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ABSTRACT DGPS system principles are introduced. Analyses and discussions are made of the major residual errors in carrier wave phase DGPS positioning and influences under low dynamic states. A type of algorithm is put forward which--in carrier wave phase DGPS receivers--does not require solving for integral cycle ambiguity but calculates positioning rapidly.

SUBJECT TERMS +Carrier phase DGPS +Fast positioning +Measuring sequence +Window type computation

1 INTRODUCTION

Following along with the establishment of global satellite systems, the GPS satellite positioning system has already far, far surpassed the original intentions of the U.S. Defense Department. Not only has it set off an upsurge of research applications in international armament technology, it has, moreover, achieved wide spread applications in a great many civilian lines of work as well.

As far as difference GPS (DGPS) technology is concerned--particularly, carrier wave phase DGPS technology--during medium and low dynamics, high precision measurement positioning, due to limitations imposed by U.S. government secrecy associated with P code (Y code), it possesses, moreover, relatively higher precison. Therefore, it has even broader prospects in various national military and civilian lines of work.

2 DGPS DETERMINATION PRINCIPLES

DGPS technology is to make use of correlations associated with GPS positioning errors, carrying out mutual reductions and elminating common conjugate error terms in order to increase precision.

DGPS systems include a reference station and several user stations. Through taking GPS receiver positioning results and the coordinates of locations that are already precisely known, reference stations do comparisions to obtain real time positioning correction quantities. In conjunction with this, they take these correction quantities and broadcast them out using radio waves. Then, a method is used where, through using received positioning correction quantities broadcast by reference stations, user stations do real time corrections on user GPS receiver positioning results in order to increase GPS positioning precision. This is nothing other than the basic principle associated with GPS. General correction methods include direct corrections and indirect corrections.

(1) Direct Correction Methods: Reference station X, Y, Z coordinate correction quantities which are calculated out are directly added into GPS receiver positioning solutions. The drawback of this method is that, following along with increases in the distance from user GPS receivers to reference stations, improvements in positioning accuracy will clearly diminish.

(2) Indirect Correction Methods: First, calculate out the pseudo range correction amount associated with each GPS satellite tracked by reference stations. Then, transmit to users. User GPS receivers carry out calibration with respect to pseudo ranges before doing positioning calculations. An introduction is made below of the positioning correction principles associated with this method.

Assume that the pseudo range from ground reference station R to the ith GPS satellite, that is, the pseudo range obtained for the ith reception channel, is /22

$$\rho_r^i = \rho_{rt}^i + (C d\tau_x - d\tau_s^i) + d\rho_x^i + d\rho_{xion}^i + d\rho_{rtrop}^i + dM_r + V_r \tag{1}$$

In the equation, ρ_{rt}^i --true distance from reference station R to the ith satellite

ρ_{rt}^i --clock deviation of reference station R relative to GPS time system

C --speed of light, m/s

$;d\tau_s^i$ --ith satellite clock deviation relative to GPS time system

$d\rho_s^i$ --range error caused by GPS ephereris error (includes artificial SA errors)

$d\rho_{rion}^i$ --range error caused by troposphere time delay

$d\rho_{rtrop}^i$ --range error caused by ionosphere time delay

dMr --range error caused by receiver multiple path effects

VMr --range error caused by receiver measurement noise

From already known values associated with reference station three dimensional coordinates and GPS ephereris, it is possible to calculate ρ_{rt}^i, . Moreover, ρ_r^i can be measured by reference station receivers. From equation (1), one obtains the psuedo range correction quantity $\backslash\Delta\rho_r^i$

$$\begin{aligned}\Delta\rho_r^i &= \rho_{rt}^i - \rho_r^i \\ &= -C(d\tau_r - d\tau_s^i) - d\rho_r^i - d\rho_{rion}^i - d\rho_{rtrop}^i - dM_r - V_r\end{aligned} \tag{2}$$

With regard to pseudo ranges measured by user receivers, from equation (1), one has

$$\rho_k^i = \rho_{kt}^i = C(d\tau_k - d\tau_s^i) + d\rho_k^i + d\rho_{kion}^i + d\rho_{ktrop}^i + dM_k + V_k \tag{3}$$

If use is made of $\Delta\rho_{k}^{i}$ to carry out user range measurement corrections, then, from equations (2) and (3), one has

$$\begin{aligned}\Delta\rho_{r}^{i} + \rho_{k}^{i} &= \rho_{kt}^{i} + C(\mathrm{d}\tau_{k} - \mathrm{d}\tau_{r}) + (\mathrm{d}M_{k} - (\mathrm{d}M_{r}) + (V_{k} - V_{r}) \\ &= (\mathrm{d}\rho_{k}^{i} - \mathrm{d}\rho_{r}^{i}) + (\mathrm{d}\rho_{kion}^{i} - \mathrm{d}\rho_{rion}^{i}) + (\mathrm{d}\rho_{ktrop}^{i} - \mathrm{d}\rho_{rtrop}^{i})\end{aligned}$$

When distances between GPS receivers and reference stations are relatively close (100km)

$$\mathrm{d}\rho_{r}^{i} = \mathrm{d}\rho_{r}^{i};\ \ \mathrm{d}\rho_{kion}^{i} = \mathrm{d}\rho_{rion}^{i};\ \ \mathrm{d}\rho_{rion}^{i} = \mathrm{d}\rho_{rtrop}^{i}$$

Therefore,

$$\begin{aligned}\Delta\rho_{r}^{i} + \rho_{k}^{i} &= \rho_{rt}^{i} + C(\mathrm{d}\tau_{k} - \mathrm{d}\tau_{r}) + (\mathrm{d}M_{k} - \mathrm{d}M_{r}) + (V_{k} - V_{r}) \\ &= [X^{i} - X^{k})^{2} + (Y^{i}\ \ Y^{k})^{2} + (Z^{i} - Z^{k})^{2}]^{1/2} + \Delta\mathrm{d}r^{i}\end{aligned} \tag{4}$$

If reference stations and users simultaneously observe the same 4 satellites, then, one has 4 simultaneous equations of the type of equation (4). From these, it is possible to solve for the unknowns Xk, Yk, Zk and Δdri , Δdri to include various residual error terms obtained by the ith reception channel associated with the same observation epoch

$$\Delta\mathrm{d}r^{i} = C\ (\mathrm{d}\tau_{k} - \mathrm{d}\tau_{r}) + (\mathrm{d}M_{k} - \mathrm{d}M_{r}) + (V_{k} - V_{r})$$

3 CARRIER WAVE PHASE DIFFERENCE GPS FAST POSITIONING CALCULATIONS

With regard to carrier wave phase observation quantities /23

$$\rho_{k}^{i} = \lambda\ (N_{ko}^{i} + N_{k}^{i}) + \Phi_{k}^{i} \tag{5}$$

In the equation: N_{ko}^{i} --is initial integral cycle ambiguity

N_{k}^{i} --is integral cycle change number beginning from observation epoch start instant to

Φ_{k}^{i} --is observation phase decimal portion

λ --is carrier wave wave length.

Taking equations (2) and (5), respectively, and using reference station and user device expressions to substitute into equation (4), one obtains the carrier wave phase difference GPS observation equation

$$\rho_{rt}^{i} + \lambda(N_{ko}^{i} \ N_{ro}^{i}) + \lambda(N_{k}^{i} + N_{r}^{i}) + \Phi_{k}^{i} - \Phi_{r}^{i}$$
$$= [(X^{i} - X^{k})^{2} + (Y^{i} - Y^{k})^{2} + (Z^{i} - Z^{k})^{2}]^{1/2} + \Delta \mathrm{d}r^{i} \qquad (6)$$

During general carrier wave phase measurements, the speed associated with initial integral richness is the key to increasing measurement speeds. Classical measurement methods are to opt for the use of stationary or medium and low dynamics measurements made for long time periods on a base line. Making use of a batch of observation data obtained--at the same time as calculating out common unknown parameters--calculations are made for many estimate values associated with initial integral cycle precision values. From error ranges associated with the calculation values in question determination is made of the only whole number to act as the initial integral cycle precision value. As far as new methods are concerned--for example, the Leica Company's GPS measurement technology which does not have an initial common dynamic state--there is still a need to make measurement sequences of over 200s. At the same time as location coordinates are calculated, option is made for the use of fast approximation techniques and common initial integral cycle precision values with uninterrupted accuracy, thereby obtaining the only exact initial integral cycle precision value to act as initial integral cycle precision value for later measurements and accurate positioning. In conjunction with this, the methods in question require that the distances between DGPS reference stations and user receivers be within 10km. Among the important causes for this is that, due to the fact that when reference stations and user receivers are separated by long distance differences, the influences of residual errors lead to an inability--within relatively short periods of time--to calculate out sole accurate integral cycle precision values. Moreover, the requirement associated with continuous measurement sequences of 200s or more is that, due to making fast approximations, a definite number of measurement data sequences are needed.

The fast positioning algorithms introduced by this article do not calculate initial integral cycle ambiguity values. Option is made for the use of measurement sequence window type computations. With regard to each observation epoch, use is made of forward shifts associated with 5 point computation windows. Step by step, the 5 point position coordinates associated with the epoch in question are calculated. After that, the average value for the 5 point coordinate solutions acts as the coordinate for that epoch.

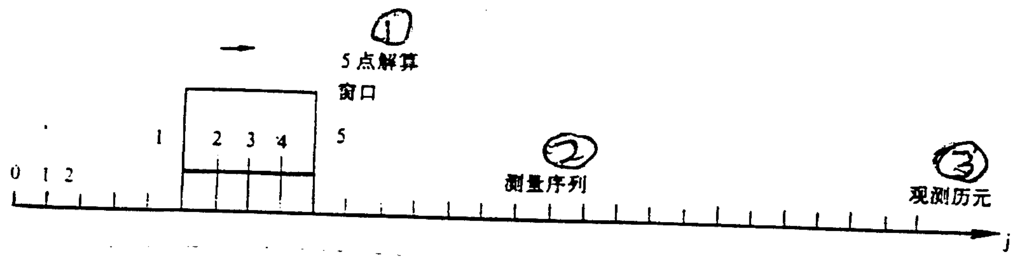

Fig.1 Observation Epoch 5 Point Position Coordinate Solution

Key: (1) 5 Point Solution Window (2) Measurement Sequence (3) Measurement Epoch

The calculation process is as follows.

Take

$$\Delta\Phi = \lambda(N_k^i + N_r^i) + \Phi_k^i - \Phi_r^i$$

to act as carrier wave measurement difference. Take

$$\Delta N^i = (N_{ko}^i - N_{ro}^i)$$

to act as initial integral cycle ambiguity difference. In situations where there is no loss of lock during test measurement processes, the values in question do not vary during the entire test measurement process. With regard to the same observational epoch, equation (6) can be written as /24

$$\rho_{ri}^i + \lambda\Delta N^i + \Delta\Phi = [(X^i - X^k)^2 + (Y^i - Y^k)^2 + (Z^i - Z^k)^2]^{1/2} + \Delta dr^i \qquad (7)$$

In the equation, unknown numbers include ΔNi , Xk , Yk , Zk as well as Δdri and ΔNi and are reference station and user receiver initial integral cycle ambiguity differences with regard to the ith satellite and take the form of whole numbers.

In cases where there is no loss of lock during test measurement processes, when there is continuous observation of a number of epochs, the unknown numbers ΔNi do not vary. However, Xk Yk , Zk as well as Δdri have some differences in each epoch. However, with regard to Δdri

$$\Delta dr^i + C(d\tau_k - d\tau_r)(dM_k - dM_r) + (V_k - V_r)$$

In this expression, as far as C(dτk - dτr) , that is, distance errors given rise to by GPS receiver clock errors relative to reference station receivers is concerned, this term can also be expressed as

$$C(\Delta T_0 + \Delta dt(t_{e0} - t_0))|$$

In the expression, ΔTo is initial observation epoch to . In respect to absolute deviations associated with instantaneous GPS receivers relative to reference station receiver clocks, during test measurement processes, the terms in question are maintained invariable. Δdt is the degree of deviation given rise to by internal clock oscillator frequency instabilities of the two receivers. With regard to the quartz oscillator frequency scale used by general GPS receivers, the stability is on the order of magnitude of 1010 . For this reason, Δdt should be higher than an order of magnitude of 1010 . Then, the changes of C(ΔTo + Δdt(tto - to)) in middle and low dynamic states will, in all cases, not be lower than the order of magnitude of 10-2 m/s. Relative to L1 wave band carrier wave wave lengths of 19.3cm, it is possible to assume that there is basically no change between the jth observation epoch and the j+1th observation epoch Δdt. Thus, it is possible to assume that, as far as C(dτk - dτr) associated with the term in question is concerned, there is basically no change between the jth observation epoch and the j+1th observation epoch.

With regard to (dMk - dMr), due to the fact that correlations of user GPS receivers relative to reference station receivers are relatively small, the terms in question are important sources of errors during measurement and positioning. As far as concrete environments with different positioning landforms are concerned, there are also some differences in changes between two observational epochs. However, with regard to reference station receiver dMr , there is basically no change. Changes between two observational epochs are fundamentally changes associated with user GPS receivers in dynamic environments. Option is made for the use of specialized antennas. With respect to static states, use is made of (dMk - dMr) between two observational epochs, and there is basically no change. In regard to dynamic state utilizations--in extreme cases--the terms in question lead to errors estimated on the order of magnitude of 10-2m.

With regard to (Vk - Vr), GPS receiver correlations relative tc reference station receivers are also relatively small. However, the quantities in question--in certain dynamic utilizations--possess a definite randomness. Going through measurements associated with multiple observation epochs, applications of statistical treatments are capable of the influences on the order of magnitude of 10-2m .

Thus, as far as Δdri between each observational epoch is concerned, it can be assumed that Δdri between the jth observational epoch and the j+1th observational epoch is basically invariable. With respect to deviations between Δdri channels, they are primarily caused due to noise associated with various receiver channels, that is, they are still under the influence of (Vk - Vr).

Reductions of the error sources in question are capable of being resolved in receiver designs and statistical processing of data obtained in measurments. Pseudo range errors given rise to by the deviations in question--in extreme cases--are capable of reaching cm level.

Combining pseudo range changes given rise to by all the error quantities, the error grand total is still on the cm level. It is possible to assume that Δdri between various channels as well as between each observational epoch is invariable. The deviations manifested in differences associated with initial integral cycle ambiguity values ΔNi are, thus, selected as

$$\Delta dr = \Delta dri$$

/25

For this reason, as far as making observations associated with the 1st epoch with respect to 4 satellites is concerned, it is possible to arrive at 4 single error equations of the type of equation (7). However, at this time, there are 8 unknown numbers: Xk , Yk , Zk , Δdr , and ΔNi (i=1,2,3,4). There is no way to solve for significant solutions. In succession, 2d epoch observations also are capable of arriving at 4 single error equations of the type of equation (7). Combining the 4 single error equations obtained for the 1st epoch, there are, then, 8 single error equations. However, this epoch also adds 3 unknown numbers: Xk , Yk , Zk . Calculating the total for the 8 single error equations, there are 11 unknown numbers. Thus, following along with the addition of observational epochs, each epoch is capable of arriving at 4 single error equations of the type of equation (7). However, 3 unknown numbers are also added. After continuously observing 5 epochs, it is possible to reach 20 single error equations of the type of equation (7). At the same time, there are 20 unknown numbers.

Common unknown numbers: Δdr, ΔNi (i=1,2,3,4)
Respective epoch unknown numbers: Xk , Yk , Zk (k=1,2,3,4,5)

It is then possible to calculate meaningful solutions. After continuing with observations of the next epoch, they are then set up simultaneously with the single error equations of the type of equation (7) obtained from the previous 4 epochs. It is also possible to calculate a set of solutions. Thus, beginning with 5 point calculation window displacement calculations--after carrying out 5 iterations of window calculations--each epoch is capable of producing one set of calculated values

$$X_j^k Y_j^k Z_j^k kj$$
$$(k = 1,\ 2,\ 3,\ 4,\ 5)$$
$$(j = 1,\ 2,\ 3,\ 4,\ 5)$$

Taking the 5 coordinate values $X_j^k,\ Y_j^k,\ Z_j^k$ which are obtained in association with calculations for each observation epoch, option is made for the use of solutions for mean values to obtain positioning solutions Xk , Yk , Zk .

4 CONCLUDING REMARKS

Through analysis with regard to Δdr--as far as option being made for the use of carrier wave phase difference positioning is concerned--residual errors are already very small. With regard to positioning solutions obtained with the calculation methods in question--due to opting for the use of multiple point average wave filtering--to a certain degree, it is possible to reduce errors given rise to by receiver internal noise. In the end, positioning precisions are able to achieve centimeter levels.

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