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CALCULATION AND ANALYSIS OF THE VARIATION EFFECTS IN HORIZONTAL PROTECTION LEVEL (HPL) USING RECEIVER AUTONOMOUS INTEGRITY MONITORING (RAIM)

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***Abstract*—the key point of this paper is to modify coding that may possibly determine the Horizontal Protection Level (HPL) from a GPS receiver. HPL is used to describe the user location errors with an assurance of 99.9999% and generally useful in aviation industry. The use of navigation systems in aviation demands a high value of belief in the result to be used. Integrity referred as the measure of the belief that can be placed in the accuracy of the information provided by a navigation system. Reliability characterizes a navigation capability to give well-timed caution to users when the Global Positioning System (GPS) ought not to be used for navigation. There is much architecture that permits calculating the degree of reliability on a solution allocated by the system. One of them are the reliability monitoring strategy known as Receiver Autonomous Integrity Monitoring (RAIM) which consist of algorithms applied at the receiver and permit to calculate the reliability level and in case of a defective satellite that error is not only identified but the defective satellite may be excluded. Technology of RAIM has been developed around its two tasks (or functions). One of which is to identify whether there is a satellite failure. The other one is to establish whether the satellite's spatial geometry fulfill the precision of navigation, or relevant to Horizontal Protection Level (HPL).**

This paper is concerned with the calculation of HPL and examines the outcome of variety in Protection Level using RAIM algorithm. RAIM algorithm identifies GPS abnormalities and satellite failures and provides the HPL value. HPL means the smallest detectable horizontal location error with available probabilities of a (FA) and (MD).

The results acquired by this technique led to conclude that it could be a helpful opportunity to a future airport environment execution.

***Keywords*—GNSS; RAIM; HPL; FD; FDE; PMD; PFA; MATLAB; DOP; HAL; GPS; RinexData file.**

I. Introduction

The RAIM technique is based on the confirmation of the reliability of the satellite measurements used in a navigation solution. If a defective measurement error or satellite error or satellite failure is identified, a process may be started to detect and exclude the faulty satellite or error from the navigation solution, which therefore remains faultless and authentic for use in a defined program. The reliability for the non-precision approach (NPA) is of consideration here, for which the RAIM is used to create HPL and examine the effects of variation for users to acknowledge exact level of protection.

A. Background Information

GPS satellites are designed to provide users with warnings of satellite malfunctions. However, sometimes, the warnings may take more than 5 minutes before the user is aware of a malfunction. Aviation applications require a more timely notification of a satellite failure condition. Thus, a means to independently monitor satellite integrity is required.

One of these means is Receiver Autonomous Integrity Monitoring (RAIM). The RAIM method is based on a self-consistency check among the available measurements.

The RAIM consistency check uses redundant measurements as a means to determine GPS integrity. The discussion given below can be found in [1] "Global Positioning System: Theory and Applications", "Volume II, chapter 5, by Bradford W. Parkinson and James J. Spilker Jr., published by the American Institute of Aeronautics and Astronautics, Inc. in 1996".

There are two main approaches to RAIM (not considering several hybrid approaches). "In the first main method, the snapshot scheme [2], only current redundant measurements are used for the self-consistency check. In the second main method, the averaging or filtering scheme, both past and present measurements are used in the RAIM decision".

The theoretical foundation for RAIM is the statistical detection theory. "Two hypothetical-testing questions are posed: (1) Does a failure exist? And (2) If so, Which is the failed satellite? The basic assumption is that there is only one failed satellite at a time. Determination of which satellite has failed is more difficult than simple failure detection, and it requires more measurement redundancy".

B. Research aims and objectives

In this paper the main theme is to design a true integrity control method which eliminates dangerous and confusing navigation information caused by failures within the navigation structure and to provide a warning message to the user if the information in the navigation structure is not correct enough for making certain implementations in the specific time frame. To address the risks of satellite navigation for integrity, the proposed action plan is the Receiver Autonomous Integrity Monitoring (RAIM).

The major purpose of this paper is to modify an algorithm in the Matlab environment that computes the Horizontal Protection Level (HPL) of a GPS receiver.HPL is used to define the geographic location errors of a receiver with a confidence of 99.99999% being applied in the industry. This Matlab algorithm designates to equip GPS precise positioning with low cost with the computation of this parameter, since it is a necessary requirement for every maneuver in the air to evaluate the performance of the same. The HPL calculation is achieved through Rinex Navigation and Observation data files using RAIM algorithm in Matlab [3].

II. RAIM

RAIM is a user algorithm which establishes the GNSS solution reliability. When more satellites are available than requirement of a position fix (satellite number > 4), the extra pseudoranges should be constant with the calculated position. If the pseudorange from one satellite is dissent considerably from the estimated value some fault may be associated with it or with another signal integrity problem.

In order for a receiver to use a RAIM algorithm it is necessary to have a minimum of five visible satellites with a good geometry. With five satellites available we can use an algorithm called Fault Detection (FD). If six or more satellites are available we can use a more sophisticated algorithm called Fault Detection and Exclusion (FDE) [4] [5].

There are different types of RAIM algorithms: conventional RAIM, Relative RAIM, and Advanced RAIM.

- "Conventional RAIM algorithms focus on pseudorange measurements using those measurements and position noises, along with the false alarm and missed detection probability to compute the corresponding protection levels for the position solution".
- "Relative RAIM (RRAIM) uses precise carrier phase measurements to propagate older pseudorange based positions solutions forward in time. RAIM is performed on the carrier trajectory to ensure integrity and the new protection levels are calculated based upon the original values and the accumulated uncertainty over time".
- "The Advanced RAIM (ARAIM) scheme was introduced by the GNSS Evolutionary Architecture Study (GEAS) to guarantee localizer performance with vertical guidance operation worldwide. This algorithm uses multi constellations data and takes advantage from dual frequency capabilities as well as an integrity support message".

III. HPL Calculation using RAIM

Global Navigation Satellite Systems (GNSS), such as the Global Positioning System (GPS), are typically used for navigational purposes for a variety of mobile vehicles in which relatively accurate position data is required. For instance, the GPS system is used in aircraft for guidance and navigation, in land vehicles for navigation, and in marine vehicles for navigation. A typical GPS system includes: (1) a nominal 24 satellite constellation that is positioned in six earth-centered orbital planes; (2) a ground control/monitoring network; and (3) various GPS receivers. The GPS satellites are known to use direct sequence, spread spectrum modulation for transmission of ranging signals and other navigational data. The ranging signals broadcast by the satellites are modulated with pseudo-

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random noise (PRN) codes that are replicated by the GPS receivers. The broadcast ranging signals generated by the GPS satellites are subject to significant errors due to anomalies in the satellite clocks, broadcast data, and atmospheric contributions, such as ionospheric and tropospheric effects. Other types of systems that provide ranging signals for navigation purposes also have similar issues.

These errors, as well as other errors in signals transmitted from GPS satellites and other ranging devices, can cause significant problems in navigation systems, such as aircraft navigation systems, which use GPS receivers and GPS satellite signals to calculate a navigation solution. For instance, an aircraft's navigation solution represents the calculated position of the aircraft in three-dimensional space at a particular time, plus heading and speed information. Navigation solution integrity, which is the guarantee to some specified high confidence level that some scalar measure of navigation solution position error (e.g., horizontal, vertical) is below a threshold called the Horizontal Alarm Limit (HAL) [6], is essential.

$$P(FA|NC) = \left(\|\hat{e}\| > R|NC\right) = \frac{1}{2^{(m-4)/2}\,\Gamma\left(\frac{m-4}{2}\right)} \int_{R^2/\sigma_b^2}^{\infty} S^{\left(\frac{m-4}{2}-1\right)} e^{-S/2}\, ds.$$

Above equation for residual threshold can be set analytically to achieve any desired probability of false alarm under normal error conditions. Given the possible values and we may solve the equation for the residual threshold R. The situation is depicted in the figure 1.

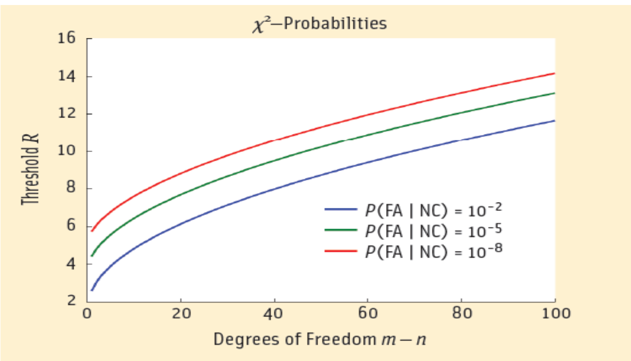

Figure 1: Probability Graph of a False Alarm

The function or device that ensures navigation solution integrity performs a computation of the current estimated position error and also continuously monitors a variable that is indicative of navigation solution integrity also known as the Horizontal Protection Level (HPL).

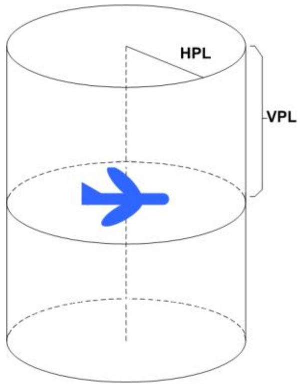

Figure 2: Horizontal and Vertical Protection Levels

The figure 2 shows Horizontal Protection Level which is the radius of a circle in the horizontal plane (the plane tangent to WGS-84 ellipsoid), with its center being at the true position, "that describes the region assured to contain the indicated horizontal position. It is a horizontal region where the missed alert and false alarm requirements are met for the chosen set of satellites when autonomous fault detection is used".

"RAIM is typically implemented in software in the GPS receiver and employs an instantaneous self-consistency check. In order for RAIM to function as intended, a minimum plurality of satellite or other ranging signals are required. Where such a minimum plurality of ranging signals is not available, the RAIM internal consistency check is not available; therefore, horizontal position integrity information is not available. In addition, RAIM may also generate error values based upon the consistency check, which are then compared to predetermined error limits. Accordingly, should an error value exceed the corresponding allowable, error limit, a RAIM alarm may be generated to indicate the failure of the consistency check. This alarm is a warning to the user that although horizontal position data may be available, it may be erroneous. In such instances, where RAIM is not available or a RAIM alarm is generated, the integrity of the navigation solution is questionable. We can examine the residual statistics and analyze that if the residual statistics is larger than that the 'R' threshold. If it is larger so then a failure system will be declare. Four outcomes are possible within the given simple algorithm which can be seen in the figure 3".

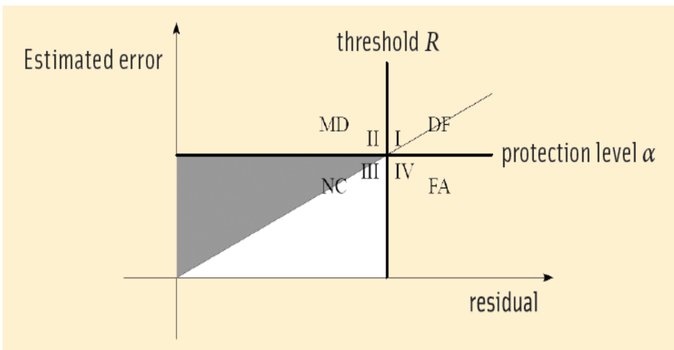

Figure 3: Basic RAIM States

'One aspect of the present invention is directed to a method for a Satellite receiver autonomous integrity monitoring (RAIM) real time fault detection for each timing cycle of Said Satellite receiver'.

In one embodiment of the present invention, the method comprises the following steps:

(a) “Identifying a default set of navigational measurements using a real time available GPS Satellite constellation, and acquiring a plurality of GPS Satellite Signals by using a satellite receiver”.

(b) “For each timing cycle of the Satellite receiver continuously determining an effective configuration of real time measurement geometry adjusted for a normalized weights factor associated with different error Sources, the effective configuration of real time measurement geometry adjusted for the normalized weights factor corresponds to the default Set of navigational measurements”.

(c) “If the number of default navigational measurements is greater than or equal to a first predetermined number, for each timing cycle of the Satellite receiver continuously computing a horizontal protection level (HPL) associated with the effective configuration of real time measurement geometry adjusted for the normalized weights factor”.

(d) “If the number of default navigational measurements is less than the first predetermined number, for each timing cycle of the Satellite receiver adding an additional measurement to the default set of measurements and repeating the Steps (a-c). The additional measurement is selected from the group consisting of: GPS measurement”.

In one embodiment of the present invention, the Step (c) of continuously computing the horizontal protection level (HPL) associated with the effective configuration of real time measurement geometry adjusted for the normalized weights factor further comprises the following steps: (e) “if the number of default navigational measurements is greater than or equal to the first predetermined number, checking whether the horizontal protection level (HPL) is less than or equal to a horizontal alert limit (HAL), and (f) if the number of default navigational measurements is less than the first predetermined number, adding an additional measurement to the Set of available measurements, and repeating the Step (e).Some of the operational Conditions of RAIM states with protection level, Alert limit and position error according to Stanford Integrity Diagram are shown in figure 4”.

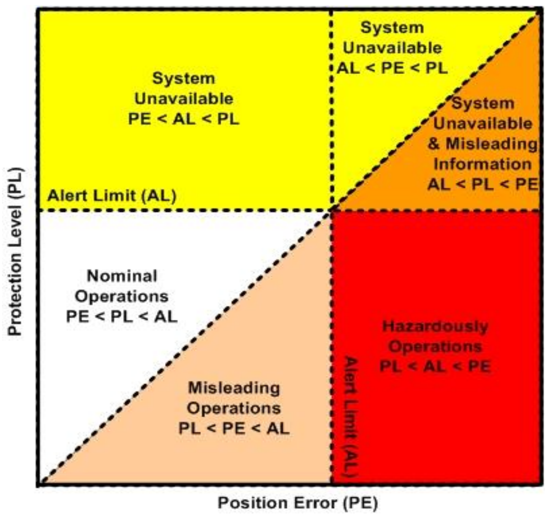

Figure 4: The Stanford Integrity Diagram

In one embodiment of the present invention, “the Step (e) of checking whether the horizontal protection level (HPL) is less than or equal to the horizontal alert limit (HAL) further includes the following steps: (g) if the horizontal protection level (HPL) is less than or equal to the horizontal alert limit (HAL) declaring a receiver autonomous integrity monitoring (RAIM) detection function available based on the Set of available measurements and declaring the Set of available measurements as substantially sufficient; (h) if the horizontal protection level (HPL) is greater than the horizontal alert limit (HAL), adding an additional measurement to the Set of available measurements and repeating the Step (g); and (i) if the horizontal protection level (HPL) is greater than the horizontal alert limit (HAL) and if no additional measurement is available to add to the Set of available measurements, declaring a receiver autonomous integrity monitoring (RAIM) detection function as not available and declaring the set of available measurements as not Substantially Sufficient”.

IV. Results

GPS Navigation and Observation parameters used which are taken with the help of GPS Receivers. The GPS receiver used in the thesis work is Topcon receivers and Data given by these receivers is transfer to TEQC (Translation, Editing, and Quality Checking).TEQC is used to translate (convert) certain native binary formats to RINEX 2.11 observation and/or navigation files. To be able to perform detection a data set of 7 satellites is chosen having lowest GDOP value to calculate lower error in the Position results. After the implementation of Matlab coding [7] on the data set of the 7 satellites and with the help of RAIM fault detection algorithm and Horizontal Protection Level is calculated, the test statistic [8] is computed and compared the Results with the given threshold ‘R’.

Calculation of Horizontal Protection Level by getting Alpha_max $(\alpha_{\max})$ and sigmaσ :

The Slope $\alpha_i$of the satellite i failure mode axis is calculated as:

$$\alpha_i = \sqrt{\frac{m_{1i}^2 + m_{2i}^2}{s_{ii}}}$$

The values of Slope (α_i) are then calculated for the all $i1,\ldots,7,$ their corresponded lines which are taken with the help of Matlab code implementation. It is possible that may the RAIM algorithm calculate or detect an observation error depend on satellite geometry. When the satellite geometry is poor then it does not be necessarily identify observational errors, but if there are errors then it can be difficult to estimate.

In detecting a fault accurately the slope (α_i) provides difficulty measurement in the presence of noise. We can say that when the slop is larger the detection of fault will be more difficult.

The failure mode axes through the beginning with the slope (α_i) are only given by the geometry of the satellite determined by satellite and the satellite receiver.

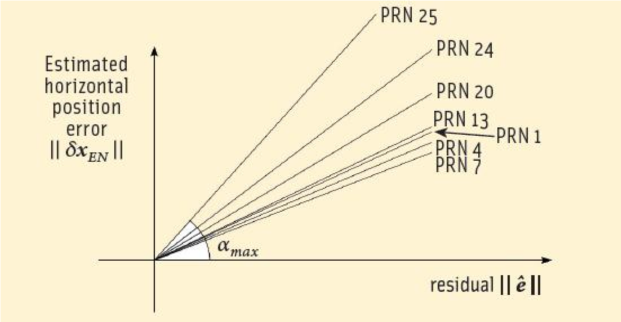

Figure 5: Characteristics Slopes of Seven Visible Satellites

The maximum calculated value of slope (α_i) along with mode axes is known as $\alpha_{\max}$ [9] and the Horizontal Protection Level (HPL) is defined as

$$HPL = \alpha_{\max} \sigma_0$$

Here 'σ_0' is the standard deviation of the pseudoranges:

$$\sigma_0 = \sqrt{\frac{\hat{e}^T \sum_b^{-1} \hat{e}}{m-4}}$$

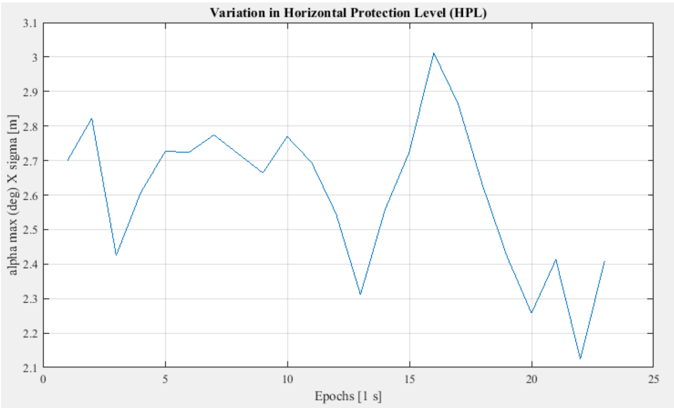

Figure 6: Variation in Horizontal Protection Level

V. CONCLUSION

The aim of this paper is to make low cost software that can generate or compute value for the Horizontal Protection Level (HPL) with variations. This is achieved by processing the Navigation and Observation RINEX 2.10 data files in the Matlab Implementation, processing the data information according to the Minimum operational performance [10] [11] Standards and generating a computed value for HPL. Under the scope of the paper a new Matlab Code is designed and modified for calculation of the variation effects in Horizontal Protection Level by using the Simplest RAIM fault detection algorithm. This work intended to perform the validation of different Integrity related algorithm. We also learned about the performance of RAIM fault detection algorithm and the modified Matlab coding also gave information of the different Horizontal Protection Level values at each and every epoch of the data recorded by the GPS receivers.

RAIM fault detection algorithm is implemented to calculate Horizontal Protection Level (HPL) and with the help of some modification we are able to get the variations in the Horizontal Protection Level (HPL) values at each epoch (which is equal to 1 sec). Test Statistic is generated and then compares the resultant (HPL) value to the given threshold. It can be concluded that RAIM fault detection Algorithm is a valid method to obtained Horizontal Protection Level (HPL) value and form this simple method we can get the variations in HPL according to the data.

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