APPLICATION OF SATELLITE STATION DIFFERENTIAL TECHNOLOGY IN REMOTE AREAS

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KEY WORDS: Satellite Station Differential, CORS System, Coordinates, Convergence time, Fixed solution, Precision.

ABSTRACT:

Aiming at the situation that there is no network and communication signal in remote areas, the idea of using satellite station difference technology to obtain relatively accurate positioning is proposed. This paper briefly introduces the current mainstream satellite station differential system, and carries out static and dynamic experiments using satellite station differential technology in the remote Ali Region of Western China. The experimental results show that the selection of satellite station differential system, the selection of receiver, the surrounding environment during observation and the motion state during observation all affect the positioning accuracy. Under the static observation conditions, the satellite station differential can obtain an accuracy better than 0.15m, and in the dynamic At low speed, the precision of 2m can be obtained. The experimental results show that the satellite station differential positioning technology is generally reliable and can be applied to many applications, such as control point measurement, position navigation and so on.

1. INTRODUCTION

At present, satellite station differential positioning system has become an indispensable supporting facility for satellite navigation systems in many countries and an important means to improve positioning accuracy. The basic principle of satellite based enhancement technology is differential positioning. The composition of satellite station differential system is similar to that of CORS(continuously operating reference stations), which is composed of reference station, data center, geosynchronous satellite and user. The reference station sends the tracked satellite signal to the data processing center (Liu et al., 2018). The data center uses these data to generate differential data, and sends the differential data to the user through the data broadcasting link. The user uses the differential data to improve the positioning accuracy (Wang et al., 2018). The working principle of satellite station differential system is shown in Figure 1.

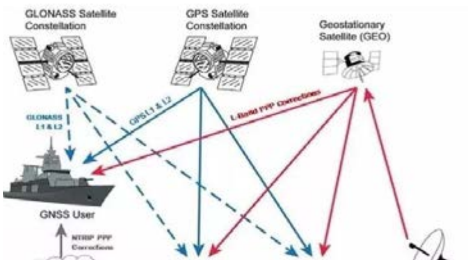

Figure 1. working principle of satellite station differential system

The United States, the European Union and other countries and regions are committed to the development of satellite positioning satellite based enhancement technology. At present, there are four satellite station differential systems that have been widely used in the market:

1.1 EGNOS System

European geostationary navigation overlay service (EGNOS) meets the needs of high security users by enhancing the positioning accuracy of GPS and GLONASS satellite navigation systems. EGNOS space part includes three geo satellites, equipped with navigation enhancement transponder to broadcast navigation enhancement signals; Two are inmarsat-3 satellites, one in the eastern Atlantic Ocean and the other in the Indian Ocean; Artemis has a geostationary communication satellite over Africa. The orbit is 15.5° west longitude, 65.5° east longitude and 21.3° east longitude respectively (Wang et al., 2019).

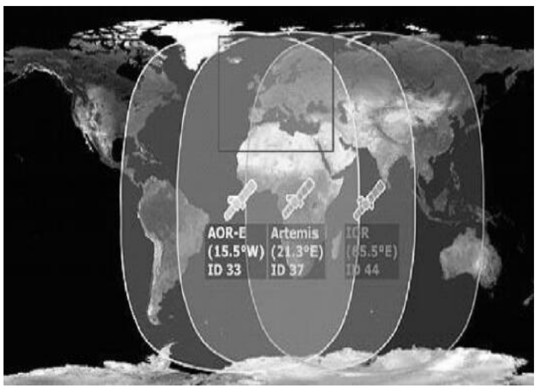

Figure 2. coverage distribution of Gnos system

EGNOS ground system includes main control center, monitoring station and land navigation earth station. The user part includes: EGNOS receiver for space signal performance verification, and special equipment for users of water transportation, air transportation and land transportation; The system static and dynamic test platform is used for user receiver acceptance, system performance demonstration and comparative analysis of positioning error. The support system includes EGNOS wide area differential network, system development

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and verification platform, detailed engineering technical design, system performance evaluation, problem discovery and other support systems. The spatial distribution of EGNOS system is shown in Figure 2.

1.2 Veripos System

Veripos system has more than 80 reference stations in Singapore and has established two global control centers in the UK. The control center monitors the overall performance of veripos communication system, and can also provide users with real-time information about system performance. At the same time, it has the authority to turn on and off veripos enhanced system. The system measures the error of GNSS system through 80 ground reference stations distributed all over the world, and then the data of each reference station are analyzed and processed by two control center stations located in Britain and Singapore respectively. Finally, the differential correction data after analysis and confirmation are distributed to users through the network or seven simultaneous satellites, so as to realize high-precision real-time single point positioning (Li Y., 2019). Veripos coverage is shown in Figure 3.

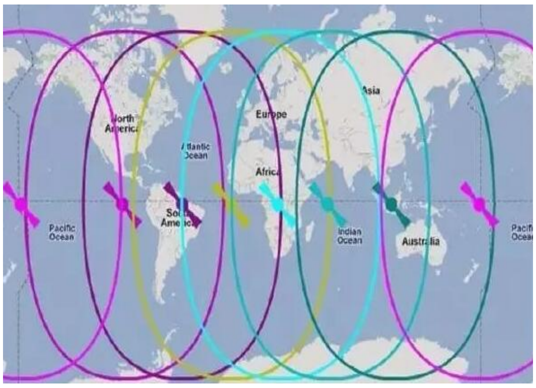

Figure 3. veripos coverage

1.3 Starfire System

Starfire system established by navcom in 1999, provides GPS differential signal service worldwide. It provides reliable positioning accuracy and has 99.99% reliability. Since its operation, Starfire network has covered any earth surface from 76 ° north latitude to 76 ° south latitude, and can provide the same accuracy.

Figure 4. Starfire coverage

Starfire system includes a dual frequency reference station network composed of more than 80 reference stations all over the world, 2 data processing centers, communication links, 3 injection stations distributed all over the world and 6 INMARSAT synchronous satellites. The correction signal is broadcast through INMARSAT geostationary satellite without establishing a reference station or post-processing in the survey area. The system provides high-precision and reliable GPS wide area differential enhancement service. The positioning accuracy reaches centimeter level and has high cost performance. It is widely used in geodesy, aerial photogrammetry, UAV precise navigation and other industries and application fields. The coverage of Starfire system is shown in Figure 4.

1.4 Ominstar System

Ominstar system, originally operated by Fugro company, was sold to Trimble company in March 2011. It is a set of high-precision GPS enhancement system that can cover the world. In terms of providing enhanced GPS data through satellites, Ominstar is a leader in the world market. The system measures the error of GPS system through 70 ground reference stations distributed all over the world. The data of each reference station is analyzed and processed by three control center stations located in the United States, Europe and Australia respectively, and the differential correction data confirmed by analysis is broadcast to users through synchronous satellites, Realize high-precision real-time positioning. Ominstar provides measurement, positioning, environment and satellite services including land and offshore. In terms of new applications on land, Ominstar services can meet the needs of precision positioning systems. After purchasing a GPS receiver with Ominstar function, users can pay the service fee to Ominstar 's service provider and apply for opening the service (Zhang et al., 2020; Zhou et al., 2020). The Ominstar coverage is shown in Figure 5.

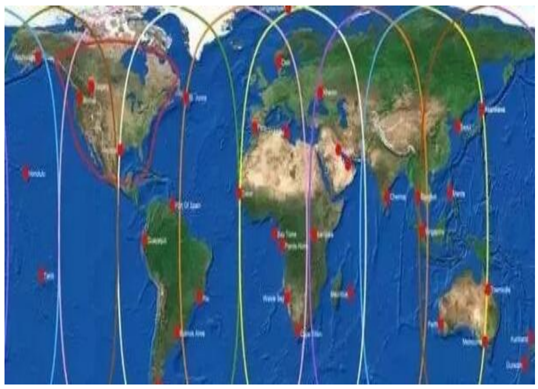

Figure 5. Ominstar coverage

Compared with CORS system, the reference station density of satellite station difference is much lower than that of CORS system, and the data broadcasting link adopts satellite communication, which solves the problem of limited coverage of CORS system. Because there are few reference stations and satellite communication is adopted for transmission, the correction number provided by satellite station difference is the model correction number, and the measurement accuracy and the convergence speed of observation results are lower than that of CORS system. The main differences between CORS system and satellite station are shown in Table 1.

category	CORS	satellite station difference
positioning principle	relative positioning	absolute positioning
communication	Network,	Satellite,

mode	bidirectional transmission	unidirectional transmission
coverage	local area	large-scale
Initialization speed	Faster	slower
positioning accuracy	higher	lower
Number of users	Limited	unlimited
Network dependence	Stable network transmission	No dependency

Table 1. main differences between CORS system and satellite station difference

Satellite station difference technology has been applied in many aspects, such as island survey, bathymetric survey, remote area control survey and so on, and achieved good results (Li et al., 2020; Liu et al., 2021).

2. APPLICATION CASE AND ANALYSIS

2.1 Applications Case

2.1.1 Experimental overview

The remote Ali area in Western China is selected for the test. There is no network CORS station signal in this area and no mobile phone signal in most areas. It is a good area for satellite station difference. The test is carried out within about 1000km2. The test area involves a variety of different terrain such as mountains, hills and flat land. The experiment is divided into two parts: static test and dynamic test. The test scope is shown in Figure 6. Experimental overview

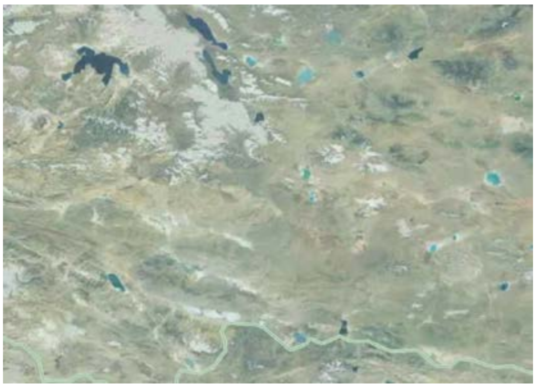

Figure 6. schematic diagram of test range

2.1.2 Instrument selection

Figure 7. starfish irtk5x GNSS receiver

The instrument selected in this experiment is haixingda irtk 5x GNSS receiver of China Haida company, which has various functions such as static observation and satellite station difference (Chen et al., 2018). The satellite station difference function of this model is based on OMINSTAR difference system. The GNSS receiver is shown in Figure 7 and the observation manual is shown in Figure 8. The specific performance of the receiver is shown in Table 2.

Figure 8. starfish irtk5x observation manual

satellite station difference	Support satellite based enhanced services	
GNSS configure	Number of channels:660	
	BDS：B1I，B2I，B3I，B1C，B2a	
	GPS：L1，L2，L5	
	GLONASS：L1，L2	
	GALILIEO：E1，E5a，E5b	
	QZSS：L1，L2，L5	
accuracy and reliability	RTK positioning accuracy	plane：±（$8+1\times10^{-6}$D）mm; altitude ：±（$15+1\times10^{-6}$D）mm（D is the distance between measured points）
	Static positioning accuracy	plane：±（$2.5+0.5\times10^{-6}$D）mm，altitude：±（$5+0.5\times10^{-6}$D）mm （D is the distance between measured points）
	DGPS positioning accuracy	plane：±0.25m+1ppm；altitude：±0.50m+1ppm
	Initialization time	＜10 second
	Initialization reliability	＞99%

Table 2. technical parameters of irtk5x GNSS receiver

2.1.3 Static test

Select 50 topographic feature points, conduct static observation with irtk5x GNSS receiver, and analyze the observation data with TEQC software to ensure that the data efficiency is more than 80%. Download the data of IGS station and CORS station near the area, network 50 observation points and known stations, and use the high-precision data processing software GAMIT to solve the baseline to obtain the accurate coordinates of the 50 points under the accurate itrf2014 framework. Using the satellite station differential function of irtk5x GNSS receiver to obtain the coordinate values of 50 points, there are four cases of satellite station differential measurement: fixed solution, floating solution and no differential signal. The accuracy of the four modes of satellite station difference in this experiment is shown in Table 3.

Type of solution	Convergence accuracy
Fixed solution	plane <0.1m， altitude <0.1m
Floating solution	plane <0.5m， altitude <0.5m
Single point solution	plane <2m， altitude <2m
Non differential signal	No signal, no convergence

Table 3. accuracy setting of four differential modes of satellite station

2.1.4 Dynamic test

The irtk5x GNSS receiver is placed on the roof to collect data along the roads in the survey area. Because the terrain along the roads in the survey area is complex, in order to collect as much data as possible, the type of Star Station difference decomposition is set as single point solution, and the data is collected every 200m. The car runs at the speed of 60km / h, and a certain number of bridge head and road characteristic points are collected relatively slowly, with a total of 2310 points collected. The schematic diagram of data acquisition is shown in Figure 9.

Figure 9. Differential diagram of on-board satellite station

2.2 Static experimental analysis

2.2.1 Satellite station differential signal analysis

In this experiment, the signals of GPS, BDS, GLONASS and Galileo satellite systems are obtained at most points. Figure10. is the satellite sky distribution map displayed at one of the points.

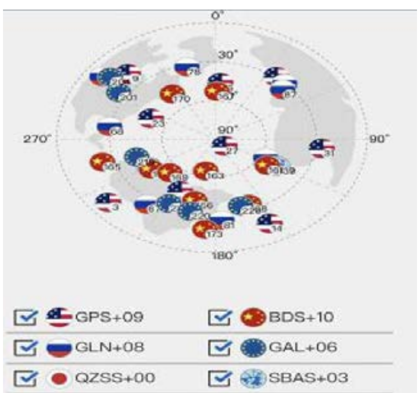

Figure 10. satellite sky distribution of observation points

The experimental results show that most of the 50 static test points can obtain fixed solutions, and the specific situation is shown in Table 1. It can be seen from the table that except for two points, the other points can obtain differential signals. After analysis, the surrounding of the two points is not open enough, and there are mountain blocking signals.

Solution type	Fixed solution	Floating solution	Single point solution	Non differential signal
point	39	7	2	2

Table 4. differential observation of 50 point satellite stations

2.2.2 Convergence time analysis

The 39 points to obtain the fixed solution are analyzed, and the convergence time of each point is different, as shown in Table 5. It can be seen from table 5 that the convergence time of most points is within 10min, and the convergence time is generally controllable.

convergence time (t)	number	proportion
t<5min	11	28%
5min<t<10min	23	59%
10min<t<15min	5	13%

Table 5. convergence time analysis of 39 fixed solutions

2.2.3 Static observation accuracy analysis

Compare the coordinates obtained from the satellite station difference with the coordinates calculated from the static observation for 2 hours, and make accuracy statistics. The specific comparison results are shown in the table below. It can be seen from the table that the mean square error of plane and elevation of static observation is less than 0.15m, and the accuracy is relatively high

type	maximum difference	minimum difference	mean square error
plane	0.38 m	0.03 m	0.14m
altitude	0.30 m	0.01 m	0.11 m

Table 6. statistics of differential static observation accuracy of satellite stations

2.3 Dynamic experimental analysis

The situation and accuracy of satellite station differential signal obtained by irtk5x GNSS receiver during on-board operation are analyzed from the following three aspects:

2.3.1 Satellite station differential signal section analysis

Like the conventional GNSS receiver, after the satellite station differential function is turned on, the receiver must first search for the satellite signal. After locking the satellite and receiving the differential signal, it will observe. When it loses the locking due to other factors, it will search again. In this on-board experiment, the satellite station differential observation signals are obtained in most sections. The data of 2310 observation points along the road collected by the satellite station differential on-board are analyzed, and compared with the accepted topographic map data, as shown in Table 7.

Satellite station differential signal	proportion
Signal	80.2%
No signal	19.8%

Table 7. Satellite station differential signal reception

It can be seen from table 7 that about 20% of the road sections have not collected data, that is, they have not received the satellite station differential signal. Through the analysis of the topographic map, it can be concluded that the road sections with missing data are the areas with serious mountain cover on both sides or tunnels.

2.3.2 Effective point proportion analysis

The observation coordinates are superimposed with the pavement data that are known to have passed the acceptance, and it is found that a small number of points are not displayed on the pavement, as shown in Table 8.

nesting condition	number	scale
on the road	2188	94.7%
Not on the road	122	5.3%

Table 8. Relationship between observation points and pavement

According to table 8, about 95% of the points are displayed on the road surface. The point does not fall on the road surface, and there is a certain deviation in plane and elevation. Through analysis, it is known that most of the deviation points are located at the place where the road turns, and the road turns are often where the vehicle speed changes greatly, resulting in the incompleteness between the measured points and the actual point.

2.3.3 Mathematical accuracy analysis

The road of this dynamic vehicle experiment is two lanes, the road is relatively flat, and the vehicle strictly follows one-way side driving. Excluding a small part of the influence caused by errors such as vehicle line change, the mathematical accuracy is compared between the coordinates of track points and the coordinates of road points and other characteristic points of the existing results. Through statistical analysis, the mean square error in plane and elevation accuracy in dynamic driving are 1.64m and 1.42m respectively.

2.4 Analysis of influence factors of satellite station difference

Through this experiment, it can be analyzed that there are multiple factors affecting the signal reception and final mathematical accuracy of satellite station difference, mainly in the following four aspects.

Selection of differential station system. Different satellite station differential systems use different differential satellites and reference base stations. For example, EGNOS system mainly serves Europe, and the differential signal will be relatively poor or even no differential signal in other regions. Therefore, in the satellite station difference, it is very important to select an appropriate difference system, which directly determines the final quality of the satellite station difference.

Selection of GNSS receiver. At present, there are many kinds of GNSS receivers in the market with different functions. Whether they can receive signals from a variety of navigation satellites is directly related to the satellite station difference results. If it can receive multi-source satellites, the number of satellites that can be observed will be more, the stability coefficient will be higher, the stability of the received differential satellite signal will be improved, and the corresponding positioning accuracy will be higher.

The influence of surrounding environment during observation. When the observation point is located in an area with complex terrain, especially when there are mountains, tall buildings and trees around it, the number of satellites observed by the GNSS receiver will be directly affected. If the receiver cannot receive the signal of the key differential satellite, the differential observation of the satellite station will not be realized at the observation point. In this experiment, the two points cannot receive the differential signal because there are many surrounding obstructions.

The influence of motion state during observation. During static observation, as long as the GNSS receiver receives the satellite station differential signal, its differential signal will be relatively stable and the accuracy of the coordinate value will be higher. When in motion, the positioning accuracy is relatively poor because the surrounding geographical environment is changing and the received signal is unstable.

3. CONCLUSIONS

The satellite station difference technology enables the user to obtain a fixed solution without relying on external communication support, and realizes high-precision positioning in areas that cannot be covered by ground reference stations in remote mountainous areas. The realization of satellite station differential high-precision positioning is related to the selection of satellite station differential system, the selection of GNSS receiver, the surrounding environment during observation and the motion state during observation. In the case of static measurement, the overall positioning accuracy of satellite station difference is better than 20cm. In the area with relatively good observation conditions, the convergence accuracy of the fixed solution is generally within 10min. However, in the area where the observation environment is not open enough, such as the canyon, the receiver can not obtain the fixed solution and can not achieve accurate positioning. In the state of medium and low speed motion, the satellite station difference can achieve positioning accuracy and elevation accuracy better than 2m. The rapid positioning and accuracy improvement of satellite station difference technology need to be further studied.

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