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CARTOGRAPHIC PROBLEMS OF GLOBAL POSITIONING

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Abstract

This paper deals with the satellite global positioning (GPS or GLONASS) in marine cartography. It especially points out its limitations and the convenience of the differential mode both in hydrographic surveys and precise navigation carried out in channels, rivers, port and harbour approaches or offshore operations.

1. INTRODUCTION

The opening of GPS (USA) and GLONASS (Russia) systems, including their possibility of being used in the future in a joint or complementary manner, requires a permanent analysis of their application, especially in geodesy, hydrography and navigation. The user may rely on an efficient means to check his route and he can also detect any errors in cartography; this may occur very frequently until nautical charts, whether be it electronic (ENC - ECDIS) or paper charts, meet the possibilities of global positioning.

As a general rule, this leads to the fact that a great number of surveys and marine publications should be repeated with new specifications. Fortunately the positioning means itself and the digital process capacities would lead to such improvement with less effort and time than in the case of traditional means. Nevertheless, a transition stage is beginning and it shall not be less than ten years; during such time it should be necessary to take temporary solutions such as the application of approximate correction constants, warnings and special reference stations.

By the same token, though receivers for autonomous use are expected to be improved and (presently selective) availabilities are expected to be extended, it should be considered that for coastal, channel and fluvial hydrography it should be

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necessary to operate exclusively in the differential mode. The same will occur with precise navigation, that is, navigation requiring position errors under ± 20 metres.

Even though there are manufacturers who assign precision values of such kind in their brochures to one frequency-equipment for autonomous use, hydrographers and mariners should be cautious in this respect. This paper summarizes the basic problems which contrast with such precision and the alternatives to attain it.

2. GLOBAL AND LOCAL COORDINATE SYSTEMS

Ephemeris transmitted by GPS satellites are referred to WGS 84 system whose center coincides with the earth mass center, its z axis is reduced to the pole epoch 1984.O and the conventional meridian (x,z plane) for the origin of universal time corresponding to the same epoch. The main gravitational constants (GM and the first field spherical harmonic constants) are disseminated as is the case of elliptical parametres (a,f).

Ephemeris of GLONASS satellites are coincident in their conception for the most part, though an adjustment should be necessary, especially in high order terminus of gravitational field. It is not expected that the leaders of both systems would be compatible among themselves within short term; nevertheless, a set of geodetic receivers with simultaneous operation and a wide cover would let us deduce within a short time the sufficient conversion constants for hydrographic purposes and marine use.

The most difficult question to be solved is connected with local systems wherein you know their elliptical parametres but it is not easy to determine strictly their translation and rotation. The strict solution to this question requires a geoid modelling and the practical limitation lies in the lack of rigidity of classic networks; this leads to the necessity of re-defining the basic geodetic structures by means of points not distant from each other more than 200 km and a series of scientific investigations the details of which go beyond the scope of this report. The outcome of a good connection leads to the adoption of a complex transformation or else to the use of correction constants which may vary according to position.

In the case of simplified connections with a poor geodetic investigation, some assumptions should be adopted such as the consideration of parallel axes, the scale preservation, the adoption of some geoidal and ellipsoidal heights, and the approval of internal rigidity.

The aggregate of assumptions, in addition to the difficulties in obtaining good isolated positions through the most known geodetic equipment, lead transformation constants to cause hesitations of about ± 10 metres in certain systems areas larger than 2000 km. If corrections are obtained by means of simple differences among latitudes and longitudes instead of the three-dimensional treatment, greater differences are to be expected and if cartographic compilation derives from sources whose the connection is approximate, the uncertainty may be even more harmful.

3. TYPICAL ERRORS OF CARTOGRAPHY

Apart from what is stated above, cartography has its own errors. In works with updated standards it is relatively easy to calculate the error starting from geodetic support, the positioning used and its subsequent process. On paper charts we may agree that any detail will be within ± 0.5 mm at the respective scale. Nevertheless, it is not always so in the case of charts produced under rules not covering the present ones; in this sense, the worst case appears when information arises from compilations having a different nature instead of arising from recent hydrographic surveys.

In some instances, marine cartographers, in their intention to warn mariners who had primitive positioning means, have reached the point of distorting the representation of some dangers by impairing fidelity they were delimited with.

But not all the difficulties arise from old-time surveys or from criteria; it is necessary to admit that those hydrographers who worked during the first half of this century devoted more effort than the present persons to the description of coastal unevenness. Nowadays hydrographers transfer most of such responsibility to image processing (photogrammetry and remote sensing) which on many occasions leads to misunderstandings which finally distort the representation of certain coastal characteristics.

Even though those questions do not arise as a consequence of global positioning errors, they should be taken into account as a limit to the compatibility required by such technology with available cartography.

4. TYPICAL DIFFICULTIES OF GLOBAL SYSTEMS

It is widely known that the strict spatial-time solution is obtained from the reception of four satellites which together with the motive give rise to the shape of a pyramid; the larger the volume of such pyramid, the more advantageous the geometry of the determination for the accuracy of the position.

Moreover when the user has access to undisturbed precise codification (Code P without limitations SA or AS at GPS) and has the possibility of operating at double frequency to lessen the influence of ionospheric refraction, the system may be expected to provide him with real-time position having errors of the order of ± 20 m.

Broadly speaking, up to date users do not have equipment of such characteristics at least for commercial use and they must solve their problems with single frequency receivers (L_1 at GPS) and wave length code (C/A = Clear Acquisition at GPS, 293.1 metres). In this case, the application of global systems shows the following difficulties:

a. Residual error of tropospheric refraction:

It derives from the difference between the application of the refraction with which the equipment microprocessor is programmed to introduce the influence of atmospheric layer covering the earth surface, and the actual physical influence of such layer. It is estimated that the influence can be ±10 metres in the position.

b. Ionospheric refraction error:

It derives from the influence of ionosphere on the propagation of waves which are received. Its significative attenuation is attained with the reception of two frequencies (L_1 and L_2 at GPS) and an algorithm which deducts the coefficient from the main term which is inversely proportional to the square of carrying frequency.

The effect does not admit a good modelling without the above mentioned resource and there may be position errors of the order of ± 80 metres for one-frequency equipment. However, apart from twilight at sunrise and sunset, the influence tends to be lower with satellites with angles having a higher height than 10° on the horizon.

c. Errors due to system degradation:

If the user has no selective availability (S/A at GPS), he may find disturbances introducing a position error of ± 50 metres and up to ± 100 metres.

d. Clock error:

When spatial-time solution is not available with the use of more than three satellites, the equipment processor extrapolates the correction of the receiver clock or appeals to a two-dimensional solution. Any of these simplifications may lead to errors of ± 100 metres.

e. Ephemeris errors:

Calculation of positions of observed satellites arises from transmitted orbital data which are the result of an extrapolation of estimates made by sweeping operational stations. The error of calculation of an isolated position may amount to several tens of metres. These errors are expected to diminish when satellites will be located in their final positions with more adjusted movement models. On the other hand, such errors effect may diminish if more than 4 satellites are received.

f. Discrimination errors:

The error resulting from obtaining a pseudo-range arises from the equipment possibilities to determine the codification phase difference. The coded wave length at GPS (C/A) is about 300m and it may be expected to discriminate a pseudo-range within 1% of such value; therefore, it is logical to assign it a random error of the order of ± 3 metres. Even though this error extends with a disturbed movement, as is the case of navigation, a good filtering process may keep it within such limit.

Influence of above mentioned errors (a, ..., f) can lessen when there is a good geometry. Use of DOP (Dilution of Precision) coefficients has been disseminated. Estimate of the three-dimensional error of position is distinguished by the PDOP symbol and it can be deducted from the elements of the main diagonal of variance-covariance matrix of the adjustment algorithm; it basically shows the extension with which the pseudo-range error is translated into the position and it is usually divided into a horizontal component (HDOP) and a vertical component (VDOP) so that the relationship

$$(PDOP)^2 = (HDOP)^2 + (VDOP)^2$$

is fulfilled.

If there are not four satellites, the equipment has a tendency to go to a two-dimensional solution or to extrapolate the clock correction; nevertheless, there are few who take into account the limitations of simplification, as it is indicated in paragraph d.

5. ERROR ESTIMATES IN AUTONOMOUS RECEIVERS

A quick review of items 2, 3, and 4 allows us to deduce we can hardly assure that there should be a compatibility between the position obtained and the charted position with errors under ± 100 metres and with one- frequency equipment. This conclusion differs from equipment manufacturers expectations which are more optimistic since they use to assign substantially minor errors (e.g., ± 30 metres).

A segment of such difference is based on the error statistical conception. We should remember that the circular error probable (CEP) only shows that the probability of being below such value is 50% while for standard error or root mean square (RMS) such probability is 67%. The most scrupulous manufacturers use 2RMS, but hydrographers and users should use 3RMS which statistically assign an estimate probability of error cover over 99% .

But such estimate basically considers the random or pseudo-random effects, though some people explain that degradation (SA at GPS) is not considered. Undoubtedly the following systematic hesitation sources (modelling defects) should be added:

- Definition of geodetic datum (2)
- Typical errors of cartography (3)
- Refraction residual effects (4.a; 4.b)
- Clock error or two-dimensional solution error when less than 4 satellites are operated (4.d).

6. ADVANTAGES AND LIMITATIONS OF DIFFERENTIAL MODE APPLICATION

A large part of systematic effects as well as some random and semi-random effects remarkably diminish with the differential mode. If the reference station is located at a representative point strictly linked to the geodetic support, which acted as a basis for hydrographic survey, the uncertainty of geodetic datum constants is solved. The main part of refraction effects, degradation, clock errors and ephemeris are absorbed by the mere fact that they are similar in such station as well as in the mobile receiver.

Corrections are either transmissible through a special communication network or a post-process is made with two receptions. The latter is only valid for some hydrographic surveys but it is not so in the case of precise navigation. Nevertheless, it should be noted that typical errors of cartography (3), discriminating hesitations (4.f), and the remaining questions mentioned in the above paragraph are still present. It is a mistake to assume that dilution of precision (DOP, see item 4) acts in a similar way on both stations since it constitutes an extension of random dispersion in the reception of each of them, especially with respect to discrimination limit and effect residues, which are not cancelled when appearing in a slightly different way in both stations. The latter increase according to distance between the mobile receiver and the reference station.

As a general rule, it is desirable to plan hydrographic operations and navigation along risky areas so that PDOP coefficient may be below 5. On the other hand, it is calculated that position error may be of the order of

$$\pm (4 + 0.01K) \text{ metres,}$$

where K is the distance in kilometres to the reference station.

Naturally it is only a preliminary estimation and it cannot be applied to distances over 500 km.

The so-called "two-dimensional solution" with three satellites is not suitable for hydrographic or precise navigation purposes. Generally HDOP consideration is not sufficient to evaluate the error in such cases since errors such as those indicated in item 4.d, which exceed the application of such coefficient in error estimation, are predominant.

7. TEMPORARY SOLUTIONS

The lack of identity between the world system (WGS 84 at GPS) and the system supporting the chart should be covered with legends, such as those provided for by Resolution B2.10 of the International Hydrographic Organization, in which the corrections to be applied are detailed. The same result may be obtained in some equipment if the geodetic datum, which chart positions or the respective parametres referred to, is introduced.

Probably some general charts (a scale of the order of 1:500,000) obtained from the compilation of different information on a territory of difficult operation, e.g., Antarctica, should be subject to more than one warning on the same picture.

An early improvement of such rule may be achieved by the transmission of experimentally obtained corrections through radio navigational warnings. Thus, a user with an elementary positioning equipment, (one frequency, with no capacity to receive and process corrections which are typical of some differential equipment) may get a large part of the advantages mentioned in item 6. The major limitation to this solution lies in the fact that the pseudo-random effect, indicated in item 4c, has relatively short periods (minutes) and allows no cancellation with this procedure.

Amidst the solution mentioned in the above paragraph and a good differential system in time there are other intermediate solutions such as the transmission of corrections through radiobeacons or the operation of long-range active control stations. In such cases the digital process manages to absorb degradation of SA type.

8. CONCLUSIONS

The use of global positioning equipment receiving isolated one-frequency data can lead to errors in the order of 100 metres.

Even in such cases it is necessary for nautical charts to be compatible with such navigational means through temporary solutions. It is necessary to resort to a differential system both in the case of precise navigation and hydrographic surveys.

If we have such equipment, it is also necessary that the spells during which precise tracks or hydrographic surveys are carried out in detail, should be planned with a good geometry of available satellites (PDOP lower than 5). The use of less than 4 satellites is not suitable in these cases, even though the HDOP is relatively low.

It is necessary to check with wide experience the equipment margin of error and it should be convenient to adopt 3 RMS as the representative value. Even if in possession of such value, it should be desirable to examine whether a residual systematic error (modelling error) exceeding such estimation could not be present.

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