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Design of DGPS Receiver Based on the Net of VRS

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Abstract: To improve the positioning accuracy of the GPS system, the differential technology based on real time kinematic is utilized. Comparing with the conventional differential technology, the differential technology based on the virtual reference station can minimize the size of the rover station which is of great significance for the small system such as the mini-type unmanned vehicle, smart ammunitions and so on. Due to the high cost of the GPS receivers in the market which can't be redeveloped and the limitation of their interface, it is not suitable for the application of the embedded system. In this paper, the receiver based on the aforementioned method is proposed to realize the real time differential positioning. Firstly, the concept of differential positioning based on real time kinematic is explained. Next, the composition of the virtual reference system and its working principle are introduced. And then, the design of differential GPS receiver based on the virtual reference system for rover station is illustrated. Finally, from the repeatability test, the result shows that by means of getting the differential corrections from the virtual reference station, the designed differential GPS receiver can correct the errors caused by ionosphere, troposphere and atmospheric refraction. Moreover, it can improve the positioning accuracy to centimeter-level. With low cost, small size and convertibility of the interface of the designed differential GPS receiver according to the embedded system, it will be popular in the future market. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Real time kinematic, Virtual reference system, Differential GPS receiver, Rover station, Embedded system.

1. Introduction

Differential Global Positioning System (DGPS) technology employs two or more GPS receivers simultaneously tracking the same satellites to determine their coordinates. One receiver is selected as the reference station which remains stationary with a precisely known fixed coordinate. And the other one is a rover receiver whose coordinate is determined by using the observation measured from both receivers. As we know, the reference station of the differential technology based on Real Time Kinematic (RTK) in traditionally method should be kept within 10 km to ensure the accuracy [1]. Fortunately, multiple reference station networks have been installed in many cities, which overcome the problem of limited distance for the reference stations. Recently, many mature products in the market have been designed by Leica, Trimble, Magellan, TOPCON etc. All of these products can provide high positioning accuracy, so it has a widely application in many fields such as high accuracy Geographic Information System (GIS) [2], engineering [3], automatic guidance system [4], surveying [5] and some other relative works [6-9]. However, in some special application, taking the unmanned aircraft

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flight control system for example, the limited interface and large size of the mature products cannot meet the requirement of such embedded system. Thus, it is necessary to research and develop a DGPS receiver with multiple interfaces, small size and low cost.

The DGPS receiver designed in this paper is based on the background of the unmanned aircraft flight control system. Firstly, the principle of RTK for DGPS positioning is described. And then the composition and working principle of Virtual Reference Station (VRS) is introduced. Meanwhile, the design of DGPS receiver based on the net of VRS is illustrated. Finally, the experiment result demonstrates that the designed DGPS receiver can work steadily while providing high accuracy positioning information by getting the differential corrections from the virtual reference station.

2. DGPS Positioning Principle of RTK

The RTK technology is also called carrier phase differential technology, which is based on the real time processing the carrier phase of two observation stations. A conventional RTK system consists of two receivers and a radio communication system [10]. The radio communication system is to transport data from reference station to rover station. One receiver at a known location (reference station) will observe the satellites continuously and then send the observation data to the users by the radio communication. Another receiver for rover station will receive not only the information from the satellites but also the real time information from the reference station. According to the positioning principle discussed as follows, it will provide high accuracy positioning information to the users.

RTK technology can be divided into correction method and differentiation method. The correction method sends the corrections of carrier phase to the rover station which will correct the carrier phase to realize the high precision of positioning. As for the differential method, the carrier phase of the reference station will be sent to the rover station which will calculate the difference between the carrier phase and the observation data from the satellites.

The phase difference of the satellites can be determined by:

$$\Phi_i^j = N_i^j(t_0) + N_i^j(t-t_0) + \delta\varphi_i^j, \quad (1)$$

where $N_i^j(t_0)$ is the initial integer ambiguity, $N_i^j(t-t_0)$ is the integer cycle change values from the initial moment to the observation moment, and $\delta\varphi_i^j$ is the decimal part of the observed phase. The distance between the satellites is the product of the carrier wavelength and the phase difference.

$$\tilde{\rho}_i^j = \lambda(N_i^j(t_0) + N_i^j(t-t_0) + \delta\varphi_i^j), \quad (2)$$

If the real distance ρ_i^j between the satellites can be obtained from the known position and satellite ephemeris which are provided by the reference station, the pseudo range can be written in (3):

$$\begin{aligned}\tilde{\rho}_i^j = \rho_i^j + c(\delta_i - \delta_j) + \delta_i^j + \delta T_i^j \\ + \delta M_i + V\end{aligned}, \quad (3)$$

where δM_i is the multipath effect and V_i is the noise of GPS receiver. Then the pseudo correction can be calculated:

$$\begin{aligned}\delta\rho_i^j = \tilde{\rho}_i^j - \rho_i^j = c(\delta_i - \delta_j) + \\ \delta_i^j + \delta T_i^j + \delta M_i + V_i\end{aligned}, \quad (4)$$

Using the correction expressed in (4), the pseudo range can be modified as follows:

$$\begin{aligned}\tilde{\rho}_i^j - \delta\rho_i^j = \rho_k^j + c(\delta t_k - \delta t_j) \\ + (\delta L_k^j - \delta L_i^j) + (\delta T_k^j - \delta T_i^j) \\ + (\delta M_k - \delta M_i) + (V_k - V_i)\end{aligned}, \quad (5)$$

When the distance of the reference station and the moving station is less than 30 km, we consider that δL_k^j equals to δL_i^j and δT_k^j equals to δT_i^j. Then (5) can be written as:

$$\begin{aligned}\tilde{\rho}_k^j - \delta\rho_i^j &= \rho_k^j + c(\delta t_k - \delta t_j) + (\delta M_k - \delta M_i) \\ &\quad + (V_k - V_i) \\ &= \sqrt{(X_j - X_k)^2 + (Y_j - Y_k)^2 + (Z_j - Z_k)^2} \\ &\quad + \Delta\delta\rho\end{aligned}, \quad (6)$$

Substituting (2), we can get the following expression:

$$\begin{aligned}\tilde{\rho}_k^j - \delta\rho_i^j &= \tilde{\rho}_k^j - \tilde{\rho}_i^j + \rho_i^j \\ &= \rho_i^j + \lambda(N_k^j(t_0) - N_i^j(t_0)) + \lambda(\delta\varphi_k^j - \delta\varphi_i^j) \\ &\quad + \lambda(N_k^j(t-t_0) - N_i^j(t-t_0)) \\ &= \sqrt{(X_j - X_k)^2 + (Y_j - Y_k)^2 + (Z_j - Z_k)^2} \\ &\quad + \Delta\delta\rho\end{aligned}, \quad (7$$

Take $N_j(t_0) = N_k^j(t_0) - N_i^j(t_0)$ as the initial integer cycle difference. $N_j(t_0)$ can be considered as a constant on condition that the satellite will not lose lock during the observation. And then the measurement error of the carrier phase is expressed as follows:

$$\begin{aligned}\Delta\varphi &= \lambda(N_k^j(t_0) - N_i^j(t_0)) \\ &+ \lambda(\delta\varphi_k^j - \delta\varphi_i^j)\end{aligned}, \quad (8)$$

Substituting (7), we will get:

$$\begin{aligned}&\rho_i^j + \Delta\varphi = \\ &\sqrt{(X_j - X_k)^2 + (Y_j - Y_k)^2 + (Z_j - Z_k)^2}, \\ &-\lambda N_j(t_0) + \Delta\delta\rho\end{aligned} \quad (9)$$

where $N_j(t_0)$, X_k, Y_k and Z_k are constants. Since clock error of the two receivers and multipath effect between the two stations are small, $\Delta\delta\rho$ can be also considered as a constant during the analytic process. Thus, if there are 4 satellites observed at the same time and the initial integer cycle can be determined, then the positioning of the user can be realized.

Since there are many reference station networks installed in many cities, the virtual reference stations instead of those in traditional method are used. Also with the development of wireless communication, the radio communication system is gradually replaced by the wireless modems which takes advantages of today's almost complete coverage of wireless network, such as GPRS (General Packet Radio Service), GSM (Global System of Mobile communication), CDMA (Code Division Multiple Access) and so on. Therefore, the reference station and the moving station are not constrained by the distance.

3. Composition and Working Principle of VRS

3.1. Composition of VRS

The system for VRS contains three parts: the fixed reference station, the rover station and the control and data processing center. As we know, VRS is a differential network technology based on the data fusion of multiple reference stations. The number of reference station should not be less than three. To ensure the positioning accuracy, the distance of them should not exceed more than 70 km. The fixed reference station has the responsibility to upload the real time measured data to the control center by the special communication line. The rover station contains GPS receiver and the wireless communication module. The wireless communication module will transport the differential corrections when GPS receiver received the information of satellites. After the differential calculation, the high accurate positioning information will be output. The control and data processing center is the core of VRS, and will transport the differential corrections to the rover station by the wireless network. In this design, GPRS is utilized as the transporting network.

3.2. Working Principle of VRS

In the net of VRS, each fixed reference station will transport the original data to the control and data processing center. Before the rover station begins to operate, it will send its outline coordinate to the center by the wireless communication module. After the center has received this positioning information successfully, the computer will select a group of optimal fixed reference stations. The information sent from this reference station will modify the orbit error, satellite clock error and the errors caused by ionosphere, troposphere and atmospheric refraction. And then the differential corrections with high accuracy will be sent to the rover station.

4. Design of DGPS Receiver

4.1. Composition of Designed DGPS Receiver

As the mature products in the market are so expensive and they can not be redeveloped especially for the embedded system, we designed the DGPS receiver based on VRS for the unmanned aircraft flight control system. Generally, A DGPS receiver usually contains the satellite antenna, the control module, the wireless communication module and so on. The block diagram of the designed DGPS receiver is shown in Fig. 1.

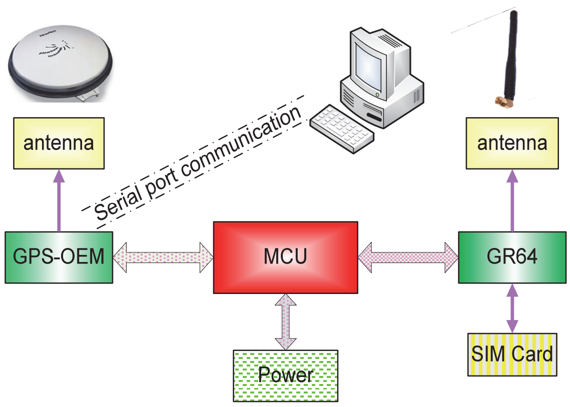

Fig. 1. Block diagram of the designed DGPS receiver.

This design is under the background of the unmanned aircraft flight control system, and the serial interface is required to communicate with the main controller. Therefore the positioning information is transported by serial interface on the board. The unmanned aircraft flight control system is shown in Fig. 2.

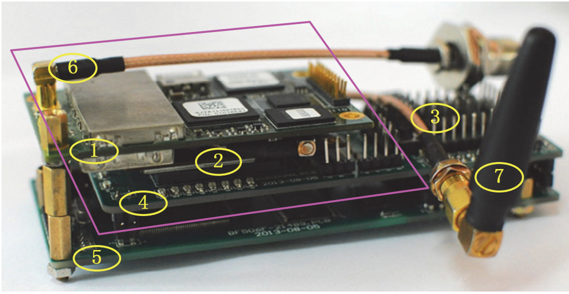

Fig. 2. The unmanned aircraft flight control system.

In Fig. 2, the left part on the board is the designed DGPS receiver. Part 1 is the GPS-OEM board with the antenna interface of part 6, part 2 is the wireless communication module with its antenna of part 7, part 4 is the control module for DGPS receiver, part 5 is the main controller of the unmanned aircraft flight control system. For the future development, other interfaces in part 3 are reserved such as SPI, I2C.

OEM615 from NovAtel and the special satellite antenna are used for GPS-OEM board in this system. MSP430F247 is utilized as the controller for DGPS receiver with the advantages of multiple interfaces, low power consumption and high operating speed [11]. The controller of DGPS receiver needs to send AT commands to realize the network connection of wireless communication module which will complete the bidirectional transmission of data stream from the control and data processing center to the rover station. Also it will transmit the corrections to accomplish the differential calculation on the GPS-OEM board. In order to ensure the reliability of the wireless data transmission, the controller has the responsibility of realizing the real-time check to guarantee the wireless communication module is on the line.

4.2. Design of Wireless Communication Module

The wireless modem GR64 offers a broad range of data features. The intrinsic TCP/IP stack enables customers to make effective use of GPRS. Also it is configurable and possesses an extended range of input/output capabilities [12]. Thus GR64 modem is selected in this design.

GR64 is controlled by AT command sent from the controller of DGPS receiver to realize the login of GPRS network. The AT commands are sent in sequence as follows:

- AT+CGDCONT=1,"IP","CMNET"

Active the network and establish an account. Connect to GPRS network and the landing node is CMNET.

- AT*E2IPA=1.1

Activate the IP connection of the current network.

- AT*E2IPO=1,"58.213.4159.132",48665

Establish the connection of TCP, where 58.213.4159.132 is the address of the server and 48665 is the access number.

After the above AT commands are sent successfully, the server will respond CONNECT, which means that GR64 is connected to the center. Then transparent data transmission can be implemented by GR64.

4.3. Data Transmission Based on NTRIP Protocol

NTRIP stands for Networked Transport of RTCM via Internet Protocol which is a protocol designed especially for transporting the DGPS data stream or other kinds of GNSS data over the internet. There are three important components for a complete NTRIP system: NTRIP Caster, NTRIP Server and NTRIP Client [13]. NTRIP Caster is the actual HTTP server program while NTRIP Client and NTRIP Server act as HTTP client. In practice, NTRIP Caster is the control center for VRS to process the data. NTRIP Server is the reference station while the NTRIP Client is the rover station. The main purpose of NTRIP Server is to upload the corrections while NTRIP client is to download them. The rover station should communicate regularly with the server to get the source table and the GNSS data stream. Thus the request should be according to the message format by NTRIP protocol; otherwise, the desired result can't be realized.

In this design, the detail regular based on NTRIP protocol for the data stream to connect the control center is as follows:

- Establish the TCP/IP connection with NTRIP Caster of the data processing center;
- Declare the demand data stream node in the format of HTTP/1.1;
- Upload the name and the version of the client;

The message format is:

GET /<MountPoint> HTTP/1.1<CR><LF>

User-Agent: NTRIP GNSSInternetRadio2.0.10 <CR><LF>

Accept: */*<CR><LF>

<CR><LF>

Where, <Mountpoint> is NTRIP Caster mountpoint of the request source, GNSSInternetRadio2.0.10 is the name and the version of the client.

- After the request is authenticated normally, the server will respond "SOURCETABLE 200 OK". And then the source table will be followed.

The format of source table is as follows:

Server: GNSS Spider 4.2.1.4065/1.0 <CR><LF>

Date: Tuesday, 04 Sept 2013 03:41:35 GMT StandardTime<CR><LF>

Content-Type: text/plain<CR><LF>

Content-Length: 2425<CR><LF>

The detailed information of the source table will be followed which contains the data type and some explanation provided by the server.

- Send the ID and passwords of the user to get the authorization. The message format is:

GET /RTCM3.0 HTTP/1.1<CR><LF>

User-Agent: NTRIP GNSSInternetRadio 2.0.10 <CR><LF>

Authorization: Basic ABCDEF<CR><LF>

<CR><LF>

Where, ABCDEF means the ID and passwords. Moreover, it should be changed into the format of base64-coded string.

- Send the outline coordinate of the user in the format of GPGGA based on the NMEA to the server. Once the server receives and authorizes the message, it will respond "ICY 200 OK".
- NTRIP Caster will send the corrections in the format RTCM3.0 to the rover station.

The whole flow chart of this process is showing in Fig. 3.

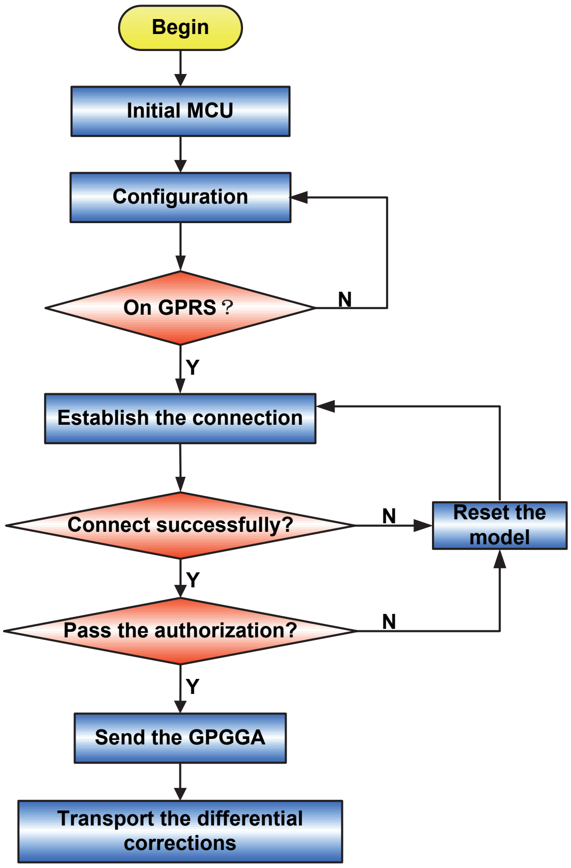

Fig. 3. Data Stream Processing based on Ntrip.

5. Experiment Result

The experiment test was carried out on a platform with an open sky. The rover receiver is installed at a site with a fixed coordinate and then records the output from the designed DGPS receiver.

5.1. Satellite Test

As we know, to ensure the high positioning accuracy, the number of the observable satellites should not be less than 4, thus the number of the observed satellites is tested. Fig. 4 shows the number of satellites visible during the test.

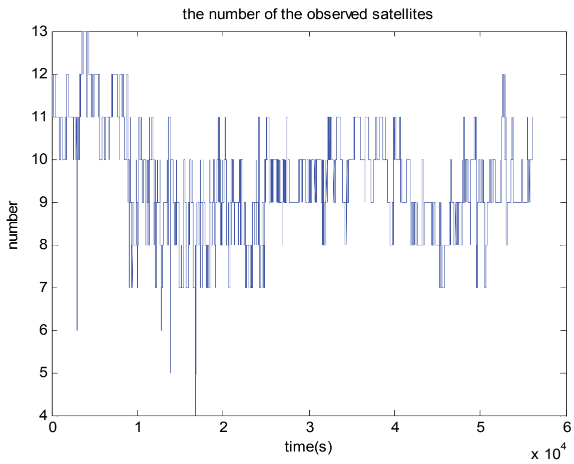

Fig. 4. Number of the observed satellites.

From Fig. 4, we can see that the number of the satellite is always more than 4 during the continuous observation. Thus the positioning output is credible and effective.

5.2. Precision Test

The continuous observation lasts more than 15 hours and there's no problem of connecting the GPRS wireless internet. Fig. 5 shows the positioning information recorded by the designed DGPS receiver.

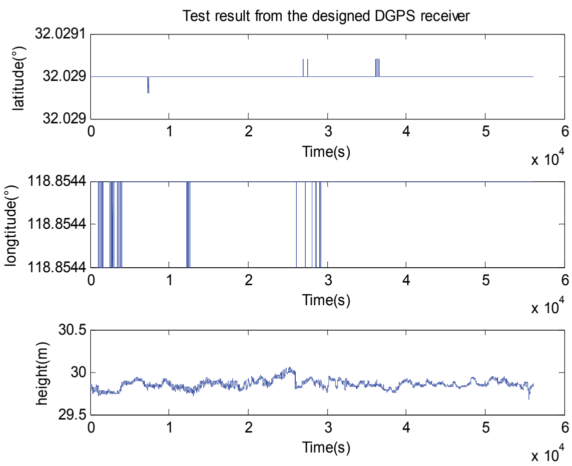

Fig. 5. Test result from the designed DGPS receiver.

In order to compare the positioning accuracy better, the single positioning result is also illustrated in Table 1. The first group of data is the result of the differential positioning system and the second group of data is the result of the single point positioning system.

Table 1. Results of the positioning systems.

Result		Mean Value	Standard deviation (cm)
Longitude	1	32.02905240°	1.460789
	2	32.02905845°	15.185080
Latitude	1	118.85443993°	1.997077
	2	118.85460106°	12.475833
Height (m)	1	299.41191859	0.07462909
	2	275.86782344	2.69946610

Compared with the results, Table 1 obviously shows that the differential positioning system has a higher positioning accuracy for longitude, latitude and height. And it can improve the positioning accuracy to the centimeter level.

6. Conclusion

In order to solve the problem that the existing products in the market can not satisfy the requirement of the embedded system, this paper introduces a DGPS receiver based on VRS. The principles of RTK and VRS for DGPS positioning are explained respectively, and then the design of DGPS receiver based on VRS is illustrated. The satellite test indicates that the system can work steadily. Comparing with the result of the single point positioning system, the designed differential positioning system can provide a high positioning accuracy to centimeter level. Moreover, there are multiple interfaces reserved for the need of other embedded systems.

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