The Hong Kong GPS Network and Reference Stations

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Abstract

The Lands Department of Hong Kong SAR government has established a GPS network and is establishing an array of GPS reference stations to facilitate application of GPS. The GPS network links GPS measurement to the Hong Kong Spatial Reference System. It defines the reference frame for GPS positioning.

The reference station array forms the Hong Kong active control system. It collects GPS data continuously from multiple reference stations and delivers quality-checked data to the users. The well-positioned and dense array of Active Control Stations enable the users to achieve cm-level accuracy within a short period of time even using only one low-cost single frequency GPS receiver. There is no need to send people to set up equipment at the base stations. This is a great advantage for high precision survey-grade GPS applications because it reduces both labour cost and equipment investment significantly.

The active control station also support meter-level navigation and transportation management applications using DGPS correction. The array of permanent GPS stations can be used for scientific research such as studying deformation of the earth, predicting earthquake and weather forecasting. It can be used for improving the environment and mitigating the damage caused by natural disaster.

1 Introduction

Global Positioning System (GPS) technology has advanced significantly during the past decade. The accuracy of positioning is improving, the equipment is reducing in weight and size, the software has improved functionality, the system is more users friendly, and yet the cost of GPS is reducing. GPS is gaining wide acceptance in Hong Kong and its application is flourishing.

Being the agency responsible for Hong Kong's horizontal and vertical positioning reference system, the Geodetic Survey Section of Lands Department has developed a GPS infrastructure to facilitate application of GPS technology to bring social and economic benefit to the society. This paper gives an overview of the evolution of Hong Kong GPS network, the establishment of GPS reference stations and the active control system, and applications making use of the GPS infrastructure.

2 Hong Kong Spatial Reference System

The Hong Kong spatial reference system is the positional reference infrastructure. It unifies the coordinate system used for the determination of position. The Hong Kong spatial reference system consists of three components. The triangulation and traverse network defines the local horizontal grid system (Hong Kong 1980 Grid). The benchmark network defines the local height system (Hong Kong Principal Datum). The GPS network defines the three dimensional global reference system for GPS survey. The establishment and maintenance of the spatial reference system are the responsibilities of the Geodetic Survey Section of Lands Department.

A common spatial reference is the key for uniquely defining the position of social activities. If there is no common coordinate system, the absurd situation of building a public road in a private

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property may arise. In order to support social and economical development, the geodetic network is continuously evolving. The early triangulation of Hong Kong was done in 1845. The standard and accuracy of the system is continuously improving throughout the last decades. Major re-triangulation work was done in 1963 to provide control for aerial mapping of the territory. The network was further strengthened in mid 70s for building the Mass Transit Railway.

In late 70s, electronic distance measurement offered great accuracy improvement. The main geodetic network was re-surveyed by trilateration using EDM. The result of trilateration survey is the Hong Kong 1980 Grid. This local grid system has been used, since then, for defining horizontal position for land surveying, construction works, environmental protection, town planning, law enforcement and many types of position related activities in Hong Kong.

3 The 1991 GPS Network

The first regional GPS network of Hong Kong was surveyed in 1991. The survey task was a cooperation project jointly conducted by the British forces, the Hong Kong Government and the Macau Government. The GPS observation and network adjustment was carried out by the 512 Specialist Team Royal Engineers (STRE).

In Hong Kong, World Geodetic System 1984 (WGS84) coordinates of 15 stations were observed. Among these stations, 13 stations were the existing main triangulation stations. Four of them were also fixed by satellite doppler positioning. In Macau, WGS84 coordinates of 6 stations were observed. Two of these stations were the existing Doppler stations.

The Hong Kong GPS network was established using the absolute position of Doppler stations as origin. It defined the reference frame for GPS survey conducted in Hong Kong. The Geodetic coordinates of GPS stations fixed in the 1991 GPS survey are called WGS84 coordinates based on STRE91 reference frame, simply WGS84 (STRE91).

The 1991 GPS survey results provided parameters to link Hong Kong local datum to WGS84 datum. Using WGS84 coordinates and Hong Kong 1980 grid coordinates of 12 triangulation stations, we can transform GPS defined position to local grid system and vice versa.

4 The 2000 GPS Network

Most of the stations of the 1991 GPS network were main triangulation stations situated at the top of high mountains. It was difficult to access these stations. In order to reduce logistic cost and travelling time, the Geodetic Survey Section established more GPS stations on low ground and at places where vehicular access was available.

The densified network consists of 46 points covering the whole territory as shown in Figure 1. The average station spacing is about 10 km. The coordinate values of the network shall be ready for publication in the year 2000. We call the new network as the 2000 GPS network.

The average relative accuracy of the 2000 GPS network is 0.2 ppm. From the results of the 2000 GPS network, we found that there is a 1 ppm scale error in the 1991 GPS network. Similar scale bias is also found when we compared the 1991 GPS network with the results of Hong Kong – Shenzhen Joint GPS survey done in 1997 for the determination of the Hong Kong Special Administrative Region administrative boundary.

The 2000 GPS network is more accurate than the 1991 network because throughout this decade there are improvement in GPS receiver hardware and processing software. Another reason for the improved accuracy is that during the 1991 survey the satellite window was limited. Full constellation of the Navster satellites was not available before 1994.

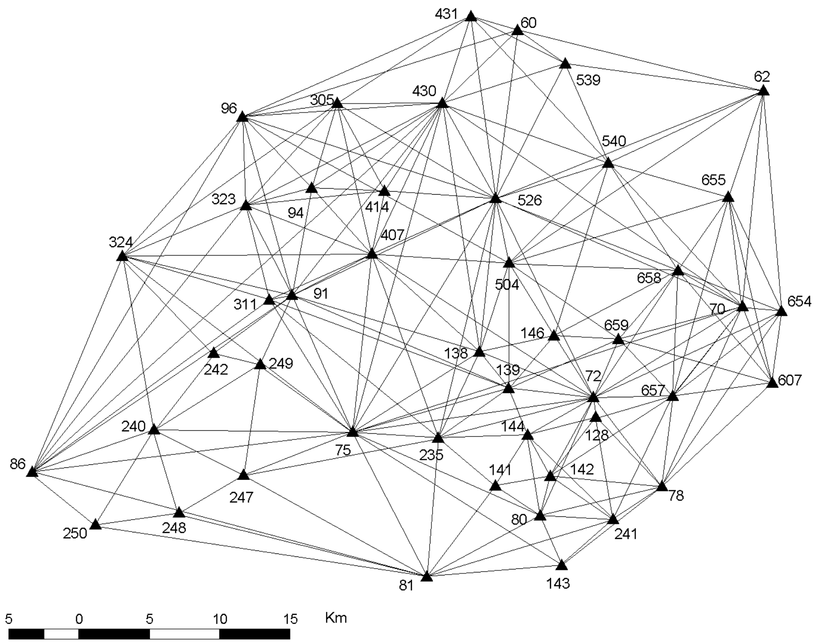

Figure 1 The 2000 GPS Network of Hong Kong

5 WGS84 (STRE91) and ITRF96 Reference Frame

The global absolute positional reference of the 1991 GPS Network was based on the WGS84 geodetic datum. WGS84 is a geocentric datum and the origin of coordinate axis is situated at the centre of the earth. Establishing a datum has the effect of defining the centre of the ellipsoid or practically, the centre of the earth mass. At the time of 1991 when STRE carried out the Hong Kong GPS survey, WGS84 datum was realised by defining the coordinates of the ground tracking stations using Satellite Doppler positioning measurement, which can achieve 1 to 2-meter absolute accuracy [Bock, 1996].

Since 1994, the International Earth Rotation Service (IERS) implemented the International Terrestrial Reference Frame (ITRF). It defined the set of coordinates of global GPS tracking stations using a combination of space techniques such as GPS, Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), and Doppler Orbitography Range Integrated by Satellite (DORIS). IERS publishes the solution of ITRF annually. The accuracy of ITRF solution is at cm-level.

As the ITRF system realises the geocentric system more accurately than the WGS84 reference frame, the International GPS Service for Geodynamics (IGS) has used the ITRF system as the datum for the precise orbit. The Defense Mapping Agency of USA has improved the original WGS84 reference frame to be compatible with the ITRF. Nowadays, the broadcast and precise ephameris are in fact based on the ITRF system. Many countries have used ITRF as the global reference frame for their geodetic network.

The reference frame of Hong Kong’s 1991 GPS network (i.e. WGS84 (STRE91)) has a bias of about 0.05m in North, 0.3m in East, and 1.5m in Up when compared with the ITRF system. In order to improve the global positional accuracy of the Hong Kong network, the 2000 GPS network was connected to the ITRF96 reference frame. The ITRF96 system was implemented using 290 GPS sites and 47 global permanent GPS stations around the global. 40% of the stations has positional uncertainty below 1cm [Neilan, 1998].

The connection of the Hong Kong GPS network to ITRF96 was established using two months continuous GPS observation (April and May 1998) taken at the Kai Yi Chau and Fanling permanent GPS reference stations in Hong Kong and six other IGS GPS global stations; namely

Cocos Island in the Indian Ocean, Guam in the Pacific Ocean, Lhasa in Tibet, the Shanghai Observatory in Eastern China, Tsukuba in Japan and Yarragadee in Western Australia. Figure 2 shows the connection of Hong Kong to Six IGS Stations.

Computation of the ITRF96 coordinates of the Hong Kong reference stations were carried out by the Hong Kong Polytechnic University under a consultancy service for the Lands Department. The baseline length of the connection survey ranged from 1200 km to 5500 km. The accuracy of the ITRF96 coordinates determined in this survey is estimated to be better than 2 cm [Chen, 1999].

Having desified the local GPS network and connected it to the ITRF global reference frame, the Geodetic Survey Section has upgraded the local GPS network which is more accurate, reliable and accessible. The Hong Kong 2000 GPS network shall be the GPS reference datum for future GPS survey in Hong Kong.

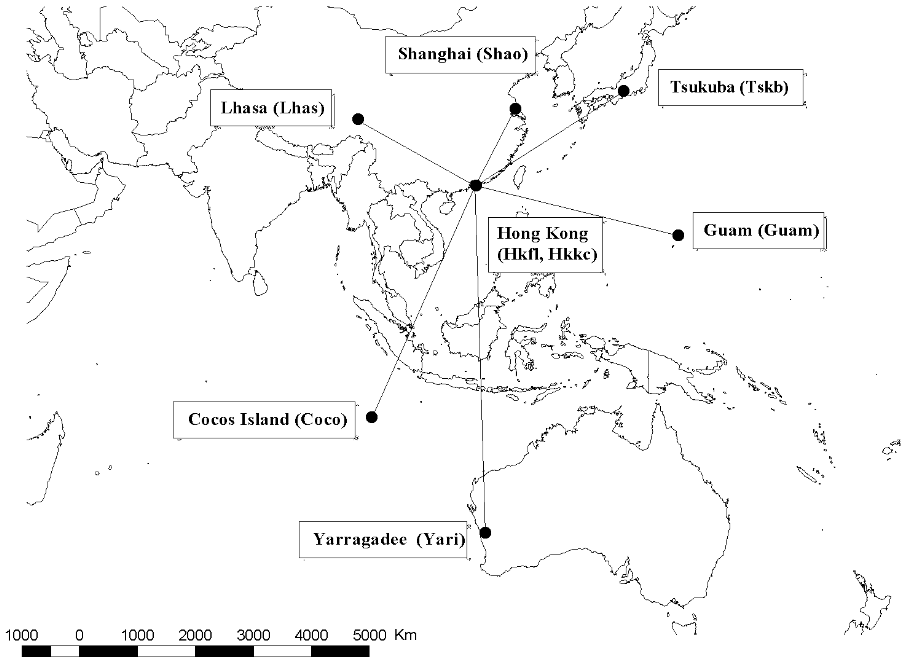

Figure 2 Connection of HK to 6 IGS global stations for linking the local datum to the ITRF system.

6 Existing Permanent GPS Reference Stations

Single point GPS positioning using one GPS receiver can only achieve an accuracy of 50m - 100m which cannot meet the requirement of most precise surveying task and navigation applications. The accuracy can be improved significantly to 5m using differential GPS (DGPS) technique. Relative positioning using carrier phase measurement even can measure position accurate to cm-level. In order to implement relative positioning effectively, a permanent GPS reference station operating continuously as a base station is necessary.

At present, there are two permanent GPS reference stations operating in Hong Kong. One of the permanent stations is located at Kai Yi Chau. It was commissioned in 1996. The GPS antenna is situated at the main triangulation monument (trig. 75) at the top of the Island. This station is operating by the Marine Department. DGPS correction signal is broadcasted to Mariners for navigation of vessels in Hong Kong waters and its vicinity. GPS measurement in RINEX format is also collected at this station for post-processing applications.

Another permanent GPS station is located at Fanling. It is operating by the Lands Department since 1997. Pseudorange and carrier phase measurements are collected for high precision land surveying applications. Users can download L1/L2 GPS data in RINEX format from the Fanling permanent GPS reference station.

Continuously operating GPS reference stations provide great benefit to the users. They do not have to set up their own reference station for high precision relative positioning. The users do not need to buy additional GPS reference station equipment, and there is no need to send people to set up receivers at the base stations. Therefore, the equipment and labour cost are reduced. The production efficient is also improved.

Although we already have two permanent GPS reference stations in Hong Kong, there is still a need to increase the number of permanent stations in order to exploit the benefits offer by GPS fully.

The Marine Department's Kau Yi Chau reference station is now broadcasting DGPS correction signal using marine radio beacon frequency band (289 KHz) which is most suitable for signal transmission in the coastal area and at sea. However, this frequency is not the optimum for signal transmission on land. There are areas in Hong Kong where ground noise is high and signal reception is poor. In order to support land mobile navigation, another permanent station broadcasting DGPS signal through wireless communication for land users is necessary.

The Lands Department's Fanling permanent station is primarily designed for land surveying application using post-processing data. However, only the Fanling station, and even together with the Kau Yi Chau station, are not always sufficient to form a good geometric pattern of control stations for high precision survey with cm-level accuracy. The users still have to setup equipment at the nearby GPS control network monument. If more permanent stations are evenly distributed all over Hong Kong, the users can use GPS data from multiple reference stations of the GPS infrastructure. What they have to do is just operating a single GPS receiver at the site where they are working. The cost and time for setting up their own base stations can be saved.

7 Active Control System – The Hong Kong GPS Reference Station Array

Lands Department is implementing a project to extend the scope of the existing permanent GPS reference stations. The aim is to develop an active control system for Hong Kong. The Active Control System consists of a array of continuously operating GPS reference stations. The station spacing is about 10 to 15 km. There will be 13 to 14 stations covering the whole territory. The preliminary layout of the Hong Kong Reference Station Array is shown in figure 3.

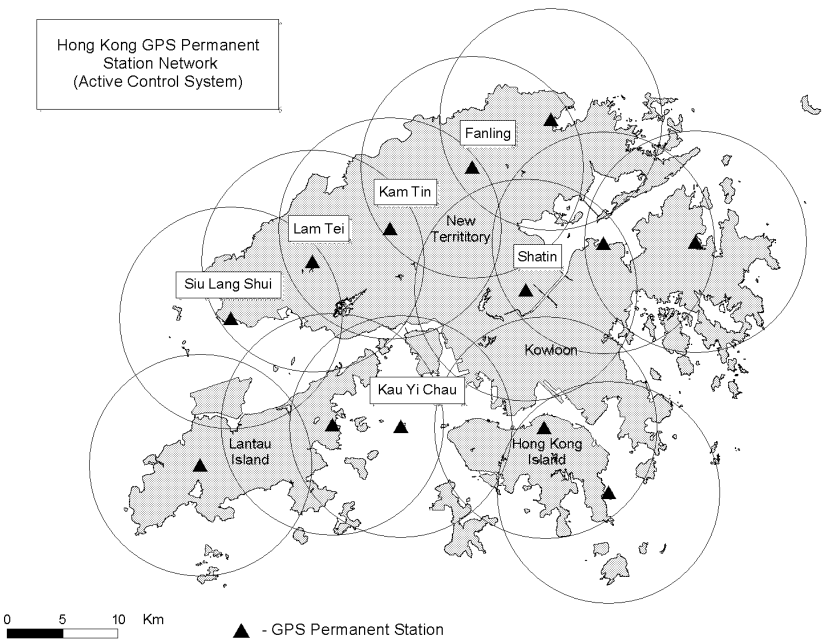

Figure 3. Preliminary layout of the Active Control System. This diagram shows distribution of the GPS Reference Stations and the 10 Km radius of each station.

The network design principle is based on the objective that a mobile GPS receiver, at most areas of Hong Kong, can measure baselines to at least 2 permanent GPS reference stations which are less than 10 km away. There are two advantages for this type of configuration. First, the surveyor can use single frequency receiver to achieve cm-level accuracy by fast static survey. It only needs a short period of observation time and without using the more expensive dual frequency receiver. It reduces equipment cost and operation time. Second, the reference station can be used as a base station for kinematic survey (either post-processing or real time survey) without lost of accuracy due to increased distance from the base station.

The Active Control Station is a permanent GPS observation station, which collect GPS data continuously 24-hours every day. Figure 4 shows the components of an Active Control Station. The station has an antenna pillar firmly fixed into the ground. The choke ring antenna is mounted on the pillar and protected by a radome. The tilt sensor measures the tilt motion of the pillar and detects any small positional change due to pillar movement. The meteorological sensor measures temperature, pressure and relative humidity of the atmosphere.

The GPS receiver and communication equipment are stored in a weatherproof and vandalism-resistant equipment cabinet. The equipment cabinet is temperature-controlled to ensure the equipment is functioning even at hostile environment. There are backup batteries to keep the system running for 7 days in case of A/C power failure.

As the station is located at high ground in order to have good sky window for GPS signal reception, it is under a constant threat of being struck by lightning. Therefore, there is a lightning protection device to protect the monument pillar and the antenna. The system also has lightning arresters to protect all the power connections, data communication port and telephone lines.

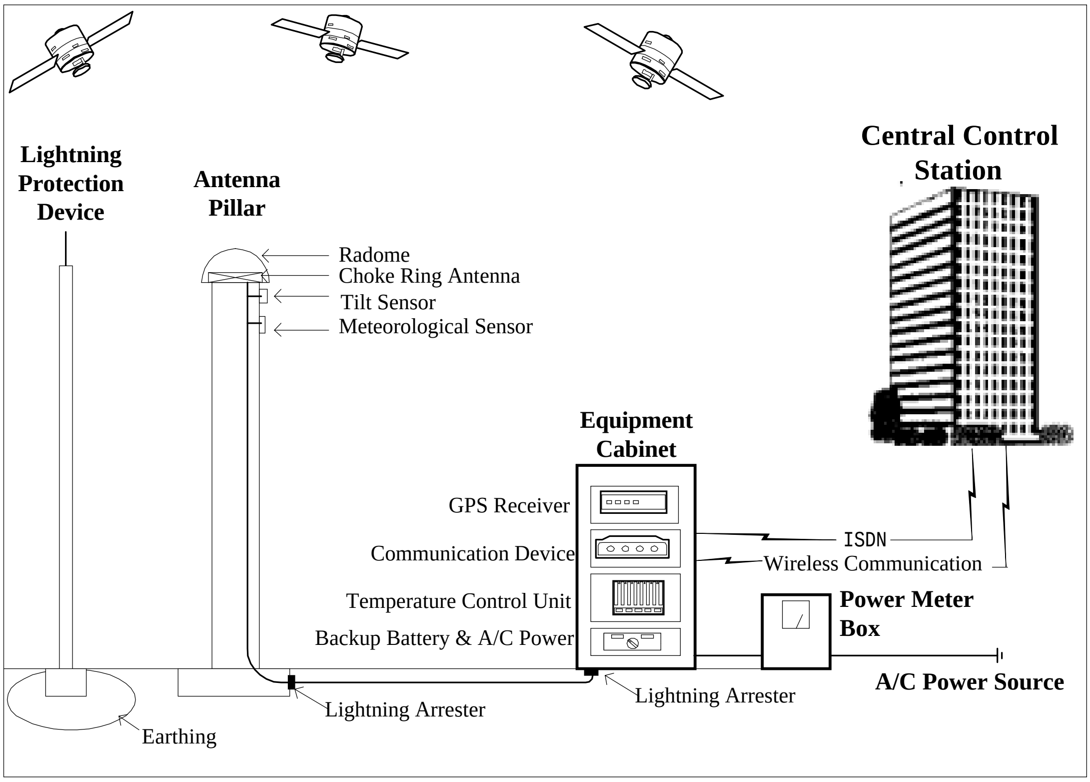

Figure 4 Schematic diagram of the Permanent GPS Observation Station ***(The Active Control Station)***

The collected GPS and meteorological data are sent to the Central Control Station via telephone line or GSM mobile phone. The data transmission from the GPS Observation Station to the Central Control Station is fully automatic at predefined interval.

The heart of the Active Control System is the Central Control Station. Figure 5 shows the linkage between the Central Control Station (CCS) and the GPS Observation Stations. The Communication Unit at the CCS can remote control the equipment at the GPS observation station. This provides great saving of system maintenance cost as the need for sending service engineers to the remote site is greatly reduced.

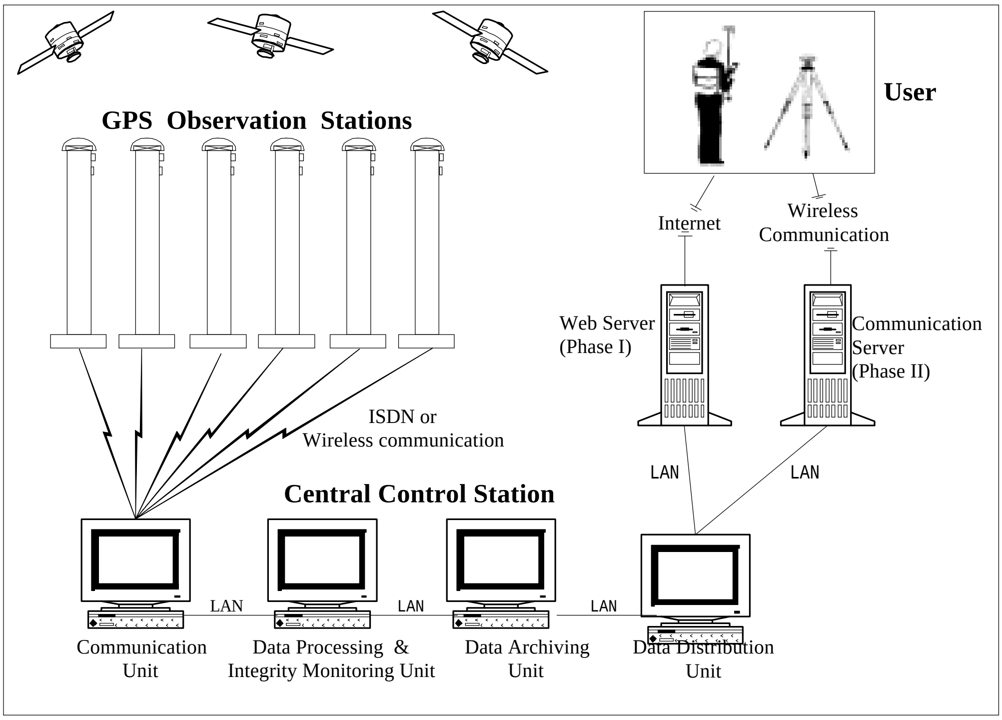

Figure 5 Configuration of Hong Kong GPS Permanent Station Array (Active Control System)

The Integrity Monitor checks the operation of GPS Observation Stations and the quality of the data collected. The system regularly checks three critical performance and reliability indicators. First, does the data being collected and transmitted to the central control station? Second, is the data quality acceptable? Third, has the position of the permanent station been moved due to vandalism or graduate ground deformation? The central control station will not send bad data to the users if the system fails to pass the integrity check.

After quality checking, the data are stored in the data archiving unit. The implementation of the active control system is carried out in two phases. For the phase I of the project, the system deliveries data to users through Internet. In the Phase II of the project, we plan to deliver GPS data to mobile users in the field through wireless communication.

The Phase I project consists of six stations covering the northwest areas of the territory. The sites are Fanling, Shatin, Kau Yi Chau, Siu Lang Shui, Lam Tei and Kam Tin (see Figure 3). The phase I site will be implemented in early 2000. In the Phase II project we shall set up 7 to 8 more Active Control Stations to cover the remaining area of the territory. The Phase II system will be implemented in 2002.

8 Products and Services

The Active Control System provides three kinds of products. Namely, first, GPS observation data in Receiver Independent Exchange (RINEX) format. Second, Differential GPS (DGPS) correction signal in Radio Technical Commission for Maritime Service Special Committee 104 (RTCM SC-104) format. Third, Meteorological data (temperature, pressure, and humidity) collected at the active control stations.

The RINEX data file containing L1 and L2 frequency pseudo-range and carrier phase measurement. These data are particularly useful for users to define position with centimeter-level accuracy. The survey mode can be static, fast static and kinematic. Users can post-process their own GPS data collected at the rover together with the GPS data downloaded from the active control system. Typical applications using RINEX GPS data are listed in table 1.

Table 1 Typical applications using RINEX GPS data

Type of Application	Potential Users	Mode of GPS Survey
Geodetic Control Survey	● Geodetic Surveyors	static, fast static
1.Topographic Mapping 2. Boundary Survey 3. Engineering Survey	● Land Surveyors ● Engineering Surveyors	fast static, kinematic, (can work together with Total Station to increase productivity)
Data collection for Geographic Information System	● Environmentalist ● Engineers ● Land Developers ● Foresters	kinematic (can work together with laser range finder to increase productivity)
Determination of position for law enforcement	● Town Planners ● Environmental Protection Officers	fast static, kinematic
Monitoring of movement of structure	● Structural Engineers ● Architect	static
Detection of earthquake and ground deformation	● Geotechnical Engineers ● Geophysicist ● Scientist	static

Table 2 Typical applications using RTCM DGPS data

Type of Application	Potential Users	Mode of communication and data processing
1. Fleet management 2. Command and control system (The mobile users (rover) do not know their real time position on board the vehicle).	● Police ● Fire Services ● Ambulance deployment ● Bus and Taxi company	Invert DGPS ● Raw GPS data of the rover is transmitted to the data center whenever it is needed. ● DGPS correction from the Base station of the Active Control System is transmitted to the data center. ● Corrected user position is computed at the data center.
1. Navigation 2. Real time position fixing 3. Real time data collection for GIS application (The mobile users (rover) know their real time position on board the vehicle).	● Drivers ● People who want to know their real time position	Direct DGPS ● DGPS correction from the Base station of the Active Control System is transmitted to the rover ● Corrected user position is computed at the rover.

The Differential GPS (DGPS) correction signal are the pseudorange correction and the range-rate correction for each of the satellite in the sky view of the ground reference station. The types of application can be categorized into two major groups; namely, Direct DGPS (base-to-rover communication) and Invert DGPS (rover-to-base communication). The applications are shown in Table 2.

The Meteorological data are the precise surface temperature, pressure and relative humidity measured at the ground GPS stations. The meteorological data together with the time delay of GPS signal caused by the atmosphere can be used for weather forecasting and research study of the atmosphere. The applications using GPS meteorology are shown in Table 3.

Table 3: Typical applications of GPS meteorology

Type of Application	Potential Users	Principal
1. Short term (0-24 hours) precipitation forecast (GPS meteorological data can perform the function of water vapour radiometry even under heavy rainfall or in the presence of heavy cloud) 2. Research in atmospheric model (The territory-wide GPS reference station network provide data covering a wide area and the data are collected 24-hours continuously)	● The Observatory ● Scientist	Time delay of GPS signals are used to estimate the amount of water vapour in the atmosphere

9 Conclusions

The 2000 GPS network and the active control system are the GPS infrastructure that link GPS fixed positions to the Hong Kong spatial reference system. The Active Control Stations collect GPS data continuously from multiple reference stations and deliver quality-checked data to the users. The well-positioned and dense array of active control stations enable the users to achieve cm-level accuracy within a short period of time even using only one low-cost single frequency receiver. There is no need to send people to set up equipment at the base stations. This is a great advantage for high precision survey-grade GPS applications because it reduces both labour cost and equipment investment significantly.

The active control system also support meter-level accuracy applications such as navigation and transportation management. However, in the phase one project, the active control system does not broadcast DGPS correction data directly. We are identifying options for delivering DGPS correction through wireless telecommunication means.

The array of permanent GPS stations can be used for scientific research, such as monitoring of the Earth surface deformation and weather forecasting.

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