A Study of Improvements in GNS Performance Applying Interoperability Associated with RAIM and Proposal of a GNSS Based Landing System

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Abstract—

With the future of Global Navigation Satellite Systems (GNSS) being almost certain to include the modernized U.S. GPS, the restored Russian GLONASS and the developing Galileo system of the European Commission (EC), it is prudent to investigate the levels of integrity that can be expected. In this paper, a GNS based Receiver Autonomous Integrity Monitoring (RAIM) scheme along with Reliability and Success rate measures are used to assess integrity performance levels of standalone GPS, Galileo and integrated GPS/Galileo systems.Various parameters, computed are the internal reliability, represented by the minimal detectable bias (MDB); the external reliability represented by the bias-to-noise ratio (BNR), MDE, GDOP; and the success rates.This paper aims to demonstrate that receivers which can combine the signals from GPS and Galileo may offer a free Integrity service which meets the needs of the majority of users, possibly up to the standards required for aviation precision approach.

Keywords— RAIM, PDOP, Minimal Detectable Outliers, Success Rate, GNSS, MDB, MDE, BNR Index Terms—Mathematical Model of GNSS, Satellite Tracking, Satellite Availability, Position Dilution of Precision (PDOP), Internal Reliability, Minimal Detectable Outliers, Minimal Detectable Cycle Slip, External Reliability, Success Rate, Biased Success Rate.

INTRODUCTION

Several processing strategies that use dual-frequency GPS-only solution, multi-frequency Galileo-only solution, and finally tightly combined dual-frequency GPS ? Galileo solution were tested and analyzed for their applicability to single-epoch long-range precise positioning. In particular, a multi-system GPS ? Galileo solution was compared to GPS double-frequency solution as well as to Galileo double-, triple-, and quadruple-frequency solutions. Also, the performance of the strategies was analyzed under clear-sky and obstructed satellite visibility in both single-baseline and multi-baseline modes. The results indicate that tightly combined GPS ? Galileo instantaneous positioning has a clear advantage over single-system solutions and provides an accurate and reliable solution. It was also confirmed that application of multi-frequency observations in case of Galileo system has an advantage over a dual-frequency solution.

For an increasing number of applications, the performance characteristics of current generation Global Navigation Satellite Systems (GNSS) cannot meet full availability, accuracy, reliability, integrity and vulnerability requirements. It is anticipated however that around 2015 the next generation of GNSS will offer around one hundred satellites for positioning and navigation. This includes constellations from the US modernized Global Positioning System, the Russian Glonass, the European Galileo, the Japanese QuasiZenith Satellite System and the Chinese Beidou. It is predicted that the performance characteristics of GNSS will be significantly improved. To maximize the potential utility offered by this integrated infrastructure, this paper presents an approach adopted in Australia to quantify the performance improvements that will be available in the future. It presents the design of a GNSS for a number of important applications within the Asia Pacific region. In quantifying the improvement in performance realized by combined systems, this paper proposes a practical approach to facilitate thedevelopment of innovative applications based on future GNSS.

In this paper, a Receiver Autonomous Integrity Monitoring (RAIM) scheme along with Reliability and Separability measures are used to assess integrity performance levels of standalone GPS and integrated GPS/GLONASS, GPS/Galileo and GPS/GLONASS/Galileo systems.

2015					
	GPS		GLONAS	SS	GALILEO
Services	2004	2015	2004	2015	2004 2015
Basic Positioning	SPS	SPS	SP	SP	0S
(unencrypted)	L1	L1CA	L1	L1	L1
	CA	L2C		L2	E5a
		L5		3 RD	E5b
				SIGNAL	
Integrity/					
Safety					SoL
(unencrypted)					L1
					E5b
					E5a
				Integrity	
Commercial				Message	
/value-					CS
added(encrypted)					E6
Security / Military					PRS
(unencrypted)					L1
	PPS	PPS	HP		E6
	L1P(Y)	L1P(Y)	L1		
	L2P(Y)	L2P(Y)	L2		
		L1M			
		L2M		HP	
				L1	
				L2	
				UNKNOWN	

Table 1
Current and future GPS, Glonoss and Galileo services and signals for 2004 and planned for

1.SPS(standard positioning service);**2.PPS**(prices position service); **3.SP**(standard precision); **4.HP**(high precision); **5.OS**(open service); **6.SoL**(safety of life service); **7.CS**(commercial service);**8.PRS**(public regulated service)

I. RECEIVER AUTONOMOUS INTEGRITY MONITORING (RAIM)

In this context "Integrity" is defined as: "...the trust which can be placed in the correctness of the information supplied by the total system. Integrity includes the ability of a system to provide timely and valid warnings to the user when the system must notbe used for the intended operation". In simple terms, Integrity is the property that someone using the system for a safety-critical purpose, such as landing an aircraft in poor weather, needs to have confidence that if something goes wrong and their estimate of position (i.e. altitude) is incorrect, they will be given correct and timely warning. It is possible to provide integrity through some kind of external augmentation system (for example, the WAAS and EGNOS systemsreferred to previously) or, as is currently defined for Galileo, by building itinto the system specifications from the outset. The problem is that anysuch system is inevitably expensive, with its need for multipleredundancy in all critical systems including wide area communicationsnetworks, software developed to the most exhaustive level of test andvalidation and,

most critically, with extremely demanding specificationson time to alarm (TTA). The Integrity Justification Study within this thesisdemonstrates this point. An alternative method of providing signal integrity information is through Receiver Autonomous Integrity Monitoring techniques. These algorithmsrely on users being able to access more satellites than the minimumnumber required for a navigation solution, in order to estimate the integrity of the signal from these redundant measurements. Currently, with a GPS constellation of 24 satellites providing only a singlefrequency in its Standard Positioning Service (SPS), RAIM cannot meetCategory I requirements for aviation precision approach, although RAIM enabled receivers can be used as a navigation aid for less demanding phases of flight. However, by using both Galileo and upgraded GPS systems together the quality of the integrity information available from RAIM algorithms will increase dramatically, due to both the increased size of the useable constellation and the improved accuracy of the signals compared with current GPS.INTEGRITY Receiver Autonomous Integrity Monitoring (RAIM) is a technique used to provide a measure of the trust which can be placed in the correctness of the information supplied by the total system (Ober, 2003). It is also a condition for RAIM to deliver the user with timely and valid warnings when the system's performance exceeds specified tolerance levels. The RAIM technique monitors the integrity of the navigation signals independently of any external 2 monitors via measurement consistency check operations. The performance is measured in terms of the 'maximum allowable alarm rate' and the 'minimum detection probability' and is dependent on the failure rate of measurement sources, range accuracies and measurement geometry. Optimal RAIM algorithms should exhibit highdetection rates and low false alarm rates. For a review of significant developments and analyses of RAIM methods and algorithms over the past decade see Hewitson et al. (2004). Statistical testing procedures focussed on the reliability of detecting fault measurements or outliers have generally been the basis for current RAIM techniques. A minimum of five satellites are required to provide the redundancy required to permit measurement consistency checks and evaluate the reliability measure. However, with only five satellites available it is only possible to detect the presence of an outlying measurement as the outlier detection statistics are fully correlated. With more than five satellites the contaminating measurement may be identified depending on the correlation of detection statistics. If the statistics are highly correlated the likelihood of flagging the wrong measurement as the outlier is severe. It should be noted that greater redundancy and geometric strength of the measurement system significantly reduces the correlation of the test statistics and therefore, improves the capability of GNSS RAIM procedures for both detecting and identifying the outliers. As a result of the RAIM procedure's dependence on redundancy and measurement geometry it is essential to assess, not only the system's ability to detect outliers, but also the system's ability to separate any outlying measurements. Thus, a measure of separability as well as the reliability measure should be included when evaluating GNSS RAIM performance. The reliability measure is used to evaluate the capability of GNSS receivers to detect outliers and assess the impact of undetectable outliers on the navigation solution, while the separability measure is used to assess the capability of GNSS receivers to correctly identify the outlier from the measurements processed. This section covers the details regarding preparation of your manuscript for submission, the submission procedure, review process and copyright information.

II.GNSS OBSERVATION MODEL AND DESIGN PARAMETERS

2.1 Observation Model

There are three types of observation models of our interest. Firstly, Geometry-Free (GF) model, in which the observation equations remain parameterized in terms of unknown DD receiver-satellite ranges. They are linear and the receiver-satellite geometry is not explicitly present in the model. The other two models are Geometry-Based (GB) model and are parameterized in terms of the unknown baseline components. The DD receiver-satellite ranges are linearized for the geometry appears in the observation equations. The two geometry-based models are different with respect to the receivers. Firstly, in the stationary receiver (SR) model both receivers are stationary, so that the baseline components remain constant for all observation epochs. In the roving receiver (RR) model, on the other hand, one receiver is moving, and thus the baseline changes in every epoch.

2.2 Mathematical Model of GNSS

Pseudo range code P and carrier range code Φ are the observations of satellite navigation. Observation can be of single difference (observation of single receiver) and double difference (observations collected by two receivers).

2.2.1 GPS and Galileo

Pseudo range code P and carrier range code Φ are the observations of satellite navigation. Observation can be of single difference (observation of single receiver) and double difference (observations collected by two receivers). Pseudo range code P and carrier range code Φ are the observations of satellite navigation. ObservationPseudo range cod Considering Double Difference (DD) observation equations for satellite r and s can be given by:

$$p_i^{rs}(t) = \rho^{rs}(t) + \frac{f_{11}^2}{f_i^2} l^{rs}(t) + e_i^{rs}(t) \qquad (1)$$

$$\Phi_{i}^{rs}(t) = \rho^{rs}(t) - \frac{f_{L1}^{2}}{f_{i}^{2}}I^{rs}(t) + \lambda_{i}N_{i}^{rs} + \varepsilon_{i}^{rs}(t)$$
(2)

These equations are applicable in satellite navigation. Unknown parameters are the DD satellitereceiver range, ρ , the DD ionospheric effect, I, the DD integer carrier ambiguities, N, the measurement noise, e and ϵ , of code and phase respectively. The carrier wavelengths are denoted by, λ . And i is the frequency any L-band/E-band frequency. Geometry free (GF) baseline model is considered, where observation equations remain parameterized in terms of the unknown DD receiversatellite ranges.

For setting up the measurement models for the three baseline models staring with the complete Double Difference (DD) measurement model for two receivers observing m satellites on f frequencies for a single epoch as:

$$y_k = (e_{2f} \otimes I_{m-1})\rho_k + (C_2 \otimes I_{m-1})a + n_k(3)$$

where,

$$C_2 = c_2 \otimes I_f; \tag{4}$$

$$y_k = (p_i(k)^T, \Phi_i(k)^T)^T;$$
 (5)

$$\rho_{\mathbf{k}} = \rho(\mathbf{k}); \mathbf{a} = (\lambda_{\mathbf{i}} \mathbf{N}_{\mathbf{i}})^{\mathrm{T}}; \tag{6}$$

$$\mathbf{n}_{\mathbf{k}} = (\mathbf{e}_{\mathbf{i}}(\mathbf{k})^{\mathrm{T}}, \boldsymbol{\varepsilon}_{\mathbf{i}}(\mathbf{k})^{\mathrm{T}})^{\mathrm{T}} \tag{7}$$

$$\otimes$$
Kronecker product: Mp \times q \otimes N =

$$\begin{pmatrix} m_{11}N & \dots & m_{1q}N \\ \vdots & \ddots & \vdots \\ m_{p1}N & \dots & m_{pq}N \end{pmatrix} (8)$$

The indices for satellites are omitted and the observations are collected by type, first the code observations on all frequencies, then the phase observations. The notation c_x is used for a vector with a one at the x-th entry and zeros otherwise. A vector consisting of x ones is denoted as e_x . the ionospheric parameters were eliminated from equation (3).

The three baseline models for k epochs of data can all be written in a form as: $y = [I_k \otimes M \ e_k \otimes N] + n$ (9)

But they will be different with respect to the matrices M and N and the unknowns b. The geometryfree measurement model follows directly from equation (3). The unknowns bare simply the ranges ρ , and the design matrices are given by:

$$M = e_{2f} \otimes I_{m-1}$$
(10)
$$N = C_2 \otimes I_{m-1}$$
(11)

The satellite-receiver range needs to be linearized to arrive at the geometry-based measurement models. For a single epoch,

$$\Delta \rho_{\mathbf{k}} = \overline{\mathbf{G}}_{\mathbf{k}} \Delta \mathbf{b}_{\mathbf{k}} \tag{12}$$

Where, Δb are the initial baseline corrections with respect to the initial baseline and \overline{G} is the (m-1) × 3 matrix that captures the satellite-receiver geometry. This is a time dependent matrix but due to the slowly changing geometry here it can be considered as time invariant. For the roving receiver model the unknowns b in equation (9) are the 3kbaseline increments Δb_k (three for every epoch). This results in the following design matrices:

$$M = e_{2f} \otimes G$$
(13)

$$N = C_2 \otimes I_{m-1}$$
(14)

For the stationary receiver model the unknowns b in equation (9) are the 3 baseline increments Δb so that,

$$M = \emptyset$$
(15)
$$N = e_{2f} \otimes \overline{G} C_2 \otimes I_{m-1}$$
(16)

3.3.2 Combined GPS-Galileo

The measurement models observed so far can be applied for both GPS and Galileo observations. For the interoperability and compatibility property of both the GPS and Galileo it would be interesting to observe at the model for the receivers that collect observations of both systems. The baseline unknowns in the GB models are common for both systems, but of course the ambiguities are not. The combined measurement model for one epoch is written as:

$$\binom{y_{\text{GPS}}}{y_{\text{GAL}}} = \binom{M_{\text{GPS}} & N_{\text{GPS}}}{M_{\text{GAL}}} & N_{\text{GAL}} \binom{D}{a_{\text{GPS}}}{a_{\text{GAL}}} + n \quad (17)$$

Where,_{GPS} refers to GPS observations and $_{GAL}$ to Galileo observations. Double differences are formed with respect to a GPS satellite and a Galileo satellite respectively. For the GF model the matrix M would become a block diagonal matrix with M_{GPS} and M_{GAL} as the sub matrices on the diagonal.

3.4 Stochastic Model of GNSS

In probability theory, a purely stochastic system is one whose state is non-deterministic so that the subsequent state of the system is determined probabilistically. Any system or process that must be analyzed using probability theory is stochastic at least in part.

3.4.1 GPS and Galileo

The variance-covariance (vc) matrix of the single differenced (SD) observations of one satellite without eliminations of the ionospheric parameters is given by:

$$C_{p\emptyset} = \begin{pmatrix} C_p \\ C_{\emptyset} \end{pmatrix}$$
(18)

where, C_p and C_{Φ} are the vc- matrices of the code and phase observations respectively. So, there may be correlation between the code observations and between the phase observations on different frequencies. Because of the elimination of the ionospheric parameters from the measurement equation, the vc- matrix becomes:

$$C = C_{p\emptyset} + 2s^{2} \begin{bmatrix} \mu \\ -\mu \end{bmatrix} \begin{bmatrix} \mu \\ -\mu \end{bmatrix}^{T}$$
(19)
$$\mu = \left(\frac{f_{L1}^{2}}{f_{1}^{2}}\right)^{T}$$
(20)

where, s^2 is the undifferencedionospheric weighting factor with units of m^2 . When ionospheric delays are absent or assumed known, $s^2=0$, which may be the case when the baseline is sufficiently short. This is referred to as the ionosphere fixedmodel. When it is assumed that the ionospheric behavior is not completely known, it is common to choose s^2 depending on the baseline length referred to as the ionosphere-weightedmodel. For long baselines, when the ionospheric behavior is completely unknown, the ionosphere float model should be used, which means that $s^2 \rightarrow \infty$. So the complete Double Difference vc-matrix becomes as,

$$Q_{v} = I_{k} \otimes C \otimes E \tag{21}$$

where,

$$\mathbf{E} = \mathbf{D}^{\mathrm{T}}\mathbf{D} \tag{22}$$

 D^{T} is the (m-1) × m DD operator; no satellite- dependent weighting is applied.

3.4.2 Combined GPS-Galileo

The vc-matrix corresponding to the combined measurement model of GPS and Galileo is given by,

$$Q_{y} = I_{k} \bigotimes \begin{pmatrix} C_{GPS} \bigotimes E_{GPS} & \\ & C_{GAL} \bigotimes E_{GAL} \end{pmatrix}$$
(23)

Noting that,

$$D^{T} = \begin{pmatrix} D^{T}_{GPS} & \\ & D^{T}_{GAL} \end{pmatrix}$$
(24)

2.3Design Parameters

A Matlab® software tool, VISUAL was developed at the department of Mathematical Geodesy and Positioning of the Delft University of Technology which is used in this thesis paper and it allows a user to compute and visualize- amongst others- the design parameters described in this section. These parameters depend on the measurement scenario that the user needs to specify.

The required input parameters are:

- System: GPS, Galileo, Combined GPS Galileo.
- Almanac: Yuma almanac files for GPS and Galileo.
- Date and Time: 29-11-2013 0:00-0:24h.
- Number of epoch: 1
- Time interval: 300 s
- **Cutoff elevation:** $15^{\circ} / 10^{\circ} / 5^{\circ}$
- Measurement scenario:Single point, single baseline, or geometry-free. Simulations have been done considering single baseline.
- **Receiver scenario:**Roving or stationary. Stationary was considered.
- **Ionospheric model:** Fixed, float or weighted; simulations in this paper has been done by considering weighted ionospheric model at standard deviation of 0.02 m.
- Tropospheric model: Fixed, float. Considered fixed model for simulation.

- **Output parameter:**MDB, BNR, MDE, success rate, biased success rate, GDOP, PDOP, number of satellites, satellite tracks.
- **Spatial variation:** Spatial variation is the variation across the landscape that is normally associated with populations. In this paper for the spatial variation analysis location is selected as world.
- **Temporal variation:** Temporal variation refers to a specific location and time for which the analysis would be carried out. In this analysis the location selected is Dhaka, Bangladesh which has latitude 23.7000° N, longitude 90.3750° E.

There are several parameterswhich can be computed without the need for actual observations and which give a quantification of the performance. Here, we will look at three parameters, namely the internal reliability represented by the minimal detectable biases (MDBs); the external reliability represented by the bias-to-noise ratios (BNRs); and the success rates. In practice often the dilution of precision (DOP) values are computed as a design parameter. However, the DOP values only give information on the geometry of the system; it is thus not a measure of the precision or reliability that can be obtained. Reliability refers to how consistent a study or measuring device is. A measurement is said to be reliable or consistent if the measurement can produce similar results if used again in similar circumstances.

3.5.1 Internal Reliability

Internal reliability refers to the extent to which a measure is consistent within itself. The MDBs describe the minimal size of a model error that can be detected by using the appropriate test statistics. The MDB can be computed once the type of model error is specified, so that the null hypothesis, H_0 , which assumes that there is no error, can be tested against the alternative hypothesis, H_a , which assumes the presence of the error. The two hypotheses can be formulated as follows:

$$H_0: E\{y\} = Ax; Q_y$$
 (25)
 $H_0: E\{y\} = Ax + c\nabla; Q_y$ (26)

Where, $E\{.\}$ is the expectation operator, y is the vector of observations, A is the design matrix, and x the vector of unknowns. The type of model error is specified by the vector c, the size of the error by V. Potential model errors in GNSS applications are outliers in the code observations, or cycle slips in the carrier phase observations.

2.4 External Reliability

External reliability refers to the extent to which a measure varies from one use to another. The MDB gives a measure of the size of the error in the observations that can be detected. Impact of such an error based on unknown parameter, which is referred to as the external reliability. It may be represented by the minimal detectable effect (MDE) or the bias-to-noise ratio (BNR). 3.5.3 Success Rate

After resolving the integer carrier phase ambiguities successfully the carrier phase observations start to act as very precise pseudo range observations, so that high precision positioning results can be obtained. The LAMBDA (Least-squares AMBiguityDecorrelation Adjustment) method can be applied to resolve the integer ambiguities. It makes use of the integer least-squaresestimator which has been proven to be optimal. It is best in the sense that it maximizes the probability of correct integer estimation. This probability is referred to as the success rate. Since it equals a probability in a statistical sense, its value will be between 0 and 1. A success rate of 0 means that it can be expected that the ambiguities are never fixed to the correct integer value; a success rate of 1, on the other hand, means that the ambiguities are fixed to the correct values in 100% of the cases.

III. SATELLITE TRACKING, AVAILABILIITY AND DILUTION OF PRECISION

3.1 Satellite Tracking

The satellite track is the path which is followed by satellite vehicle periodically. It provides the geometry of the satellite placement and has very important role in accuracy and reliability analysis.



Figure 1: Satellite tracking of GPS

The satellites of GPS are unevenly distributed over six planes. GPS satellite constellation consists of total 24 satellites; each plane may contain 4 satellites, more or less.



Figure 2: Satellite Tracking of Galileo



Figure 3: Combined constellation of GPS and Galileo

Combination of two systems can be attained by two methods. In our study the method of combining GPS and Galileo is to use both constellations separately, with user positioning containing the link which takes advantages of improved geometry. The combined constellation provides more satellites and accuracy.

3.2 Satellite Availability

Satellite availability depends on the geometry of the satellites. The combined system definitely gives more satellite availability than any single system. Two separate analyses have been carried out. One is for spatial variation where the simulation is done for the entire world; another is temporal variation which is analysis of a specific location.

When spatial variation has carried out it is found that in most places seven GPS satellites are available where as availability of four satellites is must for positioning information. In case of Galileo minimum six satellites presence give positioning. If we consider the combined system we find that the number of available satellites increases as combined constellation contains more satellites. The number of satellites in combined system doubles the number of satellites in single system.



Figure 4: GPS satellites availability all over the world.



Figure 5: Galileo satellites availability all over the world.



Figure 6: Combined GPS-Galileo system satellites availability all over the world.

The highest number of satellite available is 24 (twenty four) in combined case where GPS alone provides maximum 15 (fifteen) satellites and Galileo alone provides maximum 13 (thirteen) satellites.

Temporal variation is carried out for different time interval of a day. For GPS it is found that in the time interval of 00h ~ 06 h the maximum number of satellite is available is 12 (twelve) at epoch no. 51. The minimum satellite available in this interval is 7 (seven). In the time interval of 06 h ~ 12 h the satellite availability decreases. The satellite availability is lowest in the interval of 12 h ~ 18 h and 18 h ~ 24 h. The minimum number of satellite is 5 (five). It is obtained from simulation that the average number of satellite available is between 6 (six) to 9 (nine). This variability of result is due to satellites moving round the earth. At different times it situates at different locations. So availability of satellites to the receiver is not constant all the day, it varies receiver to receiver at different location at different time.



Figure 7: GPS satellites availability at different time interval.



Figure 8: Galileo satellites availability at different time interval.

In case of Galileo the maximum number of satellites available is 11 (eleven) at the time interval of 06 $h \sim 12 h$. The average number of satellites available is between 7 (seven) to 10 (ten). Now when the combined GPS-Galileo system considered, it is obtained that the satellite availability increases. The maximum number of satellites available is 21 (twenty one), which is twice the availability of GPS and Galileo.



Figure 9: Combined GPS-Galileo satellites availability at different interval of time.

Availability mainly depends on the geometry, location and time. The number of satellites will be different at different location at same time. This is because of the user satellite geometry. Also the number of satellites available will vary at a specific location with time as the satellites are moving on its own orbit.

4.3 Dilution of Precision (DOP)

The satellite geometry, which represents the geometric locations of the satellites as seen by the receiver(s), plays a very important role in the total positioning accuracy. The better the satellite geometry strength, the better is the positioning accuracy. Good satellite geometry is obtained when the satellites are spread out in the sky. In general, the more spread out the satellites are in the sky, the better is the satellite geometry, and vice versa. The satellite geometry effect can be measured by a single dimensionless number called the dilution of precision (DOP). The lower the value of the DOP number, the better is the geometry at any instance, that is, it requires the availability of both the receiver and the satellite coordinates. Approximate values for the coordinates are generally sufficient though, which means that the DOP value can be determined without making any measurements. As a result of the relative motion of the satellites and the receiver(s), the value of the DOP will change over time. In practice, various DOP forms are used. The analysis is carried out for position dilution of precision (PDOP) and geometric dilution of precision (GDOP).

3.3 Position Dilution of Precision (PDOP)

For examining the effect of the satellite geometry on the quality of the resulting three-dimensional (3-D) position (latitude, longitude, and height) can be done by examining the value of the position dilution of precision (PDOP). In other words, PDOP represents the contribution of the satellite geometry to the 3-D positioning accuracy. PDOP can be broken into two components: horizontal dilution of precision (HDOP) which represent the satellite geometry effect on the horizontal component of the positioning accuracy and vertical dilution of precision (VDOP) represents the satellite geometry effect on the vertical component of the positioning accuracy.

The DOP values depend on cofactor matrix $Q_{\hat{x}}$. It is defined as:

$$Q_{\hat{x}} = [G e_m]^T [G e_m] (27)$$

For combined system, $[G e_m] = \begin{pmatrix} G_{GPS} & e_{m_{GPS}} \\ G_{GAL} & e_{m_{GAL}} \end{pmatrix}$

Here, $e_m = m$ vector having all ones as its entries, m = number of satellites, G = design matrix that captures the single difference (SD) receiver satellite geometry.

$$PDOP = \sqrt{\text{trace } (Q_{\hat{X}})} (28)$$
$$\Rightarrow PDOP = \sqrt{Q_{XX} + Q_{YY} + Q_{ZZ}} (29)$$

Here, (X,Y,Z) is the receiver position.

Satellite visibility depends on the cut off elevation. So the DOP values depend on the cut off elevation angle of system. Generally if the cut off elevation increases satellite visibility decreases. The simulation for PDOP at different cut off angle is carried out which indicates the increase in DOP values when elevation increases. For GPS, PDOP values at cut off angle of 15 are very high. When cut off elevation decreases to 10 or 5, the PDOP values also decrease.



Figure 10: PDOP analysis of GPS at different cut off elevation.

From the simulation, it is found that the PDOP values of Galileo for different cut off elevation are much less than GPS in each and every case. It depicts Galileo provides better geometry and better positioning accuracy.

When the combined system is simulated huge improvement is apparent. The PDOP value at cut off elevation 15 is less than the PDOP value at cut off elevation of 5 of GPS. The peak value of PDOP is reduced to 2.2 in combined system from 9.8 in GPS system.



Figure: 11: PDOP analysis of Galileo at different cut off elevation.



Figure 12: PDOP analysis of combined GPS-Galileo system at different cut off elevation.

4.3.2 Geometric Dilution of Precision (GDOP)

Another commonly used DOP forms include the time dilution of precision (TDOP). The geometric dilution of precision (GDOP), represents the combined effect of the PDOP and the TDOP. TDOP is the effect of time on the geometry.

$$TDOP = \sqrt{Q_{tt}} (30)$$

Here, t is the time of measurement.

$$GDOP = \sqrt{Q_{XX} + Q_{YY} + Q_{ZZ} + Q_{tt}} \quad (31)$$

The GDOP analysis results in the same decisions. Actually GDOP is nothing but an extension of PDOP. The difference is that the GDOP includes the values of TDOP.



Figure 13: GDOP analysis of GPS at different cut off elevation.



Figure 14: GDOP analysis of Galileo at different cut off elevation.



Figure 15: GDOP analysis of combined system at different cut off elevation.

One important thing is that DOP values tell only the geometry of the system, however it doesn't have any effect on precision of the observation. It only increases accuracy. To ensure high-precision positioning, it is recommended that a suitable observation time be selected to obtain the highest possible accuracy.

IV. RELIABILITY OF NETWORK

4.1 Reliability

Reliability of a network refers to how consistent it is. It is the description of property performing a certain function without failure under given conditions for a specified period of time. Actually the definition of the reliability will in any case have to pertain to variants, either observation variants or estimators' variants. To avoid possible confusion between the definitions of reliability of pertaining two groups, we shall use the terms "Internal reliability" and "External reliability" respectively. There is a close connection between the two: the terminology must be seen as a provisional one.

4.1.1 Internal Reliability

Internal reliability refers to the extent to which a measure is consistent within itself. It is the ability to detect outliers. Internal reliability is dictated by the lower bound for detectable outliers and is expressed by the Minimal Detectable Biases (MDBs). Minimal Detectable Biases (MDBs), first introduced by W. BAARDA are important diagnostic tools for inferring the strength of model validation. The MDB is the magnitude of the smallest error that can be detected for a specific level of confidence. It represents a value of least observation error possible to be detected using statistical test. The MDB can be computed once the type of model error is specified, so that the null hypothesis, H_0 , which assumes that there is no error, can be tested against the alternative hypothesis, H_a , which assumes the presence of the error. The two hypotheses can be formulated as follows:

 $H_0: E{y} = Ax; Q_y$ $H_a: E{y} = Ax + c∇; Q_y$

Here, E {.} is the expectation operator, y is the vector of observations, A is the design matrix and x is the vector of unknowns, the unknown bias vector the size of error is ∇ . The bias vector, c is assumed to describe the model error. Hence it is absent under the null-hypothesis, but present under the alternative hypothesis. Corresponding size of the bias can be obtained as:

$$|\nabla| = \sqrt{\frac{\lambda_0}{c^{\mathrm{T}} Q_y^{-1} P_A^{\perp} c}} \quad (32)$$

where, $P_A^{\perp} = I - P_A = I - A(A^T Q_y^{-1} A)^{-1} A^T Q_y^{-1}$, and I is the identity matrix, P_A is the orthogonal projector on the range space of A, λ_0 is non-centrality parameter which depends on the chosen values of the level of confidence (the probability of rejecting H_0 when in fact it is true), and the detection power (the probability of accepting H_a correctly).

4.1.1.1 Minimal Detectable Outliers

In order to obtain tractable expressions of MDBs for outliers in the code data, a number of approximations have been made. The first approximation consists of neglecting the phase-code variance ratio and this ratio is of the order 10^{-4} . The second approximation consists of assuming the satellite elevation dependence of the stochastic model to be time-invariant, while the third approximation consists of replacing the time-varying relative receiver-satellite geometry by its time average. Since the receiver-satellite configuration changes only slowly with time, these last two approximations are permitted in case the observation time spans are not too long. The MDBs for the single-differenced (SD) code observable to satellite i(i=1,...,m) based on kepochs of data is expressed as:

$$\left|\nabla_{p}\right| = \sqrt{\frac{\lambda_{0}}{d^{T}Q_{y}^{-1}\left(I_{m-1} - \left(1 - \frac{1}{k}\right)P_{M} - \frac{1}{k}\left(P_{N} + P_{P_{N}^{\perp}M}\right)\right)d}}$$
(33)

The errors occurs in the observations on frequency i at epoch 1 in the DD range to satellite $s \in (1, ..., m)$, so that the vector d becomes:

$$d = c_i \otimes d_s$$

The separate terms in denominators of equation (33) can be further elaborated for different types of model.

For geometry free model,
$$d^T Q_y^{-1} P_M d = \left(c_i^T C^{-1} P_{e_{2f}} c_i\right) \left(d_s^T E^{-1} d_s\right)$$
 (34)

$$d^{T}Q_{y}^{-1}P_{P_{k}^{\perp}M}d = \left(c_{i}^{T}C^{-1}P_{P_{c_{2}}^{\perp}e_{2f}}c_{i}\right)\left(d_{s}^{T}E^{-1}d_{s}\right)$$
(35)

For roving-receiver geometry based model,

$$d^{T}Q_{y}^{-1}P_{M}d = \left(c_{i}^{T}C^{-1}P_{e_{2f}}c_{i}\right)\left(d_{s}^{T}E^{-1}P_{\overline{G}}d_{s}\right)(36)$$

For Stationary model,

$$d^T Q_y^{-1} P_M d = 0 (37)$$

4.1.1.2 Minimal Detectable Cycle Slip

A slip is a different type of model error than the outlier, we need to consider apart from the number of epochs used, also the duration of the slip. If $l \le$ keequals the epoch when the slip starts to occur, then N=k-l+1 equals the duration of the slip. For N=1, the slip occurred at the last epoch. MDB for cycle slip,

$$|\nabla_{\emptyset}| = \sqrt{\frac{\lambda_o}{\nu \cdot d^T Q_y^{-1} \left(I_{m-1} - \left(1 - \frac{\nu}{k} \right) P_M - \frac{\nu}{k} P_N \right) d}} \qquad (38)$$

The expressions for code outlier and cycle slip will change if we consider the model for combined GPS-Galileo.

In case of geometry free model no changes is applicable. However both RR (roving receiver) and SR (stationary receiver) model these equations will need further modifications.

$$d^{\mathrm{T}} Q_{y}^{-1} P_{\mathsf{M}} d = \left(c_{i}^{\mathrm{T}} C_{sys}^{-1} P_{e_{2f}} c_{i} \right) \left(d_{s}^{\mathrm{T}} E_{sys}^{-1} \overline{G}_{sys}^{-1} \overline{G}_{sys}^{-1} \overline{G}_{sys}^{-1} d_{s} \right)$$
(39)
$$d^{\mathrm{T}} Q_{y}^{-1} P_{P_{\mathsf{M}}^{\perp} \mathsf{M}} d = \left(c_{i}^{\mathrm{T}} C^{-1} P_{P_{\mathsf{C}_{2}}^{\perp} e_{2f}} c_{i} \right) \left(d_{s}^{\mathrm{T}} E_{sys}^{-1} \overline{G}_{sys}^{-1} \overline{G}_{sys}^{-1} \overline{G}_{sys}^{-1} d_{s} \right)$$
(40).

4.1.1.3 Simulation of MDB

First analysis is done for spatial variation. The simulation of MDB for dual/triple frequency of GPS alone, Galileo alone and combined system is carried out. The MDBs depend on the precision of the code data, the number of satellites tracked m, and through δ on the presence of a second/third frequency. The size of model errors that can be detected with a certain power and level of significance (quantified by the MDB) decreases with increasing number of used epochs and available frequencies.



Figure16: MDB for dual frequency GPS.



Figure 17: MDB for triple frequency GPS.



Figure 18: MDB for dual frequency Galileo.



Figure 19: MDB for triple frequency Galileo.



Figure 20: MDB for dual frequency combined system.



Figure 21: MDB for triple frequency combined system

As MDB is the bias so decreasing MDB indicates improved reliability. Through simulation the impact on reliability due to the increased number of available frequencies and the improved code accuracy is investigated. Analysis of simulations depicts that a triple frequency combined system provides a very small MDB compared to any single system.

The result summary of MDB for different combination and the improvements in the system is shown in a table below.

System	Frequency	Ranges of error	Comments
GPS	Dual	2.1 ~	Higher MDB
		2.8	lower accuracy
	Triple	2~2.45	MDB decreases than dual
			combination
Galileo	Dual	$2 \sim 2.6$	MDB lower than
			GPS alone
	Triple	$2 \sim 2.3$	MDB decreases
			than dual
			combination
Combined	Dual	1.95 ~	Improves up to
		2.35	19% than present
			GPS dual
	Triple	1 95~	Improves up to
	inpic	1.75^{-1}	27% than present
		2.2	GPS dual
_			combination

Table 2 Result summary of MDB for different combination

To analyze result for temporal variation, we select a specific location. In our case study the location is Dhaka. The comparison of single, dual and triple frequency MDB for each system has shown in one graph.



Figure 22: MDB for GPS using different no. of frequencies

In case of GPS, it is obtained that for single frequency the error is so large and thus reliability is worst. The MDB is sometimes much greater than 3. Adding a second frequency provides more reliability by decreasing MDB in an efficient manner where it reduces to a range of $2 \sim 3$. When a combination of triple frequency is considered it is found that MDB decreases to minimum which is less than 2.5 providing better reliability.

For Galileo the result is different than GPS. The MDB for single frequency combination is very much less than GPS single frequency combination and lies within 5.5. No gap is found in the graph which indicates a better reliable system than GPS.



Figure 23: MDB of Galileo using different no. of frequencies



Figure 24: MDB for combined system using different no. of frequencies

The reason behind the better reliability is the even distribution of Galileo satellites, where GPS satellites are divided unevenly over six planes. Also due to the lower precision assigned to the GPS observations, the detect ability of code outlier is far worse than Galileo.

Now in case of combined system, it provides more satellite availability as the combined constellation contains more satellites. The improvement in reliability compared to Galileo is marginal. But considering the overall comparison, a triple frequency combined combination is the possible best solution.

4.1.2 External Reliability

External reliability refers to the extent to which a measure varies from one user to another. It is applied to determine the effect of undetected gross and/or systematic error of observation on adjusted coordinates. It may be represented by the minimal detectable effect (MDE) or the bias-to-noise ratio (BNR). BNR is a dimensionless parameter, binding the effect of a single observation on all coordinates.BNR parameter may be interpreted as a relation between reliability and precision. The MDE is a vector that describes the impact of an MDB-sized bias in the observationsc ∇ , on each of the unknown parameters to be estimated. MDB can be expressed as:

$$\nabla \hat{\mathbf{x}} = (\mathbf{A}^{T} \mathbf{Q}_{\mathbf{y}}^{-1} \mathbf{A})^{-1} \mathbf{A}^{T} \mathbf{Q}_{\mathbf{y}}^{-1} \mathbf{c} \nabla = \mathbf{Q}_{\hat{\mathbf{x}}} \mathbf{A}^{T} \mathbf{Q}_{\mathbf{y}}^{-1} \mathbf{c} \nabla$$
(41)

BNR is scalar quantity is defined as the square root of:

$$\lambda_{\hat{\mathbf{x}}} = ||\nabla \hat{\mathbf{x}}||_{Q_{\hat{\mathbf{x}}}}^2 = (\nabla \hat{\mathbf{x}})^{\mathrm{T}} Q_{\hat{\mathbf{x}}}^{-1} (\nabla \hat{\mathbf{x}}) (42)$$

External reliability is solely concerned with the effect of undetected outliers upon the final solution. So the probability of detecting outliers can be quantified if they do occur and the effect they will have if they are not detected.

4.1.2.1 Simulation of MDE and BNR

The spatial variations need a vector calculation. So simulation of MDE is carried out for the entire world. The simulations show the same result as MDB as they are related to each other. MDE for GPS/ Galileo alone system is greater than MDE for combined system.



Figure 25: MDE for dual frequency GPS



Figure 26: MDE for triple frequency GPS



Figure 27: MDE for dual frequency Galileo



Figure 28: MDE for triple frequency Galileo



Figure 29: MDE for dual frequency combined system



Figure 30: MDE for triple frequency combined system.

System	Frequency	Ranges of error	Comments
GPS	Dual	1~8	Higher MDE
GIB	Duur	1 . 0	higher the
			effect of
			MDB
	Triple	0.5 ~ 5	MDE
	1		decreases,
			effect of
			MDB
			decreases
Galileo	Dual	0.2 ~	MDE much
		1.8	lower than
			GPS alone
	Triple	0.2 ~	MDE
		1.2	decreases
			than dual
	_		combination
Combined	Dual	0.2 ~	Improves up
		1.2	to 66% than
			present GPS
		0.1	dual system
	Triple	0.1 ~	Improves up
		0.8	to 150% than
			present GPS
			dual system

The result summary of MDE for various combinations is as following: Table 3: Result summary of MDE for different combinations.

The higher the value of MDE, the lower the accuracy as the effect of MDB increases. When MDB decreases, the effects also decrease thus MDE decrease. Thus MDE values depict the effect of MDB i.e. accuracy of the system.

BNR also shows the MDB effect. The difference is that MDE is vector presentation and BNR is scalar. BNR simulation is carried out for one point calculation. For temporal variation BNR represents the MDB effect of the systems. In our case of temporal variation the specific location is Dhaka.



Figure 31: BNR for GPS using different no. of frequencies



Figure 32: BNR for Galileo using different no. of frequencies



Figure 33: BNR for combined system using different no. of frequencies

The BNR for single frequency is mainly in the order of 1000 meter, which reveals the worst effect can be caused by MDB. As the MDB of dual frequency GPS system is higher than triple frequency, the BNR of dual frequency also higher than triple frequency. Same comments apply for Galileo and combined system. From the simulation of Galileo system, it has been found that the BNR for single frequency is in the order of 10 meter, far less than GPS. In every case BNR reduced that is effect of MDB is much less than GPS. Combined system with triple frequency reduced the BNR to less than 2. Analysis reveals BNR for a triple frequency combined GPS-Galileo system is the best of all of them.

V. SUCCESS RATE ESTIMATION

5.1 Success Rate

The success rate is a very important measure to determine whether or not an attempt should be made to fix the ambiguities. The success rate equals the probability that the ambiguities are fixed to the correct integers. An efficient method to resolve the integer ambiguities is the LAMBDA method. This method consists of two steps- decorrelation of float ambiguities to estimate the discontinuity is the spectrum of conditional variances. Discontinuity causes the elongated search space which makes the search for the correct integer ambiguities inefficient. So the second method is to search for the integers much more efficiently. In the statistical sense success rate equals as a probability. so the value of it lies between 0 and 1. Success rate of 0 means that it can be expected that the ambiguities are never fixed to the correct integer value. On the other hand a success rate of 1 means that the ambiguities are fixed to the correct values in 100% of the cases. Let the float solution be given as,

$$\begin{pmatrix} \hat{b} \\ \hat{a} \end{pmatrix}, \begin{pmatrix} Q_{\hat{b}} & Q_{\hat{b}\hat{a}} \\ Q_{\hat{a}\hat{b}} & Q_{\hat{a}} \end{pmatrix}$$
(43)

The decorrelation matrix Z^{T} transforms the matrix and their vc matrix into:

$$\widehat{z} = Z^{T} \widehat{a}$$
 (44)

$$Q_{\widehat{z}} = Z^{T} Q \widehat{a} Z$$

The elements of matrix Z^T are all integers and in order to be volume preserving its determinant must be ± 1 . The search step is carried out to determine the integer values, \hat{z} of the transformed ambiguities. By the inverse transformation the integer values of original ambiguities are obtained as: $\hat{a} = Z^{-T}\hat{z}$ (46)

$$\dot{\mathbf{b}} = \hat{\mathbf{b}} - \mathbf{Q}_{\hat{\mathbf{b}}\hat{\mathbf{a}}}\mathbf{Q}_{\hat{\mathbf{a}}}^{-1}(\hat{\mathbf{a}} - \check{\mathbf{a}})(47)$$

The precision of this baseline solution will be much better than the precision of the float solution. This can be seen by applying the propagation law of variances to equation 5.5 and assuming that the fixed ambiguities are non-stochastic:

$$Q_{\tilde{\mathbf{b}}} = Q_{\hat{\mathbf{b}}} - Q_{\hat{\mathbf{b}}\hat{\mathbf{a}}} Q_{\hat{\mathbf{a}}}^{-1} Q_{\hat{\mathbf{a}}\hat{\mathbf{b}}}$$
(48)

(45)

This shows that $Q_{\tilde{b}} << Q_{\tilde{b}}$ The goal of the integer ambiguity estimation is thus to improve the precision of the baseline estimates. However, when the ambiguities are fixed to the incorrect values, the fixed baseline solution may be wrong and it will be difficult to detect this error. For that reason it is important to have information on the probability of correct integer ambiguity estimation. This probability is referred to as the success rate. Its lower bound is given by:

$$P(\check{z} = z) \ge \prod_{i=1}^{n} (2\Phi\left(\frac{1}{2\sigma_{\hat{z}_{i|I}}}\right) - 1)$$
 (49)

where n is the number of ambiguities and,

$$\Phi_{\rm x} = \int_{-\infty}^{\rm x} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{1}{2}z^2\right) dz \tag{50}$$

 $\sigma_{\hat{z}_{i|I}}$ is the standard deviation which is the square root of the conditional variance of the ith ambiguity (conditioned on the previous I = 1, ..., i– 1 ambiguities). It can be obtained from the diagonal matrix Dafter an LDL^T -decomposition of the matrix Q_z. Success rate should be sufficiently high i.e. very close to one in order to guarantee that the ambiguities will be fixed to their correct values.

5.1.1 Simulation and Analysis

The simulation of Success rate for dual/triple frequency of GPS alone, Galileo alone and combined system is carried out. The success rate depends on the precision of the code data, the number of satellites tracked m and through δ on the presence of a second/ third frequency. With the increased number of available frequencies the satellite availability increases which leads to a better success rate. As success rate is a parameter varies from 0 to 1, the value of 1 or close to 1 indicates better success rate. Analysis of simulations depicts that a triple frequency combined GPS-Galileo system provides very good success rate estimation compared to any single system.



Figure 34: Success rate for dual frequency GPS



Figure 35: Success rate for triple frequency GPS



Figure 36: Success rate for dual frequency Galileo



Figure 37: Success rate for triple frequency Galileo



Figure 38: Success rate for dual frequency combined system



Figure 39: Success rate for triple frequency combined system

System	Frequency	Ranges	Comments	
		of		
		outputs		
GPS	Dual	0.2 ~	Higher	
		0.9	success rate	
			leads to	
			higher	
			accuracy	
	Triple	0.4 ~	Success rate	
		0.9	increases	
			than dual	
			combination	
Galileo	Dual	0.5 ~	Success rate	
		0.95	higher than	
			GPS alone	
	Triple	0.7 ~	Success rate	
		0.95	increases	
			than dual	
			combination	
Combined	Dual	0.95 ~	Improves up	
		0.995	to 78% than	
			present GPS	
			dual	
			combination	
	Triple	0.97~	Improves up	
		0.995	to 79% than	
			present GPS	
			dual	
			combination	

Table 4: Result summary of success rate for different combination

Table 4 shows the summary for the success rate estimation for different systems and different combinations.

Analysis for temporal variation would be done for a specific location. In this paper the location of DHAKA has been taken as reference location.



Figure 40: Success rate for GPS using different no. of frequencies



Figure 41: Success rate for Galileo using different no. of frequencies

In case of GPS, it is observed that for single frequency success rate goes as low as 0.005. Thus success rate estimation is worst. Adding one frequency increases the minimum value to 0.36 which is greater than the single frequency output. Now using triple frequency yields the minimum value as 0.55 which is better estimation among the three.

For Galileo the minimum value is 0.011 while adding another frequency gets the minimum value as 0.46 which is better. For triple frequency application the value goes to 0.69 which is better as closer to 1. It is better than the only GPS system.

For combined GPS-Galileo system the minimum output value for single frequency is 0.06 and dual frequency is 0.94. Using triple frequency determines the success rate value as 0.97 which is much closer to 1 than any other combination. So triple frequency combined system gives better success rate approximation and enhances the performance.



Figure 42: Success rate for combined system using different no. of frequencies

5.2 Biased Success Rate

One of the basic assumptions for the computation of the ambiguity success rate is the unbiasedness of the float solution. This assumption is valid as long as the float solution is based on a correctly specified model. Any mis-specification in the functional model will lead to biases in the least-squares estimator. In case of GPS, in the float solution of the ambiguities such biases could be generated by outliers in the code data, cycle slips in the phase data, multipath, the presence of unaccounted atmospheric delay or any other unmodeled error source. In this context the biased success rates in case of a code outlier or carrier cycle slip can be computed. The equation to compute probability of correct integer estimation should only be applied after first applying the decorrelating Z-transformation of the LAMBDA method. In case the original DD ambiguities are biased the transformed ambiguities will also be biased. They are distributed as:

$$\widehat{z} \sim N(z + Z^T \nabla \widehat{a}, Q_{\widehat{z}})$$
 (51)

Where z is the true but unknown transformed integer ambiguity vector and $Z^T \nabla \hat{a}$ is the transformed bias vector. In case the real-valued float solution is biased and distributed as in equation 5.9 and if the integer solution is obtained by using the bootstrapping estimator, the probability of correct integer estimation is then given as:

$$P_{\nabla}(\tilde{z} = z) = \prod_{i=1}^{n} \left[\Phi\left(\frac{1-2\zeta_i}{2\sigma_{\hat{z}_{i|I}}}\right) + \Phi\left(\frac{1+2\zeta_i}{2\sigma_{i|I}}\right) - 1 \right]$$
(52)

Where ζ_i is the *i*th entry of the bias vector $L^{-1}Z^T \nabla \hat{a}$ and $\sigma_{i|I}$ is the variance of the *i*thleast-squares ambiguity obtained through a conditioning on the previous I = 1, ..., (i-1) ambiguities.

5.2.1 Simulation and Analysis



Figure 45: Combined system Biased success rate



Figure 46: Biased success rate for different systems

In the analysis of biased success rate it is observed that for spatial variation the calculated improvement for only Galileo comparing with the sole GPS system is slightly high whereas for the combined system it is improved as high as 89%.

For the temporal variation analysis, the sole GPS has minimum value of output is 0.07 while for sole Galileo it increases to 0.51. Which is improvement in the performance about 86%. For the combined system the minimum value of biased success rate is 0.96. So 93% improvement has been observed by adopting the combined system. So the incorporated GPS-Galileo is the best option among the three.

VI. CONCLUSION

It is revealed that satellite availability increases when two systems are combined. DOP values change with the cut off elevation. The lower the cut off elevation angle the lower the DOP, the better the accuracy. Theresults of spatial variation are summarized in table 2. From the table it is revealed that the GPS-Galileo system with triple frequency combination improves up to 27% than present GPS dual combination regarding MDB. MDE and BNR is the realization of the effect of MDB. Regarding MDE the combined triple frequency combination is improved up to 150% than present GPS dual system. The BNR simulation is also depicts the improvements of combined system. The analysis was carried out by inputting various parameters and the result was being observed. By performing thorough analysis and simulation it has been synthesized that rather than using only GPS or only Galileo, adopting triple frequency combined GPS-Galileo would vield much more significant improvement in the performance at the receiver end. More precise and accurate information can be obtained by using the combined system Receiver autonomous integrity monitoring (RAIM) is used to enhance the integrity of the receiver. It is expected theoretically that a multi constellation context of Galileo and modernized GPS, could improve RAIM performance. The main focus of this study and that is the proposed GNSS Landing System (GLS). As meeting the high requirements of the modernized landing system needs precision and accuracy of centimeter level, the main intent of this study was to get improved integrity and reliable information. From the analysis carried out, it was figured out that interoperability improves the performance at large extent. RAIM can perform detection and isolation procedure to get more reliable data from the available satellites. So it is concluded that using triple frequency combined GPS-Galileo and RAIM together the system is much more redundant and one highly precise GNSS Landing System can be achieved successfully.

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