Integrity Simulation Test System of BDS Airborne Receiver

Chao Li

College of Electronic Information and Automation , CAUC , Tianjin 300300 , China

Abstract

Integrity is the important performance indicator of BDS airborne receiver. For integrity test, the integrity test system is designed. The system is mainly composed of an environment configuration module, a data interface module and a test evaluation module. The system uses the ARINC429 protocol to simulate the navigation data transmission between devices in the real environment, and uses the UDP transmission protocol to simulate the transmission of visible satellite information through broadcast. Referring to the GPS airborne equipment test standard in the RTCA/DO-208 document, proposing the BDS airborne receiver integrity testing method and completing simulation analysis with the Monte Carlo experiment. The simulation results show that the system has the advantages of convenient operation, stable data transmission and meeting the requirement of integrity test, which can provide reference for the integrity test of the BDS airborne receiver.

Keywords

BDS airborne receiver; integrity; test system; ARINC429; UDP.

1. INTRODUCTION

Application of BDS satellite navigation system in civil aviation provides more guarantee for the safe operation of civil aviation. At present, there are many researches on the optimization and improvement of the integrity algorithm of BDS satellite navigation system[1]. The integrity test method and procedure of BDS airborne receiver need to be improved. Integrity is an important performance indicator of satellite navigation system, which is directly related to the safety of aircraft operation. The requirements for the integrity performance test of BDS airborne receiver are increasing.

The test evaluation of BDS airborne receiver can be carried out by means of simulation test or actual test. The external environment (the current position of the satellite, the atmosphere, the ionosphere, etc.) is constantly changing, and performance testing in actual scenarios does not guarantee the controllability and repeatability. In addition, the actual test will also have the target continuous shifting movement, uncontrolled test time, extreme geographical environment, etc., the performance test costs will become high[2]. Therefore, the BDS airborne receiver integrity test system and method are developed according to the test standard of the navigation device.

2. PERFORMANCE ANALYSIS OF BDS AIRBORNE RECEIVER INTEGRITY

2.1. The integrity of BDS airborne receiver

Integrity mainly reflects the ability of the system to issue effective alerts to users in a timely manner when they are unable to meet the requirements of the scheduled flight phase. Receiver Autonomous Integrity Monitoring(RAIM) can directly use the internal redundancy information of the receiver, or use other auxiliary equipment on the aircraft (barometric altimeter, inertial navigation, pseudo-satellite, etc.) to achieve satellite fault detection and identification[3]. Integrity can be determined by the alarm limit, false alarm rate, alarm time limit, and minimum detection probability. The alarm limit refers to the limit value of the horizontal protection limit of the specified flight phase. When the horizontal positioning error exceeds the horizontal protection limit, the system should give an alarm; the false alarm rate is for the normal operation of the aircraft but an alarm is issued; the alarm time limit is when the fault occurs. The time at which the alarm is issued; the lowest detection probability is the probability that no miss detection will occur[4],[5].

RAIM is able to quickly identify and eliminate satellite faults. The availability of RAIM is compared to the corresponding horizontal alarm limit (HAL) by the horizontal positioning error protection limit (HPL). When the protection limit is outside the alarm limit, RAIM is not available, but instead is available. After the RAIM method detects that the system has a faulty satellite, the parity vector method can be used for troubleshooting. Among them, the HPL calculation formula is:

$$HPL = Slope_{max} * \sigma * \sqrt{\lambda} \tag{1}$$

In the formula: $Slope_{max}$ is the maximum slope that can be produced by the deviation , σ is the standard deviation, .

The least squares residual method in the RAIM algorithm calculates the least squares solution based on the observed variance of the satellite navigation system, and obtains the pseudo-distance residual construction test statistic. The comparison between the test statistic and the detection threshold determines whether the satellite is faulty[6]. If the deviation exists, that is, when the satellite fails,T subject to decentralized χ2 distribution. When the false alarm probability is determined, the detection threshold can be calculated. The calculation formula of the detection threshold Td is as follows:

$$\int_0^{T_d} f_{\chi^2(n-4)}(x)dx = 1 - P_{FA} \tag{2}$$

In the formula: fχ2(n-4) is probability density function of centralized χ2 distribution ,and the degrees of freedom is n-4.

2.2. Compass airborne receiver integrity standards

RTCA/DO-208 standard document gives the GPS integrity performance test standard , which is also applicable to the performance test of the BDS airborne receiver. Based on this, the BDS airborne receiver integrity test method is proposed. Integrity reflects the ability of the system to issue an alarm to the user in a timely manner without satisfying the navigation and positioning service. The receiver must be able to issue an alarm for each flight phase within a specified time period . Timely alarm capability is reflected in the different performance indicators. The normal performance of aircraft during different flight phases has different requirements for airborne equipment.The integrity performance requirements are shown in Tab1[7].

The BDS airborne receiver integrity test needs to meet all the requirements of Tab1. Before testing the performance indicators in Table 1 , you should pay attention to whether RAIM is available[7].The false alarm rate applies to any time in the world, but does not include the incomplete system unavailability period due to poor satellite geometry distribution.The lowest detection probability is opposite to the missed detection probability. The alarm time limit refers to the maximum allowable time delay from the start of the failure to the notification of the integrity alarm.

Tab 1. Requirements of Airborne equipment integrity

Phase of Flight	Alarm Limit	Allowable Alarm Rate	Time to Alarm	Minimum Detection Probability
Route route	3.7km	0.002/h	15s	0.999
Terminal	1.85km	0.002/h	15s	0.999
NPA	556m	0.002/h	10s	0.999

3. BDS AIRBORNE RECEIVER INTEGRITY TEST METHOD

The constellation configuration plays a decisive role in the constellation coverage characteristics, performance and operational maintenance capabilities. The satellite constellation is a hybrid navigation constellation composed of five geosynchronous orbit satellites, five tilted geosynchronous orbit satellites and four medium-high earth orbit satellites of the BDS navigation satellite system[8]. The BDS airborne receiver integrity test is divided into static test and dynamic test. The static test uses the non-precision approach phase instead of all flight phases to perform the integrity test, while the dynamic test is the integrity test for the entire flight process.

3.1. Static test

The performance test method uses the most stringent test criteria to assess whether the integrity of the flight meets the test requirements[4],[7]. Therefore, Static testing needs to consider the situation of poor satellites, and use poor test samples for test evaluation to achieve integrity testing of the entire flight. In the non-precision approach phase, the integrity performance test requirements are the highest, and the non-precision approach phase can be used instead of the entire flight process for integrity testing.The flow of the BDS airborne receiver integrity static test is shown in Fig1.

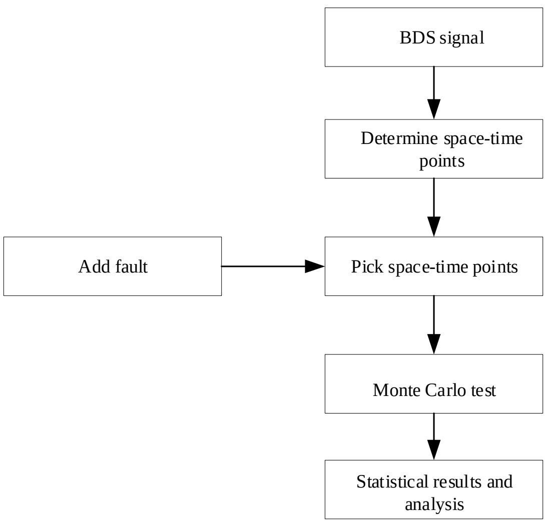

Fig 1. Flow chart of static integrity test

The test method requires a sufficient number of test sample points to facilitate statistical analysis of the missed alarm rate and false alarm rate. For static testing, determine the sometimes empty points by setting the initial sampling point and interval sampling method firstly. The satellite is considered visible if its altitude angle exceeds 7.5 degrees during the test.

The space-time point in the integrity test need to determine the availability of RAIM, remove the space-time points that do not meet the requirements, and select the space-time points that meet the flight requirements[4],[7]. Then select the least-desired detection geometric distribution from the acceptable space-time points, and use these space-time points for the test of false alarm rate and missed alarm rate.

For the space-time points selected in the above test process, the faults were randomly added, and the probability index was obtained by Monte Carlo test. The experimental results will include four situations: correct runs, timely detections, misses and early detections. After the test is over, all experimental results are recorded and analyzed.

3.2. Dynamic test

Dynamic testing evaluates receiver integrity performance by testing all flight phases,that can more accurately test the integrity performance of the BDS airborne receiver.Each flight phase needs to meet the corresponding requirements in Tab1. Dynamic testing firstly selects the flight path of the aircraft to determine the overall situation of the flight data. The method can obtain sufficient time and space points through multiple cycles to achieve integrity testing.

Dynamic testing adds random faults to the data of the flight path for Monte Carlo testing The experimental results of the dynamic test include the same conditions as the static test, including correct runs, timely detections, misses and early detections. If the indicator data in Tab1 meets the requirements, it means that the receiver integrity meets the airworthiness requirements. If one or more indicators do not meet the requirements, it means that the integrity of the receiver cannot meet the airworthiness requirements.According to the test results, the test can be repeated as appropriate to ensure the accuracy of the test evaluation.

4. INTEGRITY TEST SYSTEM OF BDS AIRBORNE RECEIVER

4.1. Test system model

The test system of BDS airborne receiver mainly includes an environment configuration module, a data interface module and a test evaluation module. The structure of the test system is shown in Fig2.

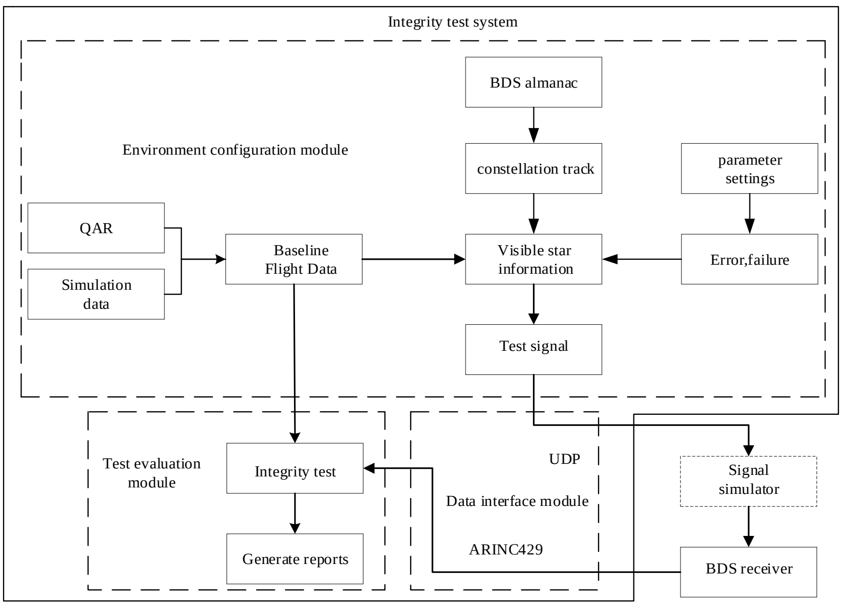

Fig 2. Integrity test system of BDS airborne receiver

The environment configuration module includes two parts: the reference flight trajectory and the parameter setting.The QAR data and simulation data generate a baseline flight trajectory for evaluating receiver performance by comparing with measured data output by the receiver.The parameter settings include errors caused by various error sources, alarm time limits and alarm limits, preset faults, etc., so as to achieve the purpose of configuring the test environment. The data interface module uses ARINC429 protocol and UDP protocol to simulate the data transmission in the real scene to ensure the normal operation of the system. The test evaluation module evaluates the integrity performance of BDS airborne receiver according to the airborne equipment integrity performance test standard.

4.2. Environment configuration module

The integrity test system environment configuration module mainly consists of two parts, one is the reference flight path data using QAR data and simulation data, and the other is the navigation system measurement error and the fault added for the integrity test under normal operation. The measurement error of BDS satellite navigation system can affect the integrity performance of the receiver. According to the source of influence, it can be divided into three aspects, including satellite, signal transmission, and ground reception.

Navigation satellite errors include satellite clock errors and ephemeris errors. The clock error is caused by the physical synchronization error of the satellite clock, and the ephemeris error is caused by the difference between the satellite orbit model and the real operation. The ionospheric error and tropospheric error are the main sources of error in the propagation process. The BDS global ionospheric delay correction model can correct the ionospheric error, and the tropospheric refractive error can be corrected by the Hopfield model. The ground receiving end has multipath error and receiver noise, multipath error is caused by satellite signal reflection, and receiver noise is caused by electronic component thermal noise and signal quantization error[9]. The error can be obtained by the error characteristics and the error model. The error range corresponding to the error source is shown in Tab2.

Tab 2. Error range of error source

Error source	Error range/m
Satellite ephemeris error	3~5
Satellite clock erro	1.6~2
Ionospheric error	1~5
Tropospheric error	1~2.6
Multipath error	0.5~1
Receiver noise	0.25~0.5

The error environment can be divided into normal conditions and abnormal conditions. According to the test needs, adjust the error environment of the integrity test. Configure the error environment by setting the fault size and duration to achieve the purpose of simulating the real scene, and ensure the completion of integrity test.

4.3. Data interface module

The data interface module mainly includes two methods: ARINC429 protocol and UDP protocol.Among them, the ARINC429 protocol uses the KMHT429 series of boards to transmit navigation information and reference trajectory information output by BDS receiver, including time, latitude, longitude, altitude, alarm and other information.UDP transmits visible satellite information, including time, number of visible satellites, PRN, pseudo range, satellite coordinates, and so on.

The frame structure of UDP data transmission consists of 5 parts: message start bit; data type; text; separator; check digit. The text includes visible satellite information, reference trajectory information, and receiver output navigation information. Transmit data in the text, each data is separated by ‘;’.The text and check digits are separated by ‘*’.The check code verifies the header and body content.The data frame structure of the integrity test system is shown in Fig3.

#	head	text (Time, number of visible satellites, PRN, pseudo range ,satellite coordinates...)	*	school Test code

Fig 3. Frame structure of UDP data

The ARINC429 bus protocol data word consists of 32 bits of binary bits forming the smallest data unit. The data words mainly use BNR data, BCD data and discrete data.ARINC429 protocol data transmission can balance transmission rate and reliability.Aiming at the problem that the UDP protocol is easy to generate data loss, a scheme for transmission reliability is proposed, which adopts flow control, acknowledge retransmission and error detection mechanism.

The ARINC429 board data transmission process is shown in Fig4. ARINC429 board data transmission first initializes the board, then reads the data, configures the channel and encodes the data. After the data is sent to the receiving end, the receiving end receives the data and saves it, and finally completes the transmission and closes the board.

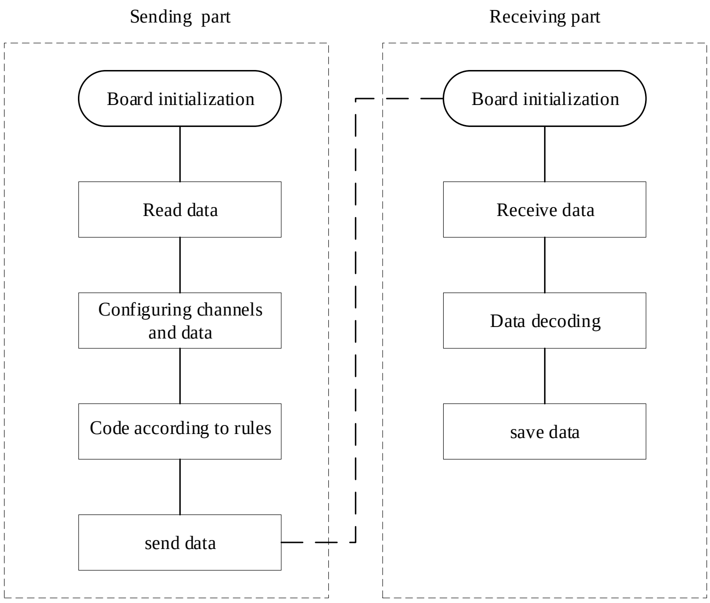

Fig 4. Data transmission flow chart of ARINC429

4.4. Evaluation module testing

Integrity static testing uses static space-time points, which correspond to the performance requirements of the NPA phase. All time-space points are obtained by setting the pre-sample position, sampling period and sampling interval. The HDOP is mainly used to determine the satellite geometric distribution of space-time points, and then all the time-space points to be tested are obtained. Integrity dynamic testing mainly uses the entire flight path data, including QAR data and simulation obtained trajectory data.Dynamic testing addresses performance requirements for the three phases of the route, terminal area and NPA.

First select the Beidou almanac, import it into the test software, and use the satellite parameters of the almanac to calculate the position of the satellite.The state of the satellite is determined by the elevation angle. Finally, the ionosphere, troposphere, clock and multipath errors, and step and ramp faults are added to the generated visible satellite data.

The BDS receiver uses the visible satellite information for positioning calculation, uses RAIM for fault detection and isolation, and finally generates navigation information and alarm information. The test software compares the indicator requirements with the generated data, and then completes the performance test evaluation of the integrity.The evaluation results can verify whether the BDS airborne receiver meets the performance requirements.

5. TEST RESULTS ANALYSIS

The transfer rate of ARINC429 board is 100Kbps, and the reliability is 100%. the transmission rate of UDP is 100Kbps, and the reliability is higher than 99%. Both data transmission is stable and the reliability is high. It can meet the data transmission requirements of the BDS airborne receiver integrity test.The transmission mode can realize the reference track information, the BDS receiver fault information and the transmission of the BDS receiver output navigation information.

5.1. Analysis of static test results

The integrity test static test uses 24 locations in China, the simulation time is 2018.8.1 0:00~24:00, the time interval is 30min. A total of 36,000 time-space points were selected for simulation testing, and faults were added every 120 time-space points. The size and time of fault are random.

When the detection statistic exceeds the detection threshold, it indicates that the satellite is faulty. Test results include horizontal positioning error and test statistic. The results of the Monte Carlo experiment in the static test are shown in Fig5. The statistics of the static test are shown in Tab3.

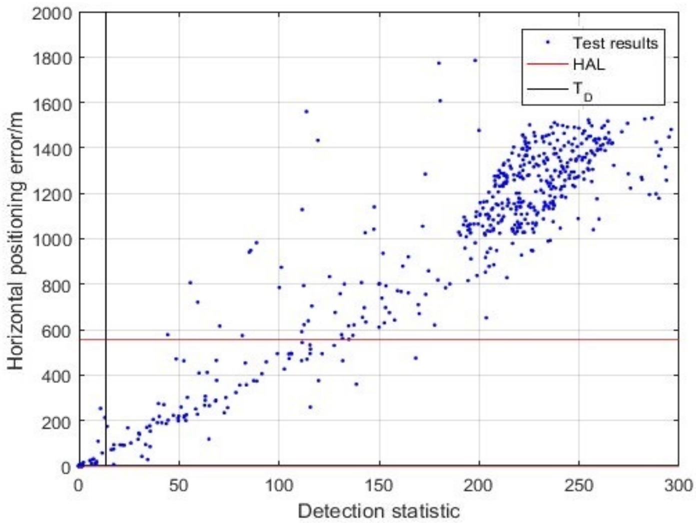

Fig 5. Monte Carlo test results of static test

Tab 3. Statistical data of of static test

item	count
correct runs	34854
timely detections	1068
misses	0
early detections	78

The above information indicates that correct runs take up most of the experimental results. Many faults can be detected, and the number of missed checks is 0. The alarm time is all less than the alarm time limit. The false alarm rate is 0.0022, the missed alarm rate is 0, and the false alarm rate meets the NPA stage requirements, but the false alarm rate does not meet. Therefore, the integrity performance of the BDS receiver does not meet the operating standards of the NPA stage.

5.2. Analysis of dynamic test results

The flight trajectory in the dynamic test is the QAR data of Chengdu-Shanghai, starting at [30.578333°N, 103.946667°E] and ending at [30.051224°N, 121.382198°E].The simulation time is 2018.6.4 9:00~11:30, and the simulation time is 9000s.

The dynamic test selects the NPA stage for integrity testing. A total of 90000 time-space points were used in the simulation experiment, and faults were randomly added every 300 time-space points. The results of the Monte Carlo experiment in the dynamic test are shown in Fig6. The statistics of the dynamic test are shown in Tab4.

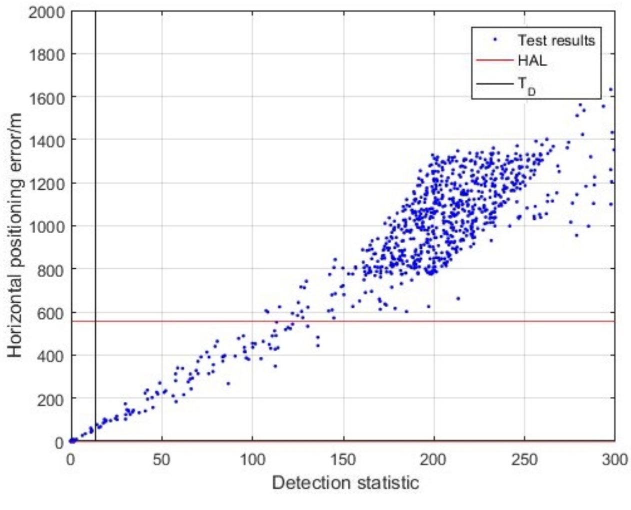

Fig 6. Monte Carlo test results of dynamic test

Tab 4. Statistical data of dynamic test

item	count
correct runs	81804
timely detections	8084
misses	0
early detections	112

The above information indicates that the false alarm rate is 0.00124, the missed alarm rate is 0. The alarm time is all less than the alarm time limit. The false alarm rate meets the NPA stage requirements, but the false alarm rate does not meet. Therefore, the integrity performance of the BDS receiver does not meet the operating standards of the NPA stage.

6. CONCLUSION

Test system can use static test method or dynamic test method for different scenarios. Through a number of performance indicators test, it is determined whether the BDS airborne receiver integrity performance meets the requirements of civil aviation operation. The integrity test system can configure various types of errors and ensure the stable transmission of data to meet the integrity test requirements in different environments. The experimental results verify the effectiveness of the test system and provide reference value for the performance test of the BDS airborne receiver.

REFERENCES

[1] Xu X, Yang C, Liu R. Review and prospect of GNSS receiver autonomous integrity monitoring[J]. Acta Aeronautica et Astronautica Sinica, 2013, 34(3): 451-463.

[2] Yang Y, Xu J. GNSS receiver autonomous integrity monitoring(RAIM)algorithm based on robust estimation[J]. Geodesy and Geodynamics, 2016, 7(2): 117-123.

[3] He P, Liu G, Tan C, et al. Nonlinear fault detection threshold optimization method for RAIM algorithm using a heuristic approach[J]. Gps Solutions, 2016, 20(4): 863-875.

[4] Jin S, Jin R, Kutoglu H S, et al. Positive and negative ionospheric responses to the March 2015 geomagnetic storm from BDS observations[J]. Journal of Geodesy, 2017, 91(6): 613-626.

[5] Lijun P, Kai J, Xiaojun D, et al. Receiver autonomous integrity monitoring parameter design and analysis for multi-constellation navigation[C]//China Satellite Navigation Conference (CSNC) 2012 Proceedings. Springer, Berlin, Heidelberg, 2012: 15-27.

[6] RTCA.DO-208.Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning System(GPS)[S].1991.

[7] BDS-SIS-ICD-B3I-1.0. Beidou satellite navigation system spatial signal interface control file B3I (version1.0) [S]. China Satellite Navigation System Management Office, 2018.

[8] Xie Jun, Zhang Jian-jun, Wang Gang. Measurement Error Index System of Bei Dou Satellite Navigation System[J]. Journal of Astronautics,2018,39(09):977-985.