A PRECISE MULTIPASS METHOD FOR SATELLITE
DOPPLER POSITIONING

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Abstract. A precise and efficient algorithm is developed for determining the locations of radio beacons (e.g. of
the ARGOS or COSPAS/SARSAT type) based on Doppler shift measurements in overflying satellites. The
method distinguishes itself through: (1) the use of a very compact analytic orbital theory valid for all
eccentricities, (2) autonomous orbit improvement based on Doppler data for one or more local reference
beacons accessible at a single LUT, (3) simultaneous orbit improvement and calculation of beacon
coordinates for an arbitrary number of satellites, satellite passes, and beacons, and (4) very efficient
semi-analytic matrix inversion by partitioning into global, semi-global, and local parameters.

The algorithm has been implemented in a FORTRAN program which can be run on a PC. Error statistics
are presented from applications of the program to a large number of actual Doppler curves obtained with the
ARGOS and COSPAS/SARSAT systems.

1. Introduction

The satellite Doppler positioning method described here has been developed out of
a need for a reliable and efficient method for locating distress beacons and drifting data
collection buoys under, respectively, the COSPAS/SARSAT system (e.g. Werstiuk
et al., 1984) and the ARGOS system (e.g. Bessis, 1981). The method has been im-
plemented on minicomputers (ND 100 and ND 500) in a Norwegian built COSPAS/
SARSAT local user terminal (LUT) for search and rescue operations at Tromsø
Satellite Station, and in an ARGOS data collection terminal at the Norwegian
Meteorological Institute in Oslo. The program is also available in a PC version.

Our goal has been to provide for autonomous service on the basis of Doppler data
only from local beacons directly accessible at a single LUT during periods when the
beacons and the LUT are both within sight of a satellite. This mode of operation has
recently been recommended for all COSPAS/SARSAT LUTs. Most LUTs now in
operation require an occasional external input of updated satellite orbital elements
whose transmission by telex is a rather costly procedure. By the end of 1987 the
COSPAS/SARSAT system, which now includes three Soviet and two American
satellites in orbit, had contributed to the saving of 1000 human lives through early

detection and locating of ship disasters and airplane and helicopter crashes.

Service Argos in Toulouse offers a positioning service for the many thousand Argos buoys now in operation around the globe. The buoys are located with accuracies of typically a few hundred meters by relying on Doppler data for satellite orbit determination from eleven global reference beacons with highly stable oscillators in known locations.

Tests with our local Argos positioning program indicate that we can achieve much the same accuracies for locally accessible beacons, based on the use of two or three local reference beacons. The relative simplicity of our decentralized approach, coupled with the fact that buoy positions can be computed within 15 min after acquisition, as compared with usually several hours with Service Argos, offers definite advantages.

We have made two different versions of our satellite Doppler positioning program (SDPP), referred to as the sequential version (SDPP-SEQ) and the simultaneous version (SDPP-SIM) for which users' guides have been prepared by Andersen and Haugen (1983) and Haugen (1986), respectively.

The normal procedure with the sequential version is to update first the orbit from the Doppler curves obtained for the reference beacons (minimum of one) on a single satellite pass. Since the total observation interval is so short, it is usually practicable to solve for only two orbital elements, the most important of which is the mean anomaly. The unknown beacon positions are next computed one by one by processing each associated Doppler curve in a sequential manner.

As will be demonstrated through some actual examples later, the simultaneous version is a considerably more precise and flexible tool in so far as it can solve simultaneously for all the unknowns (or a subset thereof) associated with all available Doppler curves and orbits of several satellites over many passes. The main advantage of the simultaneous version is that the total observation interval may be made long enough to enable improving all the six orbital elements for each satellite, with consequent improvements in the derived buoy positions. A simultaneous solution typically involves 150 or more unknowns. By appropriate partitioning of the unknowns and associated solution matrix, and by inverting the matrix semi-analytically, a very efficient solution scheme has been worked out with modest demands on computer time and storage. The parameter estimation is done by means of a Bayesian weighted least squares formulation.

Another distinguishing feature of both versions is the use of a very efficient analytical orbital model, which is a modification (Aksnes 1972) of a satellite theory due to Brouwer (1959). This first-order theory accounts only for the zonal harmonics $J_2$, $J_3$, $J_4$, and $J_5$ in the geopotential. This appears to give a sufficient accuracy for the applications at hand. Because of a singularity at zero eccentricity in Brouwer's theory, a special adaptation due to Lyddane (1963), valid only for small eccentricities, has been in common use for the near-circular orbits of the NOAA satellites. The modified Brouwer theory used by us is more compact and is valid for all eccentricities; it needs as input the ordinary Brouwer mean elements but uses internally the so-called Hill