The Hong Kong Satellite Positioning Reference Station Network (SatRef) – System Configurations, Applications and Services

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Key words: GPS, Reference Stations, CORS, Positioning Infrastructure

SUMMARY

The Survey and Mapping Office (SMO) of Lands Department of the Hong Kong Special Administrative Region has recently established a Continuously Operating Reference Stations Network System (CORS). The System which is now known as the 'Hong Kong Satellite Positioning Reference Station Network (SatRef)' has provided its services to users in Government Departments since June 2006 for the support of various kinds of surveying and positioning activities.

The SatRef System is able to collect GPS raw data continuously and provides round the clock (24X7) GPS correctional signals to users. The System services includes downloading of GPS raw data in RINEX format on Internet; real-time single-RTK, Network-RTK and DGPS data via GSM/GPRS mobile phone or Internet. Apart from GPS data delivery services, the System also provides an Automatic GPS Computation service to facilitate users to determine the positions they required by submitting their GPS observation data to the System. This article introduces the configuration, services and applications of the SatRef System.

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1. INTRODUCTION

With the widely use of GPS technique in recent years, many GNSS station networks (Continuously Operating Reference Station, CORS) are established in different places and countries all over the world. In general, the CORS networks have a specific system layout in which the numbers of stations are usually evenly distributed within their local areas.

After collecting a long period of GPS data at each reference station, the precise positions of the reference stations can be determined and become the geodetic framework of the area. Besides, the CORS network also serves as an infra-structure in some modernized areas to support the positioning, surveying and engineering applications by delivering different positioning and navigation data to users via mobile phone or Internet.

2. SYSTEM DESIGN

The Hong Kong Satellite Positioning Reference Station Network (SatRef) mainly consists of three major components; namely, Continuously Operating GPS Reference Stations, Data Centre and Control Centre (Ref. Diagram 1)

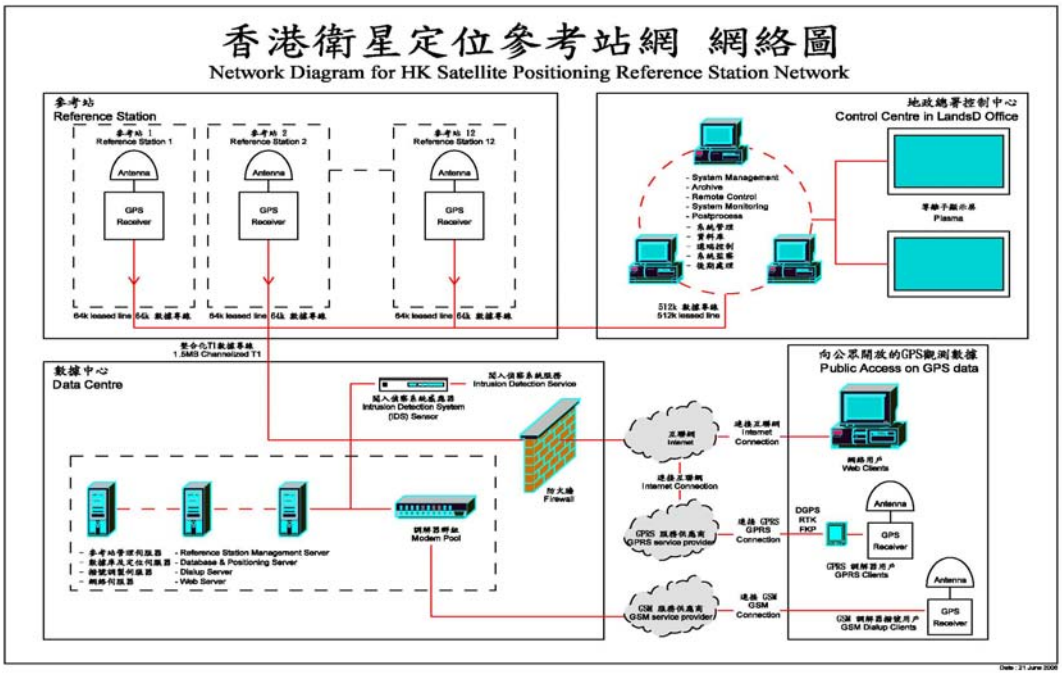

Diagram 1 – *Network Diagram of Hong Kong Satellite Positioning Reference Station Network*

2.1 Continuously Operating GPS Reference Station

The SatRef consists of 12 Continuously Operating Reference Stations (CORS) evenly set up in Hong Kong. 9 reference stations are built at hilltops in which each station has a 5m high concrete pillar and is surrounded by 8m x 8m protection fence to prevent vandalism. Lightning protection rod, various power surge protectors and a properly constructed earth grounding system are fixed in place to prevent equipment damage and service breakdown due to lightning. The other 3 reference stations are installed at roof-top of buildings in different locations. The reference stations are distributed at 10 to 15 km apart so that user can access to at least 2 stations within 10km in most areas in Hong Kong (Ref. Diagram 2)

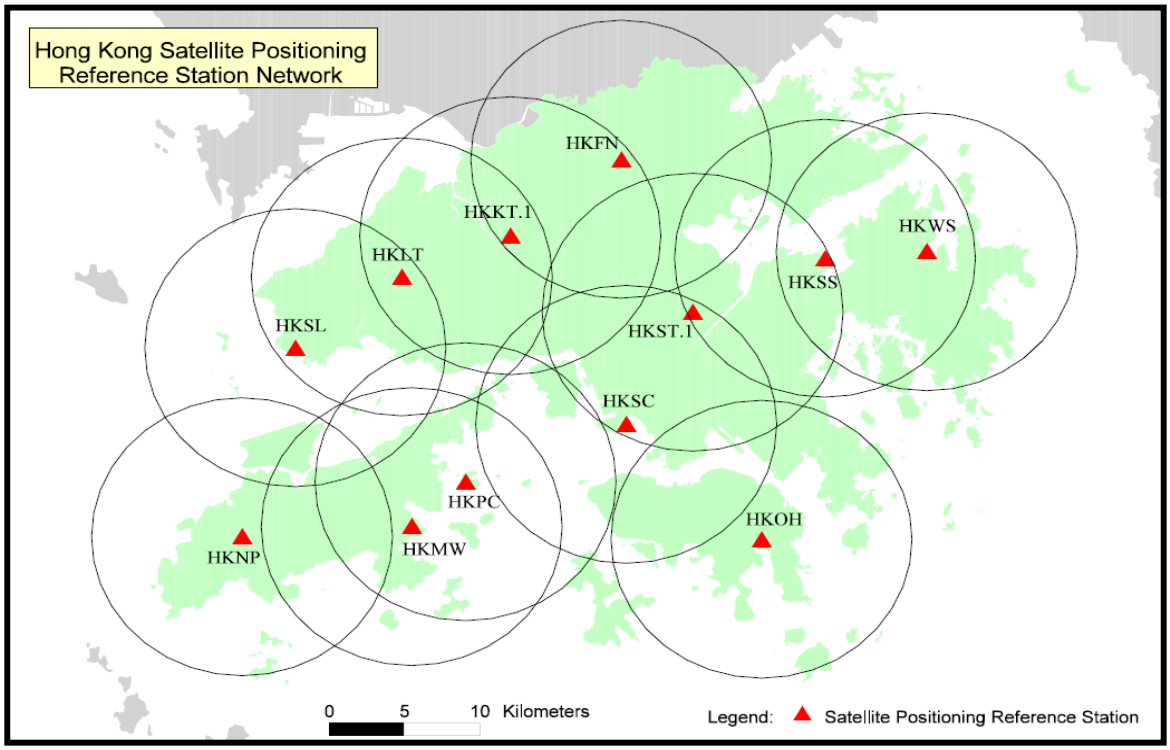

Diagram 2 – *Distribution of GPS Reference Stations*

Each reference station is installed with a dual frequency geodetic grade GPS receiver and a choke ring antenna to receive GPS signals comprising L1/L2 carrier phase and pseudo range codes. The data collection rate is fixed at 5 seconds (static) and 1 second (RTK).

Each reference station is installed with a Meteorological Sensor to receive the meteorological data (temperature, pressure and humidity) for atmospheric analysis purpose. Besides, each hilltop station is also installed with a Tilt Sensor to monitor the verticality of the 5m concrete pillar and to detect abnormal shift of the reference station. In addition, Uninterrupted Power Supply unit (UPS) is installed at each reference station to ensure the GPS receiver works continuously for four days if the main AC power fails.

About data transmission, routers are installed at the station to transfer the GPS, meteorological and tilt data to the SatRef Data Centre in TCP/IP via the 64K data line. Together, backup GSM modem will take up the role of data transmission from reference station to Data Centre should the transmission through data line fail.

2.2 Data Centre

The Data Centre is responsible for receiving, processing GPS data and delivery of positioning services. All these main functions of SatRef are shared by the Reference Station Management Server set, Database & Positioning Server set, Web Server set, Dial-up Modem and a Firewall installed in the Data Centre. Each of the server sets has a redundant unit running parallel as a backup system in order to ensure system high-availability. A customization program will detect the primary server operation status and it will immediately activate the backup server and continue the operation when the primary server fails.

2.2.1 Reference Station Management Server

The Reference Station Management Server remotely controls and manages the operation of CORS. There are a number of software installed in the Reference Station Management Server for handling different tasks. A power management software is used to monitor the operation of UPS and power supply of the reference stations. A reference station management software is used to download the GPS raw data, met data (including temperature, atmospheric pressure and relative humidity), and tilt data from each reference station at every 10 minutes interval.

If there is any fault in data transmission, the reference station management software will trigger the System to send alarm email to the system operator. If the data transmission is operating normally, the (Positioning Module) of the reference station management software will automatically compute the baselines between each reference station with its adjourning two nearest reference stations. The computed baselines will automatically input into a GPS data quality control software for graphical presentation of the computed results for the preliminary checking of the data integrity of the downloaded GPS data by the system operator. Moreover, the Reference Station Management Server also monitors the delivery of DGPS data.

There is another software to monitor the integrity of DGPS data. It downloads DGPS data from Stonecutters Island Station (or secondary stations from Fanling Station or Peng Chau Station) and then uploads to the DGPS Integrity Monitoring (IM) Station. The IM station will compute the differential result at once and will deliver it to the GPS data quality control software at Data Centre for graphical presentation and monitor the data integrity of the DGPS data.

2.2.2 Database & Positioning Server

The Database & Positioning Server has two major functions. The first function is to store the GPS data downloaded from reference stations. The System will download a total of 144 (6X24) nos. of 10 minutes RINEX data files from each station every day. These 144 nos. of 10 minutes file will merge into a single 24 hours RINEX file and stored in a designated folder for each station every day. The Database & Positioning Server stores the latest 90 days RINEX data files. Users can download the RINEX file in the last three months through Internet.

Second function of the server is to use a GPS positioning software to download the GPS raw data from each reference station via leased lines to model the GPS correctional data. With reference to the position of the user, it delivers real-time GPS correctional data to users for various positioning purposes. The positioning services of the SatRef System will be described in details in the following paragraphs.

2.2.3 Web Server

The Web Server with load-balancing function is used to authenticate user's identity; display product information and delivery of products and services. User can download the RINEX data of a specified time, date and reference station as defined by the user via Internet. Also, a commercial GPS processing software is installed in the Web Server to provide automatic GPS data computation service. Moreover, a Networked Transport of RTCM via Internet Protocol (NTRIP) broadcasting software, is also installed in the Web Server for effective dissemination of GPS data, such as DGPS and RTK on Internet to users by NTRIP technology. To obtain this service, users should use GPS receiver equipped with NTRIP function.

2.2.4 Dial-up Modem

The dial-up modem is currently able to support a total of 23 concurrent users to download RTK positioning data via GSM modem. If the demand of this service increases in the future, the modem can be expanded to support a maximum of 92 concurrent users. However, such transmission mode by GSM modem will gradually be faded out as it is anticipated that more users will tend to download the data by NTRIP.

2.3 Control Centre

The Control Centre and the Data Centre are located at different places of Hong Kong. The system operator sitting in the Control Centre is able to remote control, monitor and analyze the data of the entire System. In short, the Control Centre has five major functions, namely, management of power supply, data delivery, real-time baseline processing, differential computation and high-precision baseline processing. Two 50-inches plasma displays are installed in the Centre to display the operations of the System. One of them is to display the

status of reference stations and the other one is to display different components of the System and their operations.

The Control Centre is also responsible for archiving of historical GPS data files and using independent scientific GPS software to monitor the precise position of each reference station by using the GPS data collected everyday. If there is any problem detected during the system monitoring, the system operator is able to indicate or delete those data to ensure the data integrity. The historical GPS data of more than three months will be archived in CDs. The data will be provided to the users upon request.

2.4 Three Independent Integrity Monitoring (IM) Stations

The SatRef is responsible to deliver positioning data round the clock to users. In order to secure the data quality, it is necessary to install sufficient independent Integrity Monitoring (IM) stations for monitoring purpose. One IM station has been installed at the roof top of North District Government Offices and two more IM stations are being set up at Quarry Bay and Chek Lap Kok. These three IM stations integrated to form a plane such that the performance of SatRef covered by this plane can be effectively monitored. The IM stations will carry out RTK survey every second by using the network RTK correction data collected from the SatRef. By means of real time comparison of the RTK survey results with the known station co-ordinates, the SatRef system operator is able to keep track on the performance of the System.

3. COMPREHENSIVE SERVICES AND INFORMATION PROVIDED BY THE NETWORK

The SatRef provides comprehensive positioning services including static survey, DGPS, single-RTK and network-RTK.

3.1 Static Survey

The static survey is used for precise positioning in centimeter/millimeter level positioning work. Traditionally, user requires setting up at least two GPS receivers at the two ends of a baseline and use differential phase measurement of satellite data to cancel out or to mitigate the same error. Reference station network changes the traditional GPS survey operation. User requires only one GPS receiver to collect the satellite data and to download the GPS data from a nearest GPS reference station through Internet to form a baseline for high precision differential baseline processing. The System's web site provides a user-friendly interface for user to select the required reference station and time interval for downloading (Ref. Diagram3)

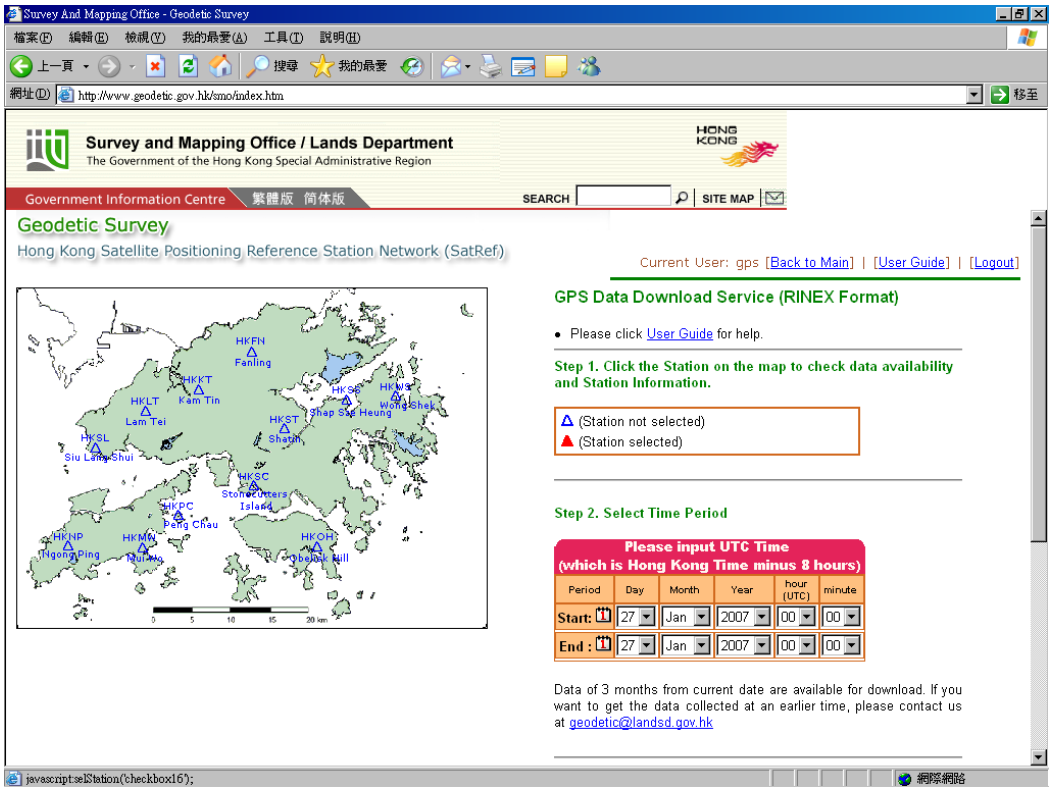

Diagram 3 – *Web Interface for Downloading of GPS Data in RINEX Format*

3.2 Differential GPS Positioning

DGPS positioning technology is based on the known geodetic position of the reference station and its collected GPS data, predicted orbit, atmospheric effect on the received data to compute the pseudo-range, range-rate of every satellite. Then, it uses RTCM file format to deliver the GPS corrected data to user. The SatRef also provides DGPS data to user. The Hong Kong Stonecutters Island Station located at the centre of the Territory is used as the primary station for processing the DGPS correction data. Another two rooftop stations, i.e. Fanling and Peng Chau stations will be configured as secondary stations. The precision of DGPS can be up to about 1 to 2 meters. The correctional data will be delivered to user for navigation or other Location Based Service (LBS) through Internet.

3.3 Network-RTK Positioning

The accuracy of positioning achieved by means of traditional RTK and DGPS will decrease with the increase in the distance between the reference station and the rover. To handle this problem, the SatRef System has applied the latest Network-RTK technique provided by a GPS positioning software to provide the Area-Corrected-Parameters, Flachen-Korrektur-Parameter (FKP) to users.

3.3.1 Flachen-Korrektur-Parameter (FKP)

The GPS positioning software uses the zero differencing processing technology, i.e. it uses the principle of un-differenced GPS Raw Data to determine the errors arising from the precise satellite orbit, atmospheric delays and shift of satellite clock. Through real time data analysis, the GPS positioning software is able to estimate the magnitudes of different errors and compute the individualized RTK correction with reference to the position of user (Ref. Diagram 4).

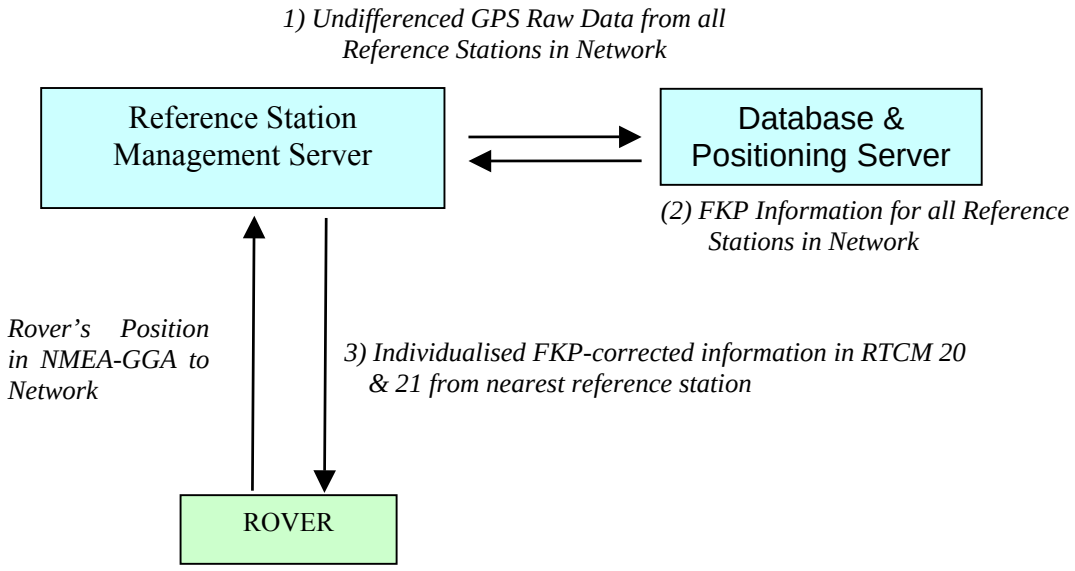

Diagram 4 – *Individualized Corrections Using FKP Delivery by Network*

There are two ways to deliver the FKP to user. Firstly, the FKP is incorporated in RTCM format for delivery to user (Traditional RTK information is stored in RTCM format of type 18, 19 or 20, 21 while FKP is stored as type 59). The rover shall install with the related programme for processing its corrected position upon receiving the FKP. Secondly, the System computes the Individualized FKP for the position of the rover. The RTK carrier phase correction and RTK/high accuracy pseudorange correction are stored as RTCM Type 20 & 21 formats for the user.

In considering of the user's GPS receiver, communication devices and the data standard, the System uses Individualized FKP as the data standard for delivery to users. Users can receive the FKP data delivery service by connecting to the Data Centre using GSM modem, GPRS modem with PDA, or direct from Internet through NTRIP.

3.4 Network Transport of RTCM via Internet Protocol (NTRIP)

The SatRef System is able to provide various positioning services to users. These services include ***static RINEX***, ***DGPS***, ***single RTK*** and ***network RTK***. User can download the RINEX at the Web of SatRef (www.geodetic.gov.hk) while the RTK/DGPS correctional data can be accessible by either one of the following three options:-

I. by using ***GSM dial-up*** + GPS equipment that would be able to process Network-RTK;
II. by using ***GPRS + PDA*** (with Mobile Windows 2003) + GPS equipment that would be able to process, DGPS, Single-RTK, Network-RTK;
III. by using ***GPRS/3G*** and get access to ***NTRIP***

However, there are limitations on the first two options. For above option (I), it limits to 23 concurrent users and needs advanced equipment for processing Network-RTK data. For option (II), there is no limit to the number of concurrent user but a PDA with GPRS communication device is needed.

Option (III) could be the most efficient and effective way. Users are able to obtain GPS correctional signal from the SatRef Web Server through NTRIP technique. To obtain this service, users shall use GPRS or 3G connection to the Web Server together with GPS receivers with built-in NTRIP client functions. To ensure the GPS correctional signals generated from the System can be transported to users effectively through Internet, an NTRIP broadcasting software is installed in the Web Server for effective dissemination of the GPS data to the users.

In theory, the SatRef can deliver the correctional data to almost unlimited number of users by means of NTRIP. The number of concurrent users is no longer limited to 23 as compared with the above option (I) GSM dial-up. Other additional accessory such as PDA in above option (II) would not be required as those new types of GPS receivers in the market have been equipped with NTRIP function.

3.5 GPS Data Automatic Computation Services

Apart from the above positioning data services, a commercial GPS processing software is also installed in the Web Server to provide automatic GPS data computation service to users. Users can upload the observation data in RINEX format to the System via the Web Server. The System will automatically select 3 nearest GPS reference stations or using the 3 GPS reference stations selected by the user for baseline processing. After computation, the System will send the computed co-ordinates of the observation data together with a computation report to user through email.

4. REQUIRED EQUIPMENT FOR USERS

Users may gain access to various positioning data services provided by the "Satellite Positioning Reference Station of Hong Kong" via GSM/GPRS mobile phone networks or Internet. Users working on static high-precision positioning need only a dual-frequency GPS receiver for geodetic survey purpose to gather GPS data at the precision level they want over a certain period before they are connected to the SatRef system website for selecting two or more nearest reference stations for the downloading of RINEX data of corresponding time and date. With the downloaded data, user can use ordinary GPS data processing software to process the baseline information and obtain an accurate positioning provided that the GPS software is capable of processing information in RINEX format.

In respect of real-time kinematic (RTK) operation by GSM dial-up method, users should be equipped with a dual-frequency GPS receiver which can handle output of position data in NMEA GGA format and support data in Type 20&21 formats (RTCM version 2.3) together with a GSM modem fitted with a mobile phone SIM card. Users need to register their mobile phone numbers with this system before they can dial-up to our system. The GPS receiver can make use of the 2-way data transmitting function of GSM network to upload the position data of the users to the system or download the high-precision individualized Flachen-Korrektur-Parameter (FKP) real-time positioning service from the System.

Apart from dialing-up with a GSM modem, users are able to obtain GPS correctional signals from the IP address and Port Number of the SatRef NTRIP services via Internet. Users may make use of a GPS receiver equipped with NTRIP function to connect to SatRef via GPRS/3G for collecting real time Differential GPS (DGPS), Single-base RTK from designated reference station or Network–RTK data. Some new models of GPS receivers have default setting for receiving GPS correctional signal direct from Internet (with appropriate GPRS/3G SIM card for connection to Internet).

5. FUTURE DEVELOPMENT

5.1 Missions under the Geodetic Datum Framework

Traditional astronomical geodetic stations and trigonometric control stations require enormous resources to establish and maintain. Moreover, their precision is limited by factors like geographic environment, disposition of the stations, survey instruments and observation technologies. Therefore, the Continuously Operating Reference Station (CORS) of the Global Navigation Satellite System (GNSS) has an obvious advantage in playing the role in geodetic datum framework. It lays the foundation of a high-precision geodetic framework covering the entire territory of Hong Kong, thus reducing the number of core geodetic stations to be maintained. And with the aid of GPS technology, its reference stations provide satellite positioning data to users spontaneously, maintain direct contacts with various levels of control survey and thereby thoroughly enhancing their efficiency and ensuring their precision.

5.2 Improving Real Time Positioning Technology, Widening the Range of Services

Although Network-RTK technology applied by the Reference Station Network is more accurate and reliable than the traditional RTK, it still has certain shortcomings. FKP contains model data output rather than the raw data of GPS. The model data contain certain proprietary information such as satellite clock biases evaluation, ionosphere models, tropospheric delayed parameter of district and individual station networks and their rate of change, etc., and all these information are not disclosed to mobile station users.

Real time positioning users can only obtain a set of parameters, and have no access to individual parameters of various kinds of biases. As for GPS receivers, single-frequency and dual-frequency receivers process ionospheric biases in different ways. Single-frequency receivers adjust biases by ionosphere models while dual-frequency receivers can adjust biases via the use of the dispersiveness of ionosphere to different frequency signals. The current system can only disseminate data in accordance with the single amended parameter provided by the commercial software.

Furthermore, as single-frequency receivers are much cheaper than dual-frequency receivers, if the station network can provide a group of amended parameters more fitting with the needs of single-frequency receivers, such that single-frequency receiver users can make use of the services provided by this station network to conduct high precision survey at centimetre level, this station network will be able to widen the range of services in a more effective manner.

The RTCM 2.3 Version information format currently used by the station network is already more concise than the former 2.0 Version. The 64 KHz GSM radio service is also sufficient for transmission of the data required. With the boarding of the radio service bandwidth and the further alignment of the format of data transmission by RTCM, a station network in continuous operation will provide the users with more detailed information for their multipurpose applications.

5.3 Matching and Being Compatible with Other Commercial Spatial Navigation Systems

Given that there must be a two-way information communication link between our station network and the users, if we want this system to be the positioning infrastructure of Hong Kong, its facilities and services must be able to cope with a large number of users. However, this will create tremendous pressure on the communication facilities of the station network. To resolve this problem, we must consider matching it and making it compatible with other commercial spatial navigation systems. We must make use of the platforms and professional knowledge of the wireless telecommunication networks to create a multipurpose positioning infrastructure to serve the public.

CONCLUSION

From the traditional geodetic survey to the establishment of a continuous satellite positioning station network, not only the surveying techniques have been changed (from two receivers of the traditional GPS to one receiver), but also, the passive mode of operation of shriving to maintain the astronomical geodetic networks and control stations in good conditions for ready use has also been changed to taking the initiative to provide the users with real-time positioning information service. Therefore, continuous reference stations are also called active stations.

Positioning information appears in front of users through common wireless telecommunication networks. Along with the advent of high-speed broadband WiFi/WiMAX wireless technology and the improvement of network RTK technology, continuous satellite positioning station network will have more room for development with a view to providing the users with more accurate, more speedy and more user-friendly positioning services.

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BIOGRAPHICAL NOTES

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