Key Technologies of Autonomous Navigation based on Inter-satellite Link

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Abstract

In this paper, key technologies such as system design, communication technologies, routing policy evaluation, and fusion algorithms are researched to construct the process of autonomous navigation based on inter-satellite link (ISL). The simulation results indicate that ISL will effectively improve the orbit prediction accuracy and increase service ability, thus to achieve autonomous navigation.

Keywords

Inter-satellite link, orbit prediction, autonomous navigation.

1. Introduction

Autonomous navigation is the basic ability to survive independently for future navigation satellites, even in the absence of support from the ground control center. It mainly refers to the estimates of spaceborne ephemeris and clock errors [1-3]. On the one hand, to deal with the situation that ground control center being destructed by enemies. At this time, satellite requires the ability to broadcast navigation satellite position and clock data to meet the accuracy requirements independently. On the other hand, the redundant satellite observations and joint orbit determination by ground and satellite, will also improve the ability of navigation service, which will promote the processing flexibility. In addition, inter-satellite links observations of the star can also be used to provide data for current satellite-based integrity monitoring, as a new means to the constellation of independent monitoring.

The premise to achieve the above functions is range measure and communication through the terminal of inter-satellite link, thus achieving network topology construction, autonomous orbit determination, and time synchronization. This article will mainly focus on critical technologies of inter-satellite links and autonomous navigation including system design, communications technology, routing policy evaluation, and self-process, in order to provide a reference for the construction of future GNSS system.

2. Research Survey

BLOCK IIR / IIF GPS satellites are equipped with a satellite link between devices, using the UHF band, through two-way ranging between satellite and data exchange to achieve the autonomous navigation [4]. At the beginning of GPS setting up, the issue of autonomous orbit determination system has been considered. Rockwell and the other two U.S. companies combined on the structural design and simulation test of independent satellite navigation devices in Block ⅡR. In 1990, the theories, models, algorithms and simulation studies of satellite autonomous navigation have been basically completed.

Currently Block ⅡR satellites have the ability to use dual-band pseudo-range observations to measure the distance between the satellites, the ability to communicate with each other between the satellites, and the ability to calculate its own satellite ephemeris and clock errors of satellite capacity on the satellite. In the absence of support from ground control system, the 180-day ephemeris of URE still be maintained at ± 6m or less. GPS Ⅲ system will use satellite link between the V-band network, which will upgrade the performance of GPS Ⅲ satellites.

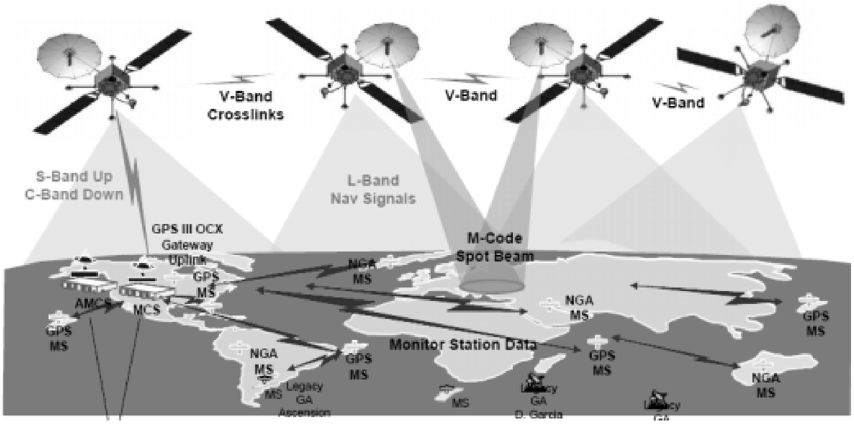

Figure 1.GPS III system operating concept diagram [5]

GLONASS has the design ideas of S-band wide-beam satellite link similar to GPS; different satellites establish measurement relationships through communication division manner to address the accuracy of orbit and clock error problem. The GLONASS-K satellites will be used as a medium between the directionality of a laser satellite link to reach the level of GPS systems [6].

Taking the possible construction costs and global distribution station into account, the Galileo system has not started the inter-satellite link design. However, considering the future integrity monitoring and development applications, inter-satellite links will become the basic configuration of the navigation constellation.

3. System Design

Ranging and communications is the premise of autonomous navigation, as shown in figure 2. By routing, ranging information will be transmitted to the appropriate computing nodes. After deducting clock error of pseudorange, integrity prediction pretreatment, orbit and clock error parameters are decoupled. And then, orbit ephemeris is completed to realize autonomous navigation.

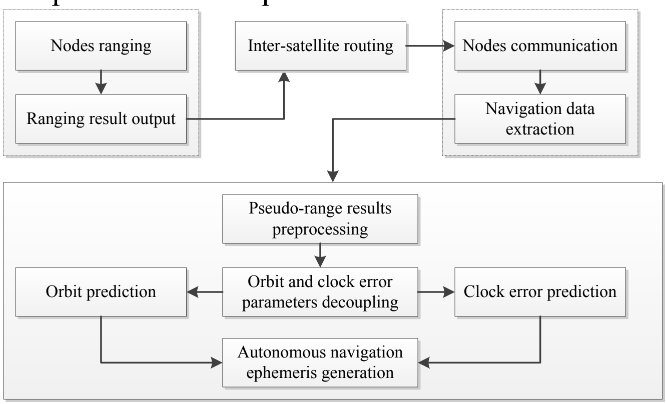

Figure 2.The program of autonomous navigation

According to the program of autonomous navigation using inter-satellite links, the key design techniques that distance and communication technology, network routing policy of inter-satellite links, and algorithm for autonomous navigation and time synchronization are summarized.

4. Terminal design for Ranging and communication

According to the literature [7], higher frequencies (Ka, EHF, V-band) microwave links and greater capacity laser link will be the development direction of ISL. In high-frequency microwave link, the antenna beam could be narrow and the available band could be wide. The possibility of signal interference and intercepted are reduced. The antennas and other equipment could be miniaturized. Compared with microwave link, laser link could bring higher data rates to meet the needs of large-capacity transmission. The divergence angle of the laser beam is smaller than microwave beam, which will greatly increase the density of electromagnetic energy. Additionally, the weight, volume and power consumption could be reduced. Meanwhile, its excellent anti-jamming performance is conducive to military applications. Both microwave links and laser links need to raise the level of design capability on the following fields.

4.1 Improve the accuracy of ranging

To improve ranging accuracy, the direct means is to inhibit or eliminate the presence of error sources. Major impact on the accuracy of satellite ranging error comprising: (a) the errors associated device itself, such as the antenna phase errors, the delay of device, and the noise of terminal (2) introduced in the signal propagation, such as multipath errors, and etc.; (3) other error such as relativistic effects, and dynamic stress errors.

Two important characteristics of the measurement error is the change in size and speed. According to its change in speed, the error term can be divided into two types of bias and noise. Biases often have certain rules to follow, and its size is certain stability, such as the antenna phase center error, ionosphere delay error, and etc. These errors can be directly measured or predicted by logarithmic corrections. Noise is always considered by increasing the robustness of the equipment or is compensated when dealing with treatment after filtering.

4.2 Improving the anti-jamming capability

ISL is utilized to autonomous navigate, which requires ISL with strong anti-jamming capability. At present, there are two basic ideas for the suppression of interference signals, include: (1) detecting and removing the received interference baseband signal, and (2) though the antenna to suppress interference signal directly. Method (1) is divided into interference suppression technique based on prediction and transform domain. Method (2) interference suppression achieved primarily through the airspace, the use of adaptive nulling antenna adaptive beam-forming antenna technology will gain in the direction of the source of interference, which set it to zero or close to zero, in order to achieve interference suppression.

4.3 Improving the communication performance

There are two targets to achieve effective, one is communication rate, and the other one is bit error rate. Communication rate is affected by C/N0 and bandwidth. To improve the quality of the wireless channel, the bit error rate should be reduced to a minimum. Channel coding technology could be used to reduce the bit error rate and improve the quality of the main technical means of communication.

5. Network and routing strategy design

5.1 Constraints for Routing Design

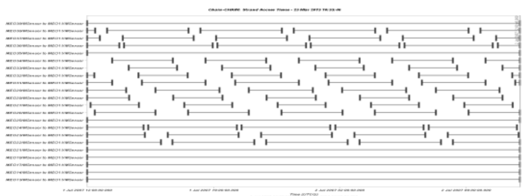

Figure 3. Satellite visibility within 24 hours

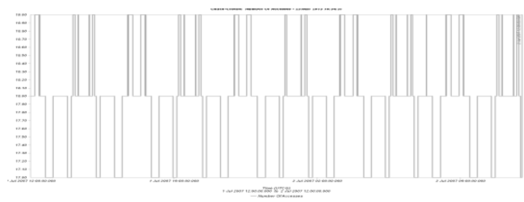

Figure 4. Instantaneous connectivity simulation

Visibility between satellites is mainly limited by earth block and scanning angle of antenna. Visible satellites in the same orbital plane and different orbital planes are analyzed respectively. Taking

Walker 27/3/1 constellation for example, analyze the visibility between MEO satellites. Assuming the width of beam is 40 °, the simulation results show that the number of visible satellites between MEO satellites remain at 17 or more.

Taking two MEO satellites' link for analysis, the related simulations are shown in following figures.

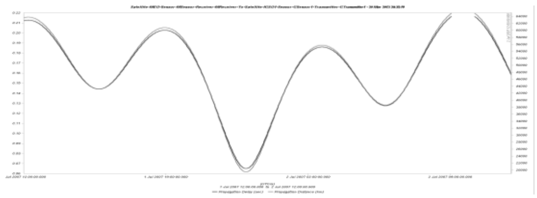

Figure 5. Transmission distance and propagation delay between satellites

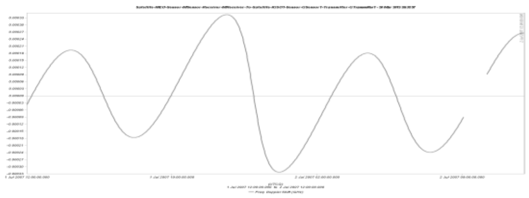

Figure 6. Relative Doppler frequency shift between satellites

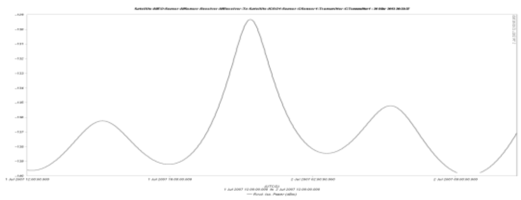

Figure 7. Signal power received by the antenna

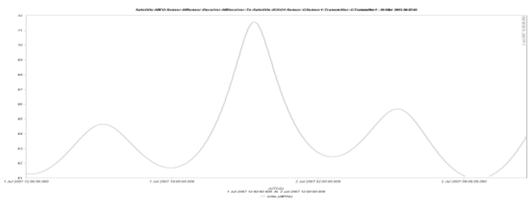

Figure 8. Signal carrier to noise ratio received by the antenna

5.2 Transit routing and network topology

Transit routing and network topology design needs to start from the evaluation system. Currently two routing strategies are more commonly used, which are minimum hop routing strategy and minimum distance routing policy. Taking the autonomous orbit determination accuracy into account, DOP configuration is another important design factor in inter-satellite links. From the view of link topology, there are three types:

Permanent link with the permanent visible satellites.

Dynamic links with intermittent visible satellites by independent control.

Self-built chain link by controlling by the ground.

6. Autonomous navigation and time synchronization design

Basic processing for autonomous navigation and time synchronization is :

(1) Start ranging for two-way satellite links to obtain pseudo range observations;

(2) Use pseudo-range system errors, and two-way pseudo-range data to achieve epoch naturalization, and then use the two-way pseudo to form orbit observations and time synchronization observables;

(3) Use orbit and clock errors autonomous updated information broadcast ephemeris parameters fitting.

Set initial conditions of Kalman filter as follows: initial satellite position error is 5 meters, initial velocity error is 1e-3 m/s. The average URE for orbit prediction without ISL is shown in figure 9, where the URE could be up to 320m in 60 days. The average URE for orbit prediction is shown in figure 10, where the URE could be less than 3m in 60 days.

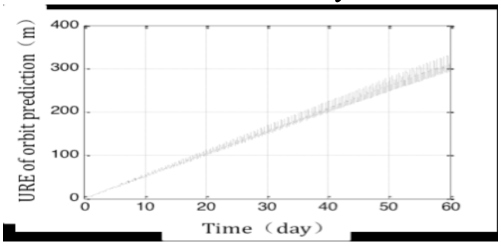

Figure 9 URE for orbit prediction without ISL

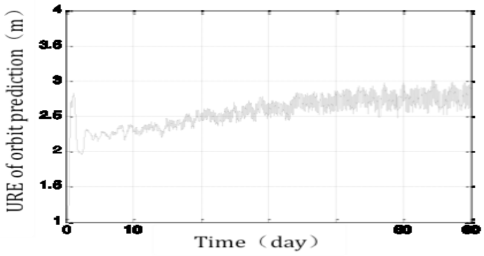

Figure 10. URE for orbit prediction with ISL

7. Conclusion

Key technologies such as system design, communications technology, routing policy evaluation, and fusion algorithm are researched in this paper. The simulation results indicate that to use ISL to achieve autonomous navigation will effectively improve the orbit prediction accuracy and service ability.

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