning with 1σ confidence level that the errors should range between 1.62km and 4.64km.

3.2. Transmitter - MTR #32840, NOAA-12 Satellite, EACF Reception Station

The sampling rate for this Mini Remote Transmitter – MTR is one transmission burst per 90 seconds, or 6 possible Doppler data samples for a 10 minutes NOAA-12 (800 Km) satellite pass. From November 1998 to January 1999, after application of the validation criteria, 6 geo-location resulted for #32840 transmitter as shown in Table 3.2.

TABLE 3.2 – Valid Geo-Locations for Transmitter - MTR #32840

Samples(+/-)	Location Error (km)	Longitude(°)	Latitude (°)
1/2	1.75	304.650	-61.206
3/1	2.24	304.659	-61.235
2/1	4.14	304.700	-61.201
2/2	0.80	304.647	-61.216
4/1	0.57	304.627	-61.216
2/1	6.92	304.642	-61.281
Mean	2.74±2.41	304.654±0.02	-61.226±0.03
Reference	**0**	**304.634**	**-61.219**

The mean of location error was 2.74km and its standard deviation was 2.41km, meaning with 1σ confidence level that the errors vary between 0.33km and 5.15km.

4. CONCLUSION

This paper showed geo-location results for two typical cases, using both the Brazilian SCD-2 and the NOAA-12 satellites, for transmitters located in center of Brazil and Elephant Island in Antarctica. The mean errors were 3.13±1.51km and 3.97±2.30km respectively, which are suitable to the applications described herein.

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