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Improved accuracy from Doppler satellite positioning

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The Defense Mapping Agency has initiated a broad study to investigate the possibility of improving the accuracy and precision of Doppler satellite geodetic positioning. The investigations include point positioning and short arc network techniques with the use of both broadcast and precise ephemerides. Analysis of hardware characteristics and software modelling for both precise ephemeris determination and surveying techniques are included in the studies. The role of fundamental constants and the use of the most recent values are being scrutinized for the purpose of making the broadcast and precise empherides compatible.

Introduction

The United States Defense Mapping Agency (DMA) Doppler geodetic point positioning software (Smith *et al.* 1976) was designed in 1969. This software, program DOPPLR, used in conjunction with Geoceiver observations of the Navy Navigation Satellite System, was the basis of a test, the conclusion of which was that worldwide geodetic positioning was attainable to an accuracy of 1.5 m in each coordinate at the 90% confidence level. The threshold of the long-awaited, truly world-wide geodetic system, had been reached. Owing to the spectacular result of the point positioning test, DMA ceased parallel development and testing of the alternate short arc network technique.

In the years after the test demonstration, the geodetic community embarked on ambitious observing programmes with the point positioning technique. As experience was gained, the precise satellite ephemeris improved, and additional geodesists contributed ideas, it became accepted that the accuracy of point positioning and other techniques could be improved.

At present, DMA is supporting a vigorous campaign to this end. This paper presents some of the more significant activities now under way at DMA.

Precise ephemeris

Accurate knowledge of the satellite ephemeris is the basis for accurate point positioning. DMA is considering plans to institute significant changes in the precise ephemeris. Users will be notified of these changes by mail. All changes will not necessarily be made at the same time. Briefly, the changes under consideration are:

(*a*) use of a more accurate value of GM, possibly 398600.5 km^3/s^2;

(*b*) referencing the ephemeris to the satellite antenna electrical centre rather than the mass centre as is now practised;

(*c*) replacing the NSWC 9Z-2 station set to be consistent with the new value of GM;

(*d*) use of a more accurate value for the velocity of light (299792.458 km/s);

(*e*) conversion of all types of observations to range differences to improve the homogeneity of the data and to eliminate certain errors;

(*f*) application of Earth tide corrections to the tracking stations;

(*g*) application of ocean tide effects to the potential field with a corresponding change in the Love number, K_L, from 0.26 to 0.316;

(*h*) application of third order ionospheric corrections to data that contain a separately recorded refraction count.

The first three changes, taken together, define a reference system that will affect point position solutions by decreasing the radius vector by 2.4 m (if the stated value of GM is adopted). No change to user point position software is required unless that software already corrects for the satellite antennae offset.

In conjunction with these software changes, DMA will have replaced the tracking equipment at 10 Tranet stations with second generation equipment by the end of 1979. This equipment known as Tranet II, is based on semiconductor state-of-the-art technology. Station operation will be controlled by an integral microprocessor which will automatically perform diagnostic equipment tests and control tracking functions. The equipment will offer better reliability and ease of operation than the existing equipment which is 17 years old. No significant increase in accuracy is implicit in this equipment. However, ionospheric refraction count will be recorded to enable third order refraction corrections to be made to the observations. This feature will become increasingly important as the solar activity cycle advances.

Point positioning

Many changes in the modelled corrections and solution methods of program DOPPLR are apparent. Some changes are possible because of increased geophysical knowledge and some are corrections to omissions of small terms that were originally deemed insignificant or otherwise overlooked. The following list of major changes each account for systematic changes in the solution of from 30 to 50 cm. It is not yet known what the total effect will be as the changes do not add linearly nor vectorially. Many will, to some extent, cancel each other. No indication exists at this time that any of the changes will materially reduce the residual r.m.s. of the solution. The changes are:

(*a*) Implementation of the tropospheric refraction correction model as given by Black (1978) with inclusion of scale height as an adjustable parameter.

(*b*) Inclusion of a third order ionospheric refraction correction model. This correction and an algorithm for its calculation are being derived by the Applied Research Laboratory of the University of Texas at Austin, under contract to DMA. The package is due for delivery to DMA before the end of 1978.

(*c*) Correction of the calculation of time delay due to signal propagation; this is incorrect owing to the fact that the velocity of light is not a constant in a non-inertial (Earth-fixed) coordinate system as used in the DOPPLR program.

(*d*) Modification of the method of interpolating the ephemeris to give better representation.

(*e*) Adjustment of the velocity of light to agree with that used in the ephemeris calculation.

(*f*) Use of actual rather than nominal satellite signal wavelength for calculations. These values may be obtained from the ephemeris calculation.

(*g*) Inclusion of the so-called C1 correction term, involving the satellite offset frequency, in the solution iteration loop to introduce the corrected frequency in the term.

The location of the electrical phase centre of satellite receiver antennae has been a recognized problem since the beginning of the point positioning project. This problem is complicated by the coupling of the antenna elements with the surrounding ground plane. The conductivity of any ground plane is highly unpredictable and a function of spatial location and time. DMA and N.A.S.A. currently have a cooperative effort under way in an attempt to define the phase centre characteristics of several antennae.

Short arc networks

DMA has reinstituted studies to determine the use of the short arc network technique to derive greater relative accuracy. The short arc software (program SADOP) originally developed in 1969 has been modified and exercised to a limited extent with encouraging results. Later this year, a 40-station short arc network will be observed with JMR receivers collecting a minimum of 40 passes per station. The Doppler data will be reduced in the single point positioning mode as well as the short arc mode, with both broadcast and precise ephemerides, and compared to external control.

Broadcast ephemeris

DMA has long been concerned with the obvious systematic differences between point positioning results from the use of the precise and broadcast ephemerides, neither of which are in the WGS 72 system. DMA is currently working with the Johns Hopkins University Applied Physics Laboratory and the Navy Astronautics Group to quantify and rectify these differences. Briefly, the chief causes of the differences arise from:

(*a*) omission of the correction U.T.1 – U.T.C. in the broadcast ephemeris, which is included in the precise ephemeris;

(*b*) use of predicted pole positions in the broadcast ephemeris as opposed to the more accurate solved-for positions of the precise ephemeris;

(*c*) use of the WGS 72 gravity field coefficients in the broadcast ephemeris as opposed to the NSWC 10E-1 coefficients used in the precise ephemeris;

(*d*) difference in the value of GM;

(*e*) differences in the station coordinate sets.

The broadcast ephemeris of necessity is predicted and as received may be from 6 to 30 h old. This presents a problem in that atmospheric drag on the satellite is poorly modelled and appears as along-track error in the ephemeris. The broadcast ephemeris can therefore never attain the accuracy of the precise ephemeris. The user of the broadcast ephemeris must pay careful attention to attaining a balanced set of north-going and south-going passes both to the east and to the west to minimize these effects in a point position.

It has come to the attention of DMA that some users of the broadcast ephemeris are using the value of the Earth rotation rate associated with the WGS 72 ellipsoid (Seppelin 1974), which is relative to the fixed stars. The proper value is relative to the true equinox and is $0.729\,211\,585\,5 \times 10^{-4}$ rad/s.

Conclusion

DMA is currently involved in an energetic programme to investigate all phases of improving Doppler positioning techniques. As results become available, they will be published and provided to the geodetic community.

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