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# INVESTIGATION OF LOCATION TECHNIQUES THROUGH SATELLITES

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## ABSTRACT

The geographical location of transmitters in near real-time through satellites is useful to monitor and rescue people in remote areas, and to track animals and oceanographic buoys in scientific research. In this paper we discuss an application of the system known as Argos on-board of the NOAA (National Oceanic and Atmospheric Administration) satellites series. This system provides locations with a time delay since processing is operationally done only in France and in USA. A method was developed based on Doppler shift for use in small receiving stations and micro-computers that allows the location of the transmitters in near real-time at low cost, even in field work. This location system can perform the same functions with the Brazilian satellites SCD-1 and 2 (Data Collection Satellites) and for the CBERS (China-Brazil Earth Resources Satellite).

*Key words*: Geographical location, Doppler shift, Transmitters

## 1. INTRODUCTION

During the last 25 years the low-orbit NOAA (U. S. National Oceanic and Atmospheric Administration) satellites have provided a service for data acquisition and location of UHF (401.65 MHz) transmitters, world-wide known as Argos (CLS, 1988).

Main current applications of this technology include the tracking of animals (Figure 1), and of drift buoys in the ocean. Data processing is normally done by centers in France and in the USA some hours after actual data reception by the satellites; users need to access computers in these centers, where the data remain stored for a few months. In addition, this same technology is used under the name of SARSAT in airplanes and ships for their location and rescue in emergencies situations (Cazenave, 1997; French, 1986; CLS, 1988 and 1989).

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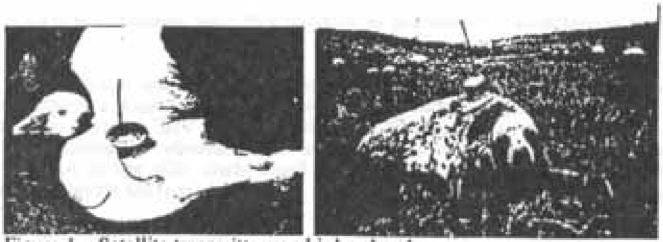

Figure 1 – Satellite transmitters on bird and seal.
Source: Cazenave, 1997 and French, 1986.

In Brazil, two versions of Argos transmitters, known as Mini Remote Transmitters MTR (Figure 2) are used to monitor and track people in remote areas. They were manufactured for the Brazilian Antarctic Program by the National Institute for Space Research (INPE) in São José dos Campos. Six MTRs operate with 17 messages and four with 144. The messages are actually pre-defined and only a numerical code is transmitted; interval between pulses of transmissions is about 90 seconds. Weight of the MTRs is about 1 kg and their internal battery pack lasts some 4 months (Setzer, 1997).

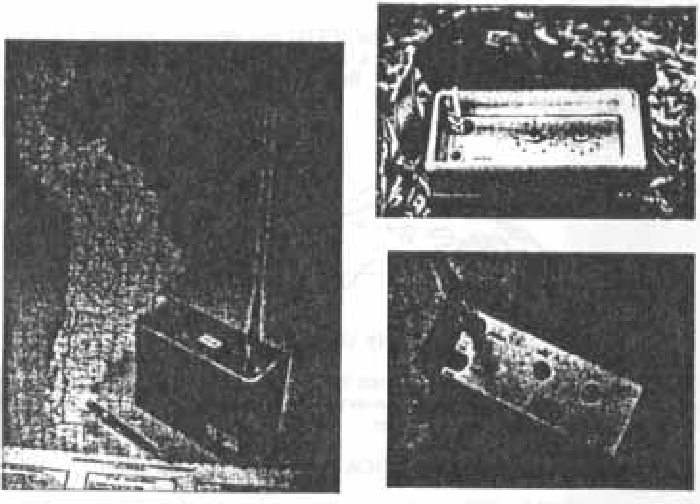

Figure 2 - Mini Remote Transmitters (MTR).

Location of transmitters in real-time by local users is of interest - if not a must – to many users as in the monitoring of people and animals in remote areas. Besides storing the data for later download to the centers in France and USA, the satellites also retransmit in near real-time in S-band (1.7 GHz) and VHF (137 MHz) frequencies. The former requires tracking dishes and are therefore cumbersome to install and operate in field work; the latter can be received with fixed antennas and is the basis for the method presented.

The present work proposes a Doppler-shift location method for use in near real-time using the Argos transmissions based on robust and generic statistical techniques. With such a general method, any other similar satellite data can be used (e.g. SCD, CBERS) as well. VHF real-time reception is made with an INPE-developed portable station such as the ones currently operational in Natal (RN), Cachoeira Paulista (SP), São José dos Campos (SP), Santa Maria (RS) and in Antarctica. Besides accomplishing the calculation of latitude and longitude in near real-time, the elevation should also be obtained.

## 2. NOAA SATELLITES-DCLS

The satellites of the NOAA series, formerly known as TIROS-N, operate with at least two satellites in the same Earth orbit, but opposite phases. Today, only for the purpose of location of transmitters the NOAA-11, 12, 14 and 15 satellites are available. Each satellite is equipped with a system location and data collection Argos (DCLS), which records all the transmissions of the platforms during overpasses, and retransmits ("download") the data for Earth stations operated in the CNES-NASA-NOAA (French, 1986) complex. Alternatively, local stations can receive frequency data in VHF and S-band (CLS,1988). Each satellite position has a nominal space resolution of 300 m, starting from a given satellite orbital trajectory model. Their orbit is polar, near circular, with inclination of 98.7°, altitude of approximately 850 km with orbital period of 101 minutes, resulting in approximately 14.1 revolutions per day (CLS, 1989).

This system also includes Earth transmitting platforms (PTTs) and reception stations. Each satellite sees, simultaneously, all PTTs and receivers inside a solid cone angle with circle of visibility of around 5000 km for a minimum elevation angle of 5°, that is, the angle between the horizon line and the platform line to satellite (Figure 3).


Figure 3 - Circle of visibility. (Source CLS, 1989).

The number of possible overpasses to gather data from the transmitters increases with the latitude. In the poles, the satellites see the platforms almost every pass. The visibility time (contact) of the platform for each satellite lasts 10 minutes on average.

## 3. BASIC TECHNIQUES OF LOCATION DETERMINATION

The Argos platform location (CLS, 1989) is determined by measures of the Doppler-shift in the platform transmitted signals. The basic principle of the location method considers each transmission received on board NOAA's satellites, and uses the records of the received frequency value and the instant of the message arrival. The transmitted PTT frequency is calculated from the set of frequencies received. For each Doppler-shifted signal measured, a cone of locations is defined based in the satellite trajectory, the nominal frequency of the PTT, and the reception frequency. The different cones of location intercept the altitude sphere that contains possible platform positions (Figure 4). These cones are symmetric with respect to the "ground-track" (projected trajectory) of the satellite. To find which the two positions is the correct one, additional information is required, as for example, the knowledge of a previous position. A second overpass removes any uncertainties.

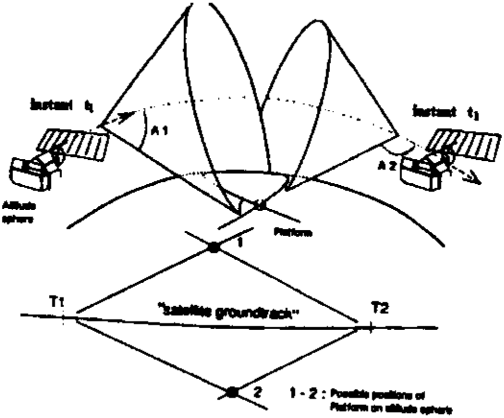


Figure 4 - Location Cones. (Source: CLS,1989).

The field of possible positions of the platform has the form of a semi-cone with the satellite in its vertex. The satellite velocity vector lies in the symmetry axis and the cone angle (Figure 4) is given by Doppler Equation:

$$\cos(\alpha) = \frac{f_{rec} - f_{ref}}{f_{ref}} \frac{C}{V} \qquad (1)$$

where $C$ is the light speed; $V$ is the satellite relative velocity to the platform; $f_{ref}$ is the transmitted frequency (from 401.646 to 401.654 MHz); and $f_{rec}$ is the received frequency.

The processing system at the Argos centers calculates a platform location from two initial inputs: an initial position estimated from the measured Doppler-shift for the first and last transmissions during the passage, and the last estimate of the actual transmitted frequency. This approach results in two possible solutions, or positions. Next, the frequency nominal value is calculated for each measured Doppler shift during the passage. The calculation is made twice with the two resulting positions (CLS, 1988).

In the present work, the geometric initialization of a PTT (latitude and longitude) is determined from two points in one satellite pass. These are the coordinates of the satellite (orbit propagated from the ephemeris e.g., given by www.celestrak.com) in the first and last PTT transmissions. A shift in the latitude or longitude is introduced depending on the satellite orbit inclination (polar or equatorial respectively) to perform a first estimate of the PTT geographical coordinates, obtaining two initial guessed positions. This estimate is then refined by differential corrections (e.g. Newton Raphson's method).

The resulting positions, together with the whole set of measured Doppler data (not only two) of the satellite pass, are then adopted as the new initials values of the proposed geographical location system. These measures are processed through statistical techniques using the Least Squares sequential method (viz. Aksnes, 1988) to obtain the two refined PTT's positions. The next satellite pass will determinate which is the real position.

A specific example of least squares estimates is that of a curve fitting that best represents a certain type of measurements. The fitting is made minimizing the sum of the squares of the differences between the measured and the modeled functional form (Gelb,1974). The method essentially solves systems that are in the form:

$$z = Hx + v \qquad (2)$$

where $z$ is the vector of $m$ observations (received Doppler shifted frequencies); $x$ is a vector of $n$-variables to be estimated; $H$ is a matrix $mxn$ of coefficients; and $v$ is the $m$-dimensional vector of the observation errors.

The solution of least-squares is given in the form (Kuga, 1989):

$$\Delta x = \left( H^T H \right)^{-1} H^T \Delta Z \qquad (3)$$

where $\Delta x$ is a correction to minimize the Euclidian-norm of the residues; $H=(\partial h/\partial x)_{x=\bar{x}}$ is a matrix of partial derivatives calculated over a reference trajectory; $(H^T H)^{-1}$ is the covariance matrix of the error in the estimate.

Thus, with updated satellite ephemeris the precision of the proposed method can be compared with the locations provided by the Argos system. This work also proposes to use the NORAD analytic model (Hoots and Roehrich, 1988) to compute the satellite ephemeris, starting from the "two-lines elements" standardized by NORAD.

## 4. FIELD WORK VALIDATION

The mathematical equations for the transmitter's location is being developed for use with measured Doppler shifts. The measurements of the PTTs frequencies received by the NOAA satellites allow an implicit correlation with the relative speed between the satellite and the platform. Assuming that the platform transmits signals in a well-known and constant frequency, the difference between the received frequency and the transmitted frequency gives a direct measure of Doppler shift, directly related to the relative speed between the transmitter and the receiver. If at that instant the position and the velocity of the satellite (receiver) are known, only the transmitter position remains as unknown.

The data being collected by the portable station and processed through the algorithm being developed will provide the platform location. This position estimate, given in terms of latitude and longitude, is compared with the position location as supplied by the Argos system. This step will pre-qualify the software to solve the problem. Another requirement is that enough data is gathered to provide near real-time location using the existing resources.

## 5. ACKNOWLEDGMENTS.

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