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Designing a Universal GNSS Simulator for Pseudorange Calculation

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Abstract— With the increasing number of users to G.N.S.S. services it's crucial to lower the time to market and cost for handheld user devices. It's also very important that those devices are reliable enough to be used in real time application. Real time satellite signals for any G.N.S.S. systems are subject to different types of error (Signal Unavailability, Blockage, Tropospheric, Ionospheric, Multipath, etc.). G.N.S.S. simulators can be a solution to these problems. The difficulty in designing a G.N.S.S. simulator is that they have to be modelled as close to real world as possible, taking into account all types of error. The signal simulators help us achieve lower system and hardware complexity and provide us with a ready test bench for end user devices. The advantage of the simulators is that they can provide precise pseudorange even in the absence of satellite signals. The aim is to design a simulator which can simulate the satellite signals while keeping the all the errors as low as possible while keeping the G.D.O.P. in the range of 4 to 5.

Keywords:- *GNSS,Pseudo-range Calculation, GPS, Satellite Constellation, Error Minimization*

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I. INTRODUCTION

Radio based navigation systems were first developed in the 1920's. These were used widely in World War II by the ships and planes of both sides. The drawback of using radio waves that are generated on the ground is that you must choose between a system that is very accurate but doesn't cover a wide area (high frequency radio waves, like UHF TV) and one that covers a wide area but is not very accurate (like AM radio). The only way to provide coverage for the entire world is to place high-frequency radio transmitters in space. The development of artificial satellites has made possible the transmission of more-precise, line-of-sight radio navigation signals and sparked a new era in navigation technology. A high-frequency radio wave can cover a large area and be very accurate (it overcomes the noise on the way to the ground by having a specially coded signal). Satellites were first used in position-finding in a simple but reliable two-dimensional Navy system called Transit. This laid the groundwork for a system that would later revolutionize navigation forever–the Global Positioning System. G.N.S.S. satellites transmit signals to equipment on the ground. G.N.S.S. receivers passively receive satellite signals; they do not transmit. G.N.S.S. receivers require an unobstructed view of the sky, so they are used only outdoors and they often do not perform well within forested areas or near tall buildings. GPS operations depend on a very accurate time reference, which is provided by atomic clocks. Each G.N.S.S. satellite has atomic clocks on board which are regularly monitored and are corrected for offset in the time using the reference clock. Each G.N.S.S. satellite transmits data that indicates its location and the current time (ephemeris). All G.N.S.S. satellites synchronize operations so that these repeating signals are transmitted at the same instant. The signals, moving at the speed of light, arrive at a GPS receiver at slightly different times because some satellites are farther away than others.

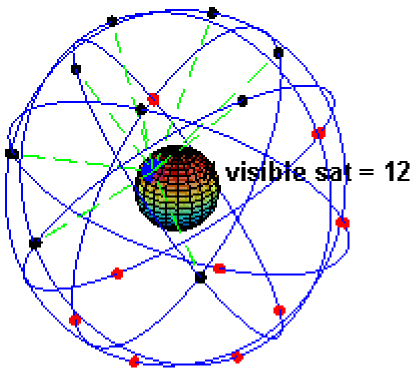

Fig 1. Diagram of a typical GNSS constellation.

Section 2. Of this article discusses on the theoretical background. Section 3. Presents the methodology which contains simulation and implementation procedures using MATLAB. Section 4. Provides the results and analysis. Section 5. Concludes the article with the research findings.

II. THEORETICAL BACKGROUND

Satellites send radio signals to the receivers which are on earth surface. Using these signals receiver calculates its location on earth. A GPS receiver needs four satellites to provide a three-dimensional (3D) fix and three satellites to provide a two-dimensional (2D) fix. A three-dimensional (3D) fix means the unit knows its latitude, longitude and altitude, while a two-dimensional (2D) fix means the unit knows only its latitude and longitude. The satellites share a

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common time system known as 'GPS time' and transmit (broadcast) a precise time reference as a spread spectrum signal at two frequencies in L-Band: L1=1575,42 MHz, L2=1227,6 MHz. Two spread spectrum codes are used: a civil coarse acquisition (C/A) code and a military precise (P) code. L1 contains both a P band a C/A code, while L2 contains only the P code. The accuracy of both codes is different. The receiver of the civil code cannot decode the military P code when the security status 'Selective Availability' in GPS satellites is turned on.

A. Calculating The Pseudorange

The receiver uses messages received from satellites to determine the satellite positions and time sent. The *x*, *y*, and *z* components of satellite position and the time sent are designated as $[x_i, y_i, z_i, t_i]$ where the subscript *i* denotes the satellite and has the value 1, 2, ..., *n*, where $n \geq 4$ When the time of message reception indicated by the on-board clock is $\tilde{t}$, the true reception time is $t_r = \tilde{t} + V_b$ where V_b is receiver's clock bias (i.e., clock delay). The message's transit time is $t_r + V_b - t_i$. Assuming the message travelled at the speed of light C, the distance travelled is $(t_r + V_b - t_i)c$. Knowing the distance from receiver to satellite and the satellite's position implies that the receiver is on the surface of a sphere centred at the satellite's position with radius equal to this distance. Thus the receiver is at or near the intersection of the surfaces of the four or more spheres. In the ideal case of no errors, the receiver is at the intersection of the surfaces of the spheres. The clock error or bias, *b*, is the amount that the receiver's clock is off. The receiver has four unknowns, the three components of GPS receiver position and the clock bias [*x*, *y*, *z*, *t*]. The equations of the sphere surfaces are given by:

$$\sqrt{(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2} = (t_r + V_b - t_i)c \,,$$

i=1,2,3…….n

Or in terms of *pseudorange*,

$$\rho = \sqrt{(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2} + t_b$$

Unit vectors from receiver to satellite is given as,

$$((x_i - x_u)/R_i \,, (y_i - y_u)/R_i \,, (z_i - z)/R_i))$$

Where R_i is given as,

$$R_i = \sqrt{(x_i - x_u)^2 + (y_i - y_u)^2 + (z_i - z_u)^2}$$

(X_u, Y_u, Z_u) denote the position of the receiver and (X_i, Y_i, Z_i) denote the position of satellite i.

So from pseudo range eqn we get the user approx position as,

$dx = H^{-1} \cdot d\rho$

Where, H is given as,

$$\begin{bmatrix} e_{x1} & e_{y1} & e_{z1} & 1 \\ e_{x2} & e_{y2} & e_{z2} & 1 \\ e_{x3} & e_{y3} & e_{z3} & 1 \\ e_{x4} & e_{y4} & e_{z4} & 1 \end{bmatrix}$$

Where,

$$e_{xi} = \frac{x_i - \tilde{x}_i}{R_i} \,,\; e_{yi} = \frac{y_i - \tilde{y}_i}{R_i} \,,\; e_{zi} = \frac{z_i - \tilde{z}_i}{R_i}$$

Where, $(\tilde{x}_i, \tilde{y}_i, \tilde{z}_i)$ denote the approximate user position.

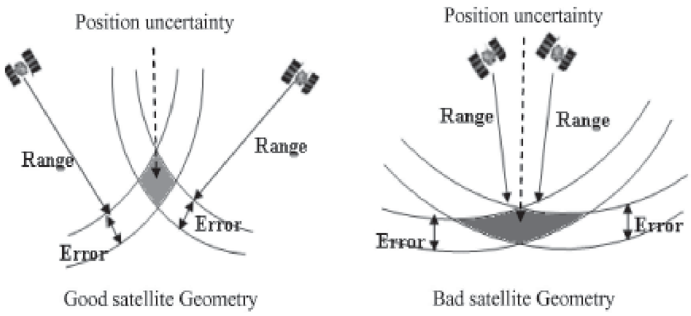


Fig 2. Different Satellite Geomatry .

B. Determining Different D.O.P.

Let's take a Matrix H,

Take pseudoinversive of it as $H^{-1} = (H^T \cdot H^{-1}) H^T$

So now $Q = cov(dx) = H^{-1}.cov(d\rho).(H^{-1}) =$

$$\begin{pmatrix} \sigma^2_{x_u} & \cdot & \cdot & \cdot \\ \cdot & \sigma^2_{y_u} & \cdot & \cdot \\ \cdot & \cdot & \sigma^2_{z_u} & \cdot \\ \cdot & \cdot & \cdot & \sigma^2_{ct_b} \end{pmatrix}$$

Fig 3. The Q-Matrix.

T.D.O.P. or Time Dilution of Precision is given as,

$$T.D.O.P = \sqrt{\sigma^2_{ct_b}}$$

P.D.O.P. or Position Dilution of Precision is given as,

$$P.D.O.P = \sqrt{\sigma^2_{x_u} + \sigma^2_{y_u} + \sigma^2_{z_u}}$$

G.D.O.P. or Time Dilution of Precision is given as,

$$G.D.O.P = \sqrt{T.D.O.P + P.D.O.P}$$

$$= \sqrt{\sigma_{x_u}^2 + \sigma_{y_u}^2 + \sigma_{z_u}^2 + \sigma_{ct_b}^2}$$

III. Methodology

We are trying to write a code using MATLAB which is the same as used in GPS receivers. The code will take the distances (as inputs) send by satellites which is between the satellite and the point. Also the code will know the position of satellites in space.

All points with d_i distance from satellite i, defines a sphere in space. We also assume that earth is spherical, the intersection of these two spheres is a circle on earth surface. For each satellite i it's the same case. If we could take the exact the distances properly then the circles formed by the circles and earth intersect at user location. But there is a problem, we cannot determine d_i exactly as there is an error term embedded. As a result of these error terms the circles intersect with at least two points among each other. As a result an ambiguity area is formed (fig 6.3), we know the point lies in between that area but we don't know the exact point.

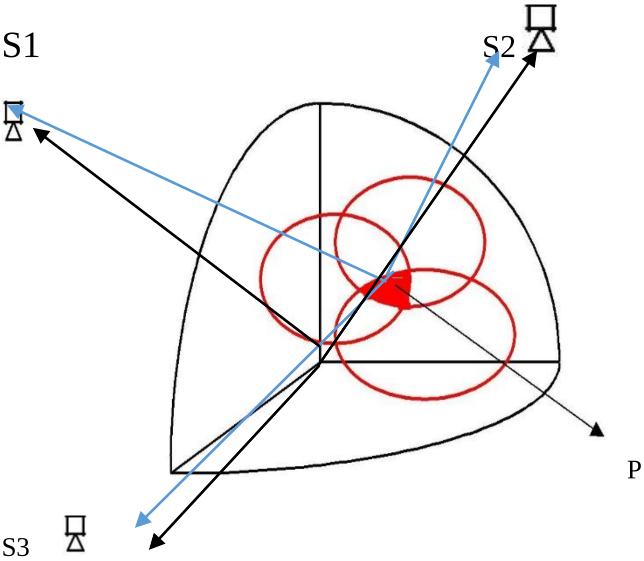
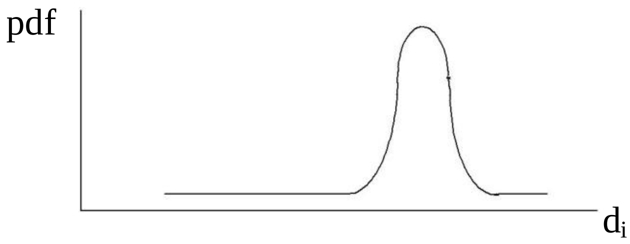


Fig.4 The Satellite Ambiguity Area

So we will try to propose a probabilistic methodology to estimate the location of point P and error incorporated while doing so. When the user of GPS receiver wants the output as lateral and longitudinal coordinates on earth, the inputs of the receiver will be

1. Radius of the earth; $r = R_E$ (Assumption: Earth is assumed to be spherical).
2. Place of satellite i (for i =1,…,N); α_i, β_i, r_i in spherical coordinates.
3. Distance between satellite i (i =1,…,N) and our location; d_{io}. (Taken from satellite i, by the GPS gadget).
4. Probability distribution of d_i and we assume that d_i has a normal pdf with $\mu = d_{io}$ and σ = 50m.



. Fig 5. Expected PDF graph

We used hatch filtering to minimize the error generated in the satellite pseudorange. Motivated by the efficiency of the Hatch gain and the advantage of position domain filtering, the position domain hatch filter (PDHF) for kinematic satellite based positioning was developed. The PDHF is more robust to changes in the visible satellite constellation during the positioning task. The stepwise PDH filtering strategy in MATLAB can be explained with the help of block diagram.

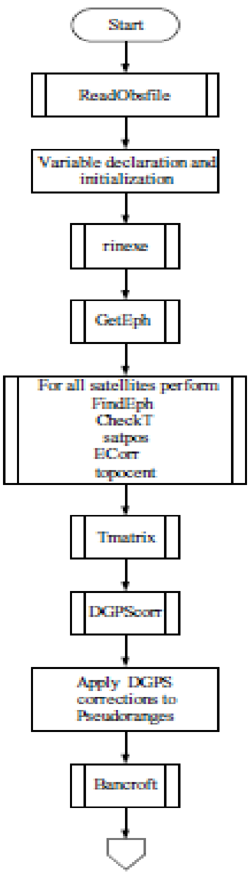


Fig.5- Flowchart for MATLAB code implemented for PDHF

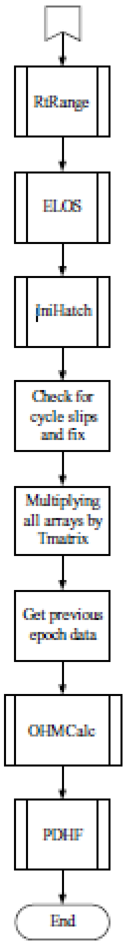


Fig.6 Flowchart for MATLAB code continued

Where,

1. ReadObsfile:
   Reads the user observation file in RINEX format containing pseudorange, carrier phase, time of week, satellite ID etc.
2. Rinexe:
   Reads the navigation file (ephemeris file) in RINEX format.
3. GetEph:
   Reshapes the navigation data into a matrix from.
4. FindEph:
   Finds a proper column in ephemeris data matrix for a given time and satellite ID.
5. CheckT:
   Repairs over and underflow of GPS time.
6. Satpos:
   Calculates X, Y, Z co-ordinates at time‘t’ from given ephemeris data.
7. ECorr:
   Returns the rotated satellite co-ordinates due to earth rotation during signal travel time.
8. Topocent:
   Calculates azimuth and elevation angle, given rotated satellite co-ordinates and receiver initial position (usually assumed as [0, 0, 0]).
9. Tmatrix:
   ‘1’ if satellite is present in two consecutive epochs, ‘0’ if not. 83
10. DGPScorr:
    Gets differential corrections from reference receiver.
11. Bancroft:
    Calculates preliminary co-ordinates (Xk) for a GPS receiver based on pseudoranges to 4 or more satellites [17].
12. RtRange:
    Calculates range from preliminary receiver co-ordinates to rotated satellites.
13. ELOS:
    Estimates line of site from the receiver to the individual satellites and forms ‘H’ matrix.
14. IniHatch:
    Initializes Hatch filter, for first epoch.
15. OHMCalc:
    Calculates the indirect measurement vector $*k$, utilizing delta phase observables.
16. PDHF:
    Performs time propagation and measurement update part of

IV. RESULTS AND ANALYSIS

The simulation was done using MATLAB. For the pseudorange calculation we simulated with 2 and 5 satellite scenarios for a known position.

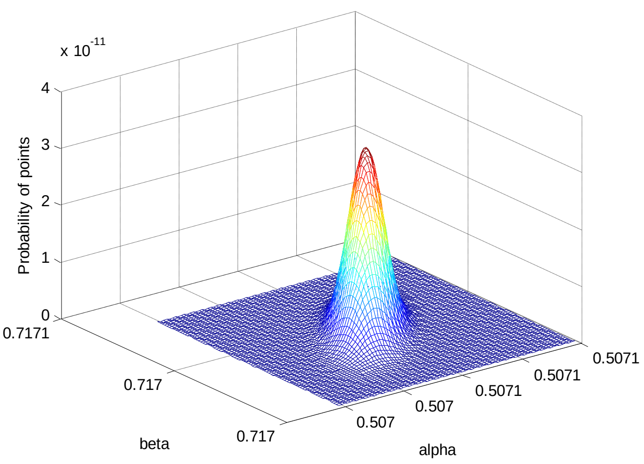


Fig.7 Satellite Pseudorange Using 5 Satellites

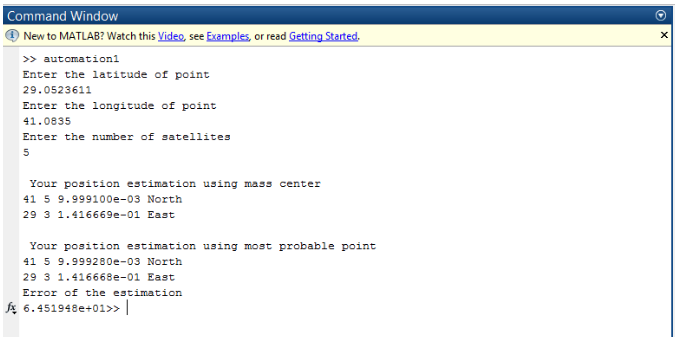


Fig 8. Error Calculated Using 5 Satellites

As we reduced the number of satellites we saw that the ambiguity area increased and the solution was much more erroneous.

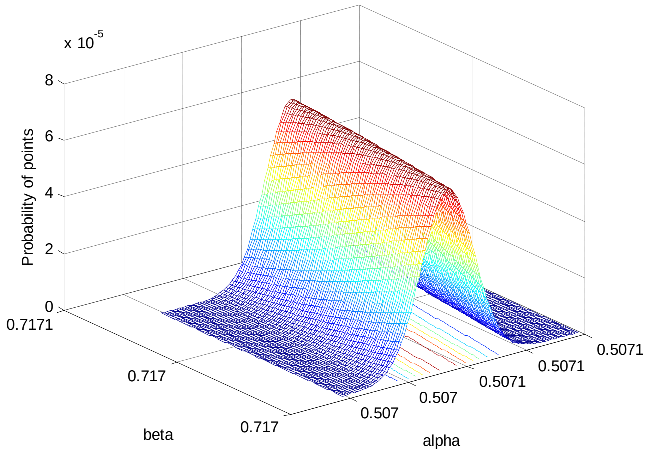


Fig 10. Satellite Pseudorange Using 2 Satellites

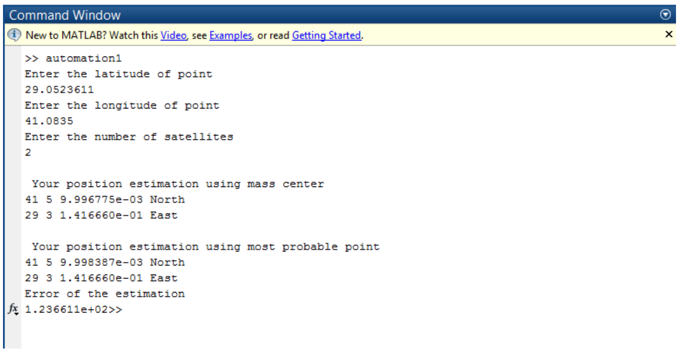


Fig 11. Error Calculated Using 2 Satellites

For the error minimization using PDHF, the error corrected is solely dependent upon the filtering duration.

Duration(seconds)	Series	Horizontal Error(cm)
160	3	23
160	2	62
160	1	85
336	3	54
336	2	38
336	1	11
392	3	71
392	2	56
392	1	35
510	3	18
510	2	8
510	1	4
697	3	45
697	2	42
697	1	32

Fig 10. Table for PDHF output

The amount or length of filtering also plays an important role in the accuracy levels obtained and the stability of the output. Consider the period of time between 350 seconds to 500 seconds (392 seconds and 510 seconds are listed in table), where the horizontal error reaches its maximum value and drops down to the minimum error range. In the case of PDHF starting at the 12th epoch, the output accuracy is less affected by drastic variations in the approximate position estimation from pseudoranges. The maximum error in the first case is 35 cm, in the second case the maximum is 60 cm and in the third case it is 70 cm.

V. CONCLUSION

GNSS has been used as a stand-alone system for many land applications that require fast and precise positioning such as mining, and automated highway systems as well as in other high-traffic land-based applications. However, there are situations where GNSS by itself does not provide the desired accuracy, for example when satellite signals are blocked or when the achievable accuracy is restricted by the geometry of the satellite constellation. This research work has focused on the use of redundant information provided by the GNSS satellite in obtaining precise and reliable results in a cost efficient manner. In current day where GNSS devices are required and crucial in every field the need to reduce the time to market also with devices with high accuracy is important. Which need a ready test bench which can simulate the satellite constellation with ease. We were able to generate precise pseudorange while kkeping the GDOP of the system under the range 4 to 5.

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