Research on GBAS Integrity Based on BD Satellite

Yu Geng[1.a], Yingdong Wang[2.b], Jing Wang[1.c]

[1] School of Shenyang Aerospace University, Shenyang 110136, China;

[2] School of Electronic and Information Engineering, Shenyang Aerospace University, Shenyang 110136, China.

[a]yug@sau.edu.cn, [b]771897447@qq.com, [c]1819509480@qq.com

Keywords: Satellite navigation, GBAS, Integrity, Aviation field, Precision approach

Abstract . At present, the performance of the satellite navigation system is based on the application requirements of ground augmentation system, the integrity of the local system, the second generation BD satellite based system of the type of precision into the near integrity algorithm and simulation analysis. It provides reference for aircraft precision approach and landing of application foundation enhancement system in the field of aviation and gives the preliminary evaluation method of navigation system integrity.

1. Introduction

The present new navigation technology in aviation field is the comprehensive application of PBN (Performance Based Navigation). PBN is a new technology concept which is proposed by ICAO to connect RNAV(Area Navigation) with RNP(Required Navigation Performance).The technical support is the combination of Global Navigation Satellite System and airborne equipment to provide more accurate, safer flight lines and more efficient air traffic control mode and reduces the overall input of ground navigation equipment .The key point of the PBN technology proposed by the CAAC (Civil Aviation Administration of China) is the integration of the second generation BD satellite navigation system and GBAS.

2. The summary of the integrity of GBAS

Satellite navigation system has been widely used in navigation and positioning and timing service in the aircraft, ship and vehicle etc. The system is mainly used in the field of aviation precision approach and landing phase, It’s a goal, RNP, which people always hope to achieve .The four parameters of the performance are precision , integrity, availability , and continuity . The integrity is one of the important indexes of satellite navigation system, and system integrity is described by alarms, the alarm time limit and the risk probability parameters of integrity.

3. Research on integrity algorithm of GBAS

3.1 Research on integrity algorithm of GBAS based on BD satellite

In aviation field, aircraft precision approach and landing phase are the most critical and most dangerous flight stage, so it is necessary to provide high precision positioning by the navigation system, and the integrity monitoring technology is the guarantee of high precision positioning and system integrity. The qualitative analysis system of the PL (Protect Level) which reflects the error of navigation system determines mainly whether the integrity of the GBAS has the risk.

In the GBAS, the pseudo range differential is able to offset the satellite clock, but there is no correlating error between the airborne receiver and the ground receiver, therefore, error sources are introduced into the differential positioning process as follows:

$$\sigma_{i}^{2} = \sigma_{\text{pr-gnd}, i}^{2} + \sigma_{\text{pr-air}, i}^{2} + \sigma_{\text{iono}, i}^{2} + \sigma_{\text{tropo}, i}^{2} \tag{1}$$

Where: $\sigma_{\text{pr-gnd},i}$ - The standard pseudo range differential correction error broadcast GBAS ground subsystem for the calculation of the difference from satellite i .

$\sigma_{\text{pr-air},i}$ -The standard deviation of the difference of the airborne subsystem is calculated from satellite i .

$\sigma_{\text{iono},i}$ -The standard deviation of the ionosphere delay residuals is calculated from satellite i.

$\sigma_{\text{tropo},i}$ - The standard deviation of the tropospheric delay residuals is calculated from satellite i.

The standard deviation of the positive error of the pseudo range differential of GBAS ground subsystem is influenced by the noise of the receiver bandwidth, the residuals of the spatial signal and the multipath effect, etc. therefore, the relative mathematical model as follows:

$$\sigma_{\text{pr-gnd}}(\theta_i)=\sqrt{\frac{\left(a_0+a_1 e^{-\theta_i/\theta_0}\right)^2}{M_{(i)}}+(a_2)^2} \tag{2}$$

Where: θ_i -Elevation from satellite i.

The values of a_0, a_1 and θ_o are defined according to the size of receiver, the variable represents the accuracy of the receiver correlation and technique index about the multipath suppression of receiver antenna . The difference error of airborne subsystem is composed of the receiver bandwidth noise part and the multipath effect part of the fuselage as follows:

$$\sigma_{\text{pr-air}}(\theta_i)\le a_o+a_1 e^{-\theta_i/\theta_o} \tag{3}$$

The parameters in the formula are defined according to the different performance level of the airborne receiver. The tropospheric delay error is transmission delay due to the difference height of the airborne receiver and the ground related receiver, the relative mathematical model as follows:

$$\sigma_{\text{tropo},i}=\sigma_n h_o\frac{10^{-6}}{\sqrt{0.02+\sin^2(\theta_i)}}\left(1-e^{-\Delta h/h_0}\right) \tag{4}$$

Where: σ_n -Standard deviation of tropospheric refraction error, h_o - Atmosphere height of troposphere, Δh - The height difference between the aircraft and the ground.

The ionosphere delay effect has a certain space irrelevance, and the relative mathematical model of the uncertain ionosphere delay error as follows:

$$\sigma_{\text{iono},i}=F_{PP}*\sigma_{\text{vert-iono-gradient}}\left(\chi_{\text{air}}+2*\tau*\nu_{\text{air}}\right) \tag{5}$$

Where: $\sigma_{\text{vert-iono-gradient}}$ - Standard deviation of vertical ionospheric gradients (4mm/km), χ_{air} - Distance between aircraft and ground related receiver antenna center, τ - Filtering smoothing time (100s), ν_{air} - Horizontal flight speed F_{PP} - Slope factor,

$$F_{PP}=\left[1-\left(\frac{R_e\cos\theta_i}{R_e+h_I}\right)^2\right]^{-\frac{1}{2}} \tag{6}$$

Where: R_e - Radius of the earth (6378.1363km), h_I - Ionosphere shell height(350km),

3.2 Calculation of protection level

On integrity monitoring, GBAS error should be controlled in a certain range, the error range is called protection level, vertical direction of protection level is called VPL (Vertical Protect Level), as follows:

$$VPL_{\text{Apr}}=MAX\left\{VPL_{\text{Apr-}H_0},VPL_{\text{Apr-}H_1}\right\} \tag{7}$$

In work of GBAS, the position error of the airborne subsystem is affected by the working state of the ground related receiver, in the stage of aircraft precision approach and landing phase, it needs to maintain high accuracy of the positioning and error free integrity ,Therefore , two hypotheses are made when the airborne subsystem calculates the VPL of:

H_0: Reference receivers and the corresponding satellite without fault as follows:

$$VPL_{Apr\text{-}H0} = K_{ffmd}\sqrt{\sum_{i=1}^{N} s^2_{Apr\text{-}vert,\ i}\,\sigma^2_i} \tag{8}$$

Where: K_{ffmd} - By no fault detection probability to determine the multiplier, N- Number of satellites used for positioning , i - Satellite i for positioning.

$$s_{Apr\text{-}vert,\ i} = S_{3,\ i} + S_{1,\ i} * \tan\theta_{GPA} \tag{9}$$

$S_{3,\ i}$ - Pseudo range error Z direction positioning component from satellite i .

$S_{1,\ i}$ - Pseudo range error X direction positioning component from satellite i .

θ_{GPA} - The angle of glide path in final approach phase,

Weighted least squares projection matrix S is defined as follows:

$$S \equiv \begin{bmatrix} S_{1,1} & S_{1,2} & \cdots & S_{1,\ N} \\ S_{2,1} & S_{2,2} & \cdots & S_{2,\ N} \\ S_{3,1} & S_{3,2} & \cdots & S_{3,\ N} \\ S_{T,1} & S_{T,2} & \cdots & S_{T,\ N} \end{bmatrix} = \left(G^T * W * G\right)^{-1} * G^T * W \tag{10}$$

Where: $G_i = \lfloor -\cos\theta_i \cos Az_i \quad -\cos\theta_i \cos Az_i \quad -\sin\theta_i \quad 1 \rfloor$, G_i - i row of G, Az_i - Related receiver to the azimuth angle of the i satellite, W- Weighted least square method,

$$W^{-1} = \begin{bmatrix} \sigma^2_1 & 0 & \cdots & 0 \\ 0 & \sigma^2_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \sigma^2_N \end{bmatrix} \tag{11}$$

H_1: A single correlation receiver is faulty

$$VPL_{Apr\text{-}H1} = MAX\ \{VPL_{Apr\text{-}H1}[j]\} \tag{12}$$

For all j(1 to MAX {M}) as follows:

$$VPL_{Apr\text{-}H1}[j] = \left|B_{j\text{-}Apr\text{-}vert}\right| + K_{md}\,\sigma_{Apr\text{-}vert\text{-}H1}$$

Where: $B_{j\text{-}Apr\text{-}vert} = \sum_{i=1}^{N} s_{Apr\text{-}vert,\ i}\, B\,[i,\ j]$

B - it is the difference between the broadcast PRC and the PRC obtained by excluding the receiver j. If the j receiver was not used to produce the i differential correction, then the ground subsystem will not provide a value for B .In this case, the airborne subsystem set B to zero.

$$\sigma^2_{Apr\text{-}vert\text{-}H1} = \sum_{i=1}^{N} s^2_{Apr\text{-}vert,\ i}\,\sigma^2_{i\text{-}H1} \qquad \sigma^2_{i\text{-}H1} = \left(\frac{M[i]}{U[i]}\right)\sigma^2_{pr\text{-}gnd,\ i} + \sigma^2_{tropo,\ i} + \sigma^2_{pr\text{-}air,\ i} + \sigma^2_{iono,\ i} \tag{13}$$

Where: $M[i]$- The number of ground related receivers used in the calculation of the pseudo range correction by the i satellite, $U[i]$- When a j receiver is excluded, the number of ground related receivers used in the calculation of the pseudo range correction value at the i satellite.

4. Integrity simulation and the result analysis

The following results are obtained by processing the data received from the receiver， the number of receivers is 4, satellite elevation angle is 5 to 90 degrees, the sampling points are 24.

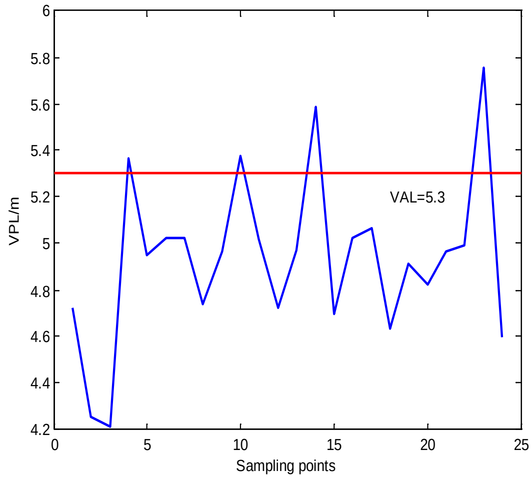

Figure1. The value of VPL under H0 condition

As shown, Figure1 is the values VPL calculated when all the reference receivers and the corresponding satellite without the fault, the parameters satisfy CAT I (<10m), Most of the sampling points can be satisfied CAT II (<5.3m).

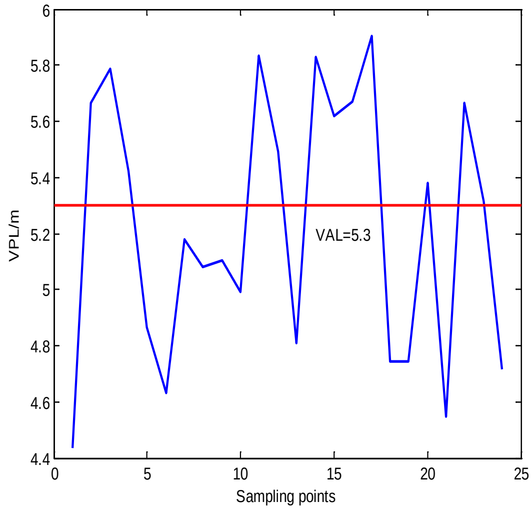

Figure2. The value of VPL under H1 condition

As shown, Figure 2 is got when a single correlation receiver is supposed to be faulty, the value of VPL under H1 condition meet CAT I (<10m) Precision approach, But most of the sampling points can not meet the CATII (<5.3m) Precision approach.

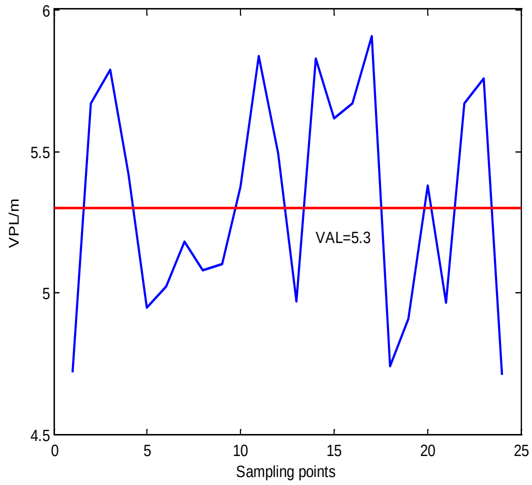

Figure3. VPL value of the final GBAS

The final approach segment VPL values are calculate through the equation (9). As shown Figure 3, the sample point meet CATII (<10m) precision approach, but don't meet CATII(<5.3m) Precision approach.

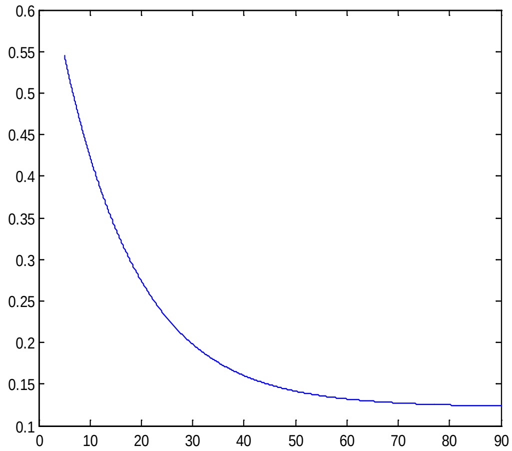

Figure4. The standard deviation of GBAS error

As shown , Figure 4 is GBAS error standard deviation associated with the parameters of the ground subsystem relative receiver and with the corresponding satellite elevation angle.

Through the above simulation analysis， in the general case ,sampling points can satisfy CATI (<10 m) precision approach, but there are some sample points which can meet CATII (<5.3 m) precision approach. In other word, in the aircraft approach process, it can meet the class I precision approach, but does not meet the class II precision approach .VPL's level calculation optimization comes from the error standard deviation and B values . The correcting error standard deviation of GBAS ground subsystem decreases along with the rising of the satellite elevation angle, which affects the calculation results of VPL.

5. Conclusion

The integrity construction of satellite navigation system has been paid close attention by the user, GBAS integrity is the security guarantees of plane approach , landing phase and an important technology in the development of civil aviation, but the system is in the stage of construction and rapid development, and it needs to be further improved . This paper analyzes the simulation of BD navigation system according to BD system influence on the system based on integrity algorithm research on BD satellite GBAS. From the simulation results, it can be obtained that in 24 sampling points, GBAS can meet the demand of CATII precision approach, but cannot meet the requirements of CATII precision approach, it offers reference to engineering application of the BD satellite navigation precision approach.

Acknowledgments

Foundation item: the Natural Science Foundation of China (U1433115), the CATIC industrial production, special collaborative innovation projects (CXY2012SH16), China aerospace science and technology group co.,LTD. Satellite application research innovation fund projects(2014_CXJJ-TX_12).

References

[1] RTCA Inc. RTCA/DO-245,Minimum Aviation System Performance Standards for the Local Area Augmentation System (LAAS)[S].1998

[2] RTCA Inc. RTCA/DO-253C,Minimum Operational Performance Standard for LAAS Airborne Equipment[S].2008

[3] Approach service type D evaluation of the DLR GBAS testbed Thomas Dautermann . Michael Felux .GPS Solut (2012)

[4] FAA .United States Department of Transportation Federal Aviation Administration. FAA-E-AJW44-2937A.October 21,2005

[5] RTCA (2008a),GNSS-Based Precision Approach Local Area Augmentation System (LAAS) Signal-in-Space Interface Control Document, RTCA Do-246D,RTCA,Washington, DC

[6] Guide For Ground Based Augmentation