Macao Geodetic Infrastructure: Permanent GPS Reference Stations

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Key words: GPS Reference Station, Geodetic Infrastructure, Macao DSCC, RTK.

SUMMARY

The first Macao GPS control network was surveyed in 1991 that consists of six Doppler stations. It was a jointly project conducted by the British forces, the Hong Kong Government and the Macao Government. In 1994, Macao regional GPS network with 14 control stations was established and provides transformation parameters to link Macao local grid datum to WGS84 datum. The rapid development of Macao urban constructions and the changes in environment conditions have increased the difficulties to conduct a traditional triangulation survey in Macao. In this case, Cartography and Cadastre Bureau (DSCC) of Macao SAR Government are putting more efforts on the use and development of GPS technology. In 2002 and 2005, two permanent GPS reference stations were built respectively to support GPS static survey and Real Time Kinematics (RTK) survey. This paper will give an overview on the evolution of Macao GPS Network; describe the infrastructure of the reference system, the state of applications, and share the result of some investigations regarding the use of different transmission methods and the reception of GPS signals in Macao. Macao is a small city of just 28.2 km^2, and it could probably serve RTK users very well with two reference stations, however the atmospheric condition will affect coordinate quality and the extent of use of RTK. This paper will indicate the necessity to construct a third GPS reference station in Macao to form a Network RTK, thereby giving directions on the future development of GPS technology in Macao to tread behind the significant modernization of GNSS.

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1. THE DEVELOPMENT OF MACAO GEODETIC SYSTEM

The Macao Government Cartography and Cadastre Bureau (DSCC) initiated the process of GPS development in Macao since 1981. Two triangulation control points were surveyed with GPS technology by the "512 Specialist Team Royal Engineers (STRE)" British forces of the Hong Kong Government. Their coordinates under WGS72 reference frame were established and they were then registered as Doppler Stations. It was not until 1991 that the first GPS network of Macao, based on WGS84 reference frame, was finally built, four more triangulation points were included to accomplish a joint survey with Hong Kong control points. In 1994, a regional GPS network with 14 control stations was established in Macao and come with a set of transformation parameters to link Macao local grid datum to WGS84 datum. This set of parameters are still using in today's survey work. With this foundation, different survey applications were performed, like carrying out static and rapid-static GPS survey in the Macao Airport area (Chan, 2002).

By the end of the 90's, the changes in the urban environment conditions increase difficulties to conduct traditional triangulation survey in Macao. According to the database from Macao Meteorological and Geophysical Bureau (http://www.smg.gov.mo/ccaa/iqa/fe_iqa.htm), the average air quality index of Macao raised from 32.7 in 1999 to 48.7 in 2006, and in 2004, the value is over 50, which belongs to a "Moderate" condition (0~50 is "Good" condition"). The environment visibility is low and the line of sight condition between triangulation control points is getting worst. In addition, as the area of Macao has gradually increased as a result of continued land reclamation, GPS technology has becoming more valuable especially in areas that lack of traditional control survey points. Since 1995, more than a hundred control points in Macao have been carrying out GPS survey. As the time-to-ambiguity fix improved, we also started to apply RTK (Real Time Kinematics) survey in 1999 to obtain real time centimeter level accuracy positioning for short baselines.

Macao is a small city with area of just 28.2 km^2, and comprises of the Macao Peninsula, Taipa Island and Coloane Island. It extends 7 km from east to west and 11.9 km from north to south. To promote the use of GPS in survey applications, DSCC constructed two GPS reference stations, named FOMO and COAL, at Macao Peninsula (next to Macao Museum) and Coloane (at mountain "Alto de Coloane") in 2002 and 2005 respectively. The selection of these two locations enables GPS survey to be performed with a baseline of less than 5 km in most areas of Macao (Figure 1).

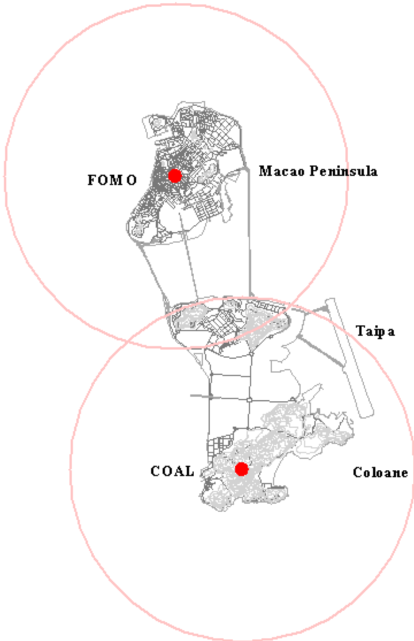


Figure 1: 5km buffer zone of the GPS reference stations

2. THE INFRASTRUCTURE OF MACAO GPS REFERENCE STATION

2.1 Functionality

The main functionality of these two GPS reference stations is to collect GPS raw data and broadcast real-time kinematic (RTK) correction messages. The raw data is logged for conventional static GPS survey, and for every year since 2002, they also participate in the APRGP (Asia Pacific Regional Geodetic Project) GPS campaigns organized by PCGIAP (The Permanent Committee on GIS Infrastructure for Asia and the Pacific). Countries including China, Japan, Australia, Hong Kong SAR and others Asia pacific countries are cooperate together to complete a join GPS observations of over 160 hours. Besides, the GPS rinex data is also provided to Macao Meteorological and Geophysics Bureau through ftp to study the geophysical science, such as crustal deformation, earthquake monitoring and time signal contrast etc. For RTK service, differential data is broadcasted to rover users with RTCM 2.1 format (Type 3,19,18,22). RTK survey is mainly applied in control survey, topographic survey and demarcation of boundaries.

2.2 Construction

The components of a reference station comprise of a pillar mounted with choke ring antenna, concrete platform and a weatherproof equipment box to store high sensitive GPS receiver, communication equipments and the UPS backup batteries to keep the system from running for 4 days in case of A/C power failure. For COAL, a chain link fence is also constructed to prevent from invader.

2.3 Earthing System

Lightning protection is an important part for the infrastructure, and it may occupy up to 50% of the overall construction budget. COAL is located at the top of the highest mountain (Coloane Alto) of Macao, and has more threats of being struck by lightning compare to FOMO, which is situated under the protection zone of the building of Macao Museum. The protection design of COAL station includes the station earthing system, telecom earthing system and a lightning rod. The earthing system is composed of copper rods planted at the four corners of a square-shaped grounding net. The rods are also connected with each other by copper strips to enable lightning discharge. There are commonly three sources of lightning strokes, from lightning rod, telecom line and from A/C power source. All the equipments are connected to a copper bar inside the equipment box and link to the grounding net. For the lightning rod, it is linked directly to the ground that provides a direct and fast way for electrons. To enhance equipment safety, the system also has surge protectors or arrestors installed on the way between the equipments and those sources of danger.

2.4 System Structure and Work Flow

The whole system includes two reference stations and a control center (Figure 2), which are communicated through telephone lines by 56K fax modems. In the control center, Leica Spider software is used for remote data transmission, and allows the operator to monitor and remote control the GPS receivers and ambient devices in the reference stations. Spider will automatically dial up to the reference stations on schedule (for example: every one hour) to download GPS raw data in Leica proprietary format to the computer in the control center. Besides, three more products are created on download, which include RINEX data, QC files and event log files. QC product contains important information concerning the tracked satellites and the observations recorded at the site. Event log file contains status messages from the sensor. In addition, with positioning module of Spider, we would be able to check and analysis GPS data by computing baseline results of the two reference stations.

For RTK service, both stations broadcast RTCM messages through 2W/35W UHF radio modem with same frequency. A GSM modem is also connected to the GPS receiver, which allows rover users to receive RTK corrections using GSM phones. UHF radio could serve unlimited users but the coverage is limited and the signal may be disturbed and blocked. On the contrary, GSM is more stable and the signal availability depends only on the GSM coverage area, however, the relationship between the reference and the rover is one-to-one currently, which means that it could only serves one user at one time. However, the number of users could be increased if GSM gateways that act as a pool of SIM cards are used. Besides, for GSM, both the service provider and receiver need to pay for it.

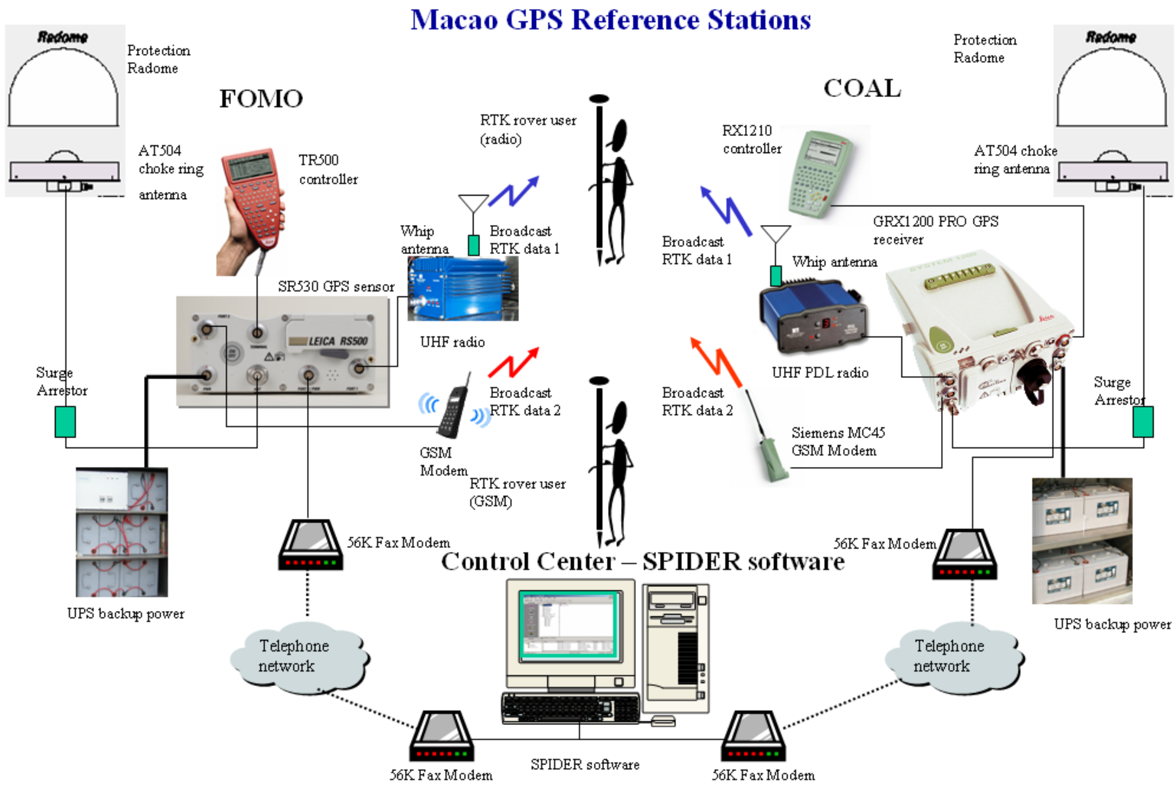


Figure 2. The Structure of Macao GPS Reference Stations

3. PERFORMANCE TESTS

The conditions required to perform a successful RTK survey is more strict compare to that of a single GPS survey. Beside from the number of visible satellites and their geometric criteria (GDOP – Geometric Dilution of Precision), the distance between the reference station and the rover is also a critical issue. Distance is considered in two aspects: signal degradation and error propagation. In case of data transmission using UHF radio, it would be easily disturbed by signal noise, obstacles like mountains and buildings, and its strength would also be degraded over long distances by environmental variables like atmospheric moisture. On the other hand, as the distance between a reference and a rover increases, the accuracy of RTK positioning would be affected by distance-dependent error sources, like ionospheric error.

3.1 Compare the usability of different transmission methods

To understand the usability and performance of the two reference stations in practical, a number of tests were accomplished. One of them aims to identity the service range of RTK with a single reference station in Macao by using different transmission methods: UHF radio and GSM modem (Law, 2004). We would also like to investigate how GSM may help to supplement the blind spots of UHF. Figure 3 shows the regions in purple that could be able to receive 4 or more satellites in both morning and afternoon sessions. Figure 4 shows the sample points that could be successfully fixed by RTK survey using UHF radio. The selection of these testing locations is basically reference to the result in figure 3. By comparing figure 3 and 4, it is discovered that the failure regions lie mainly in the southern part of Macao, in which most of the signals are blocked by mountains. Figure 5 is the result of RTK by GSM; triangles are those successful points, and circle ones fail. When compare to figure 4, we realize that those regions fail with radio could now be fixed by GSM. The test result also indicates the necessity to strengthen the signal coverage area in the south, and thus promote the construction of the 2nd reference station: COAL.

Figure 3. Reception of GPS in Macao (Law, 2004)

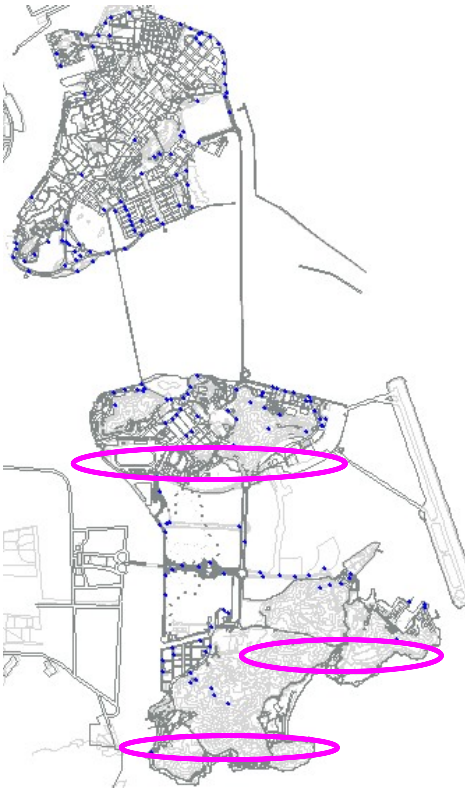


Figure 4. RTK using UHF radio (Law, 2004)

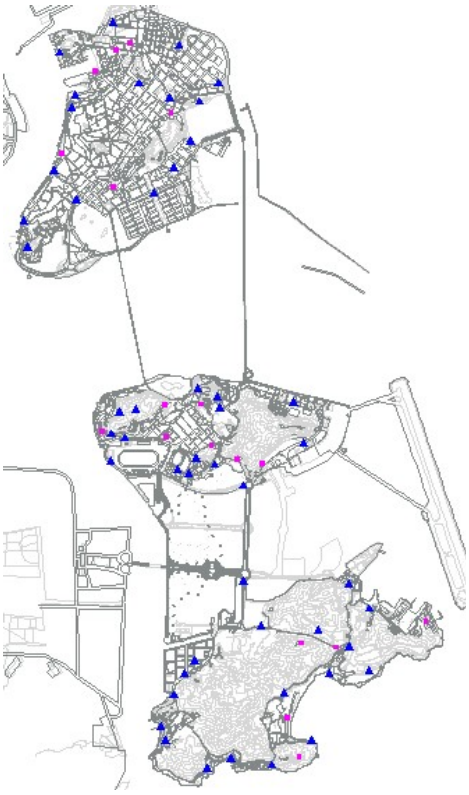
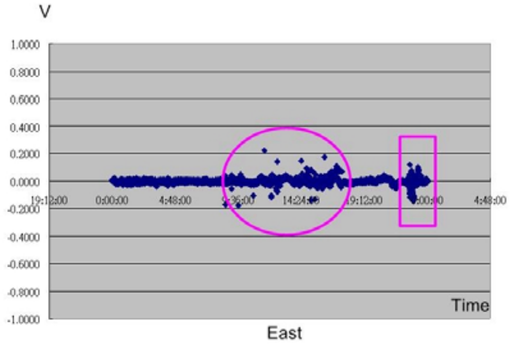


Figure 5. RTK using GSM (Law, 2004)

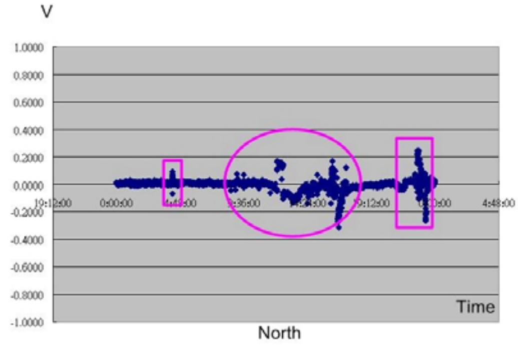
3.2 Positioning accuracy of RTK over long distances

As mentioned, the reference stations are designed to serve rover users within 5km baselines. With single-based RTK, correction provided is just a stand-alone solution. Within the coverage area, users could choose to receiver signals from either FOMO or COAL, or receive both solutions separately and check between them. As we know that, RTK accuracy would be degraded as the distance between reference and rover increases, it is essential to investigate the limitation of this baseline distance, check the dependability of a single RTK solution, and analysis its variation in all day long.

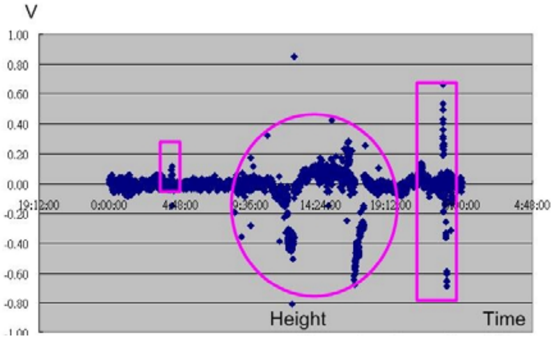
In the test, a dual-frequency GPS receiver was temporary set up at the building top of Macao Meteorological and Geophysical Bureau in Taipa, which is located 5.05 km away from FOMO. To analysis daily variation, continuous 24hrs of RTK data and static GPS data are logged with sampling interval of 15 seconds. Figure 6A~C show the distribution of coordinate differences between static GPS and RTK results. CQ (Coordinate Quality) value is an indicator of position accuracy provided by the GPS receiver, which changes with the number of fix ambiguity solution. Figure 6D shows the CQ value of RTK positioning throughout the whole day. From these graphs, it is realized that coordinate variations occur during these three sections: (1) 04:00, (2) 09:00~16:45 and (3) 23:00, and the quality index (CQ) also reflects the quality of coordinates is lower compare to other sections. We also created the graph of GDOP (Figure 6E) and realized the correlation between these variations with GDOP. The outliners in section (1) & (3) are concentrated, and in corresponding, the GDOP value is greater than 5. Thus, these variations may be caused by the worst geometry of visible satellites. However, the points in section (2) are diverse, and for most of the time, GDOP is below 5. It reflects that these dispersions may be caused by other factors.



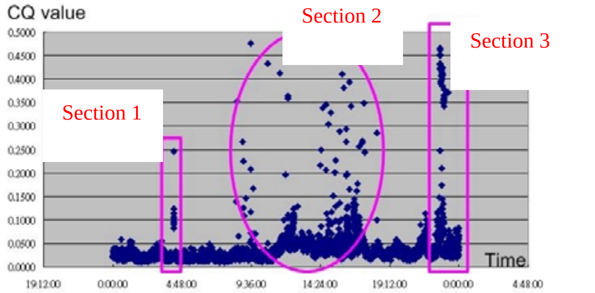
A. Coordinates differences between static GPS and single RTK in East direction



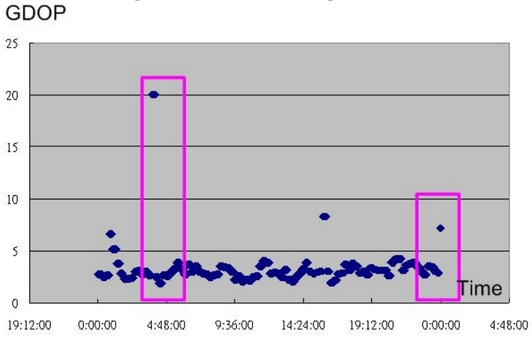
B. Coordinates differences between static GPS and single RTK in North direction



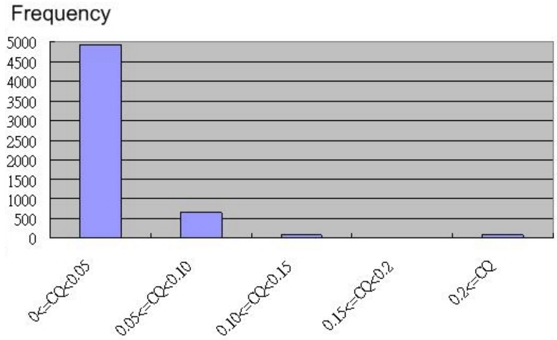
C. Coordinates differences between static GPS and single RTK in Height direction



D. CQ (Coordinate Quality) value of RTK results



E. GDOP distribution



F. Frequency of CQ value

Figure 6. Test results to check the accuracy of RTK with long baseline

Ionosphere, troposphere and multipath are those main error sources related to signal propagation. However, multipath doesn't seems to be the main cause of dispersions in this case, as the site location has a good open sky for 15 elevation mask angle. On the other hand, the effect of troposphere is much smaller than that of ionosphere. We know that the amount of ionization in the ionosphere varies greatly with the strength of solar radiation. In a low latitude region like Macao, ionospheric activities are significant, especially during the day when the solar power is strong. However, the phenomena in this case may also be caused by other interference. This test is quite preliminary; we need to capture more data to investigate further the effects of ionosphere, especially during the summer time.

4. FUTURE DEVELOPMENT

4.1 Network RTK

The maximum baseline distance of single base RTK must not exceed 10km to 20km (Wanninger, 2004). For Macao with area of just 28.2 km^2, it seems that the necessity to construct a third reference station is not imperative. However, as we have shown that distance-dependent biases may affect the accuracy of RTK positioning to some level even with a baseline of 5 km, we'll further investigate the need to apply network RTK in Macao. In network RTK, we would expect that these biases could be modeled more accurately using the measurements from a network of reference stations. In addition, from figure 1, we can see that only a small part in Taipa falls into the overlapping area that allows the users to compare RTK results from two reference stations. If there is a third station (Figure 7), it could provide high redundancy observations to the RTK rovers to obtain a more robust result.

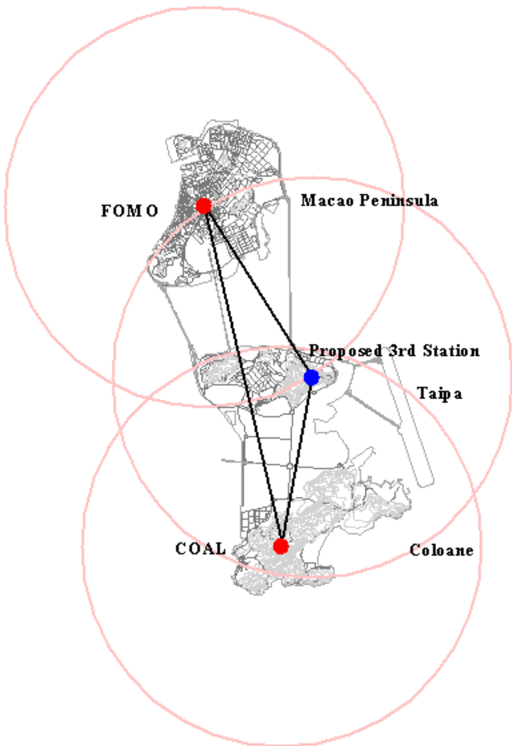


Figure 7. Redundancy coverage area with three reference stations

4.2 GPS+Glonass (GG)

Ionospheric delays on signal propagation depend on the signal frequency, the lower the frequency, the larger the impact. Dual frequency receivers could help to remove this effect by measuring the difference between the arrival times of these two frequencies. Using a combined GPS+Glonass (GG) constellation, we will expect a better GDOP, and with additional L1&L2 frequency of GLONASS, we also look for a more robust result with multiple-frequency ionospheric correction.

Furthermore, with additional GPS L5 signal (located at 1176.45 MHz) that comes with GPS modernization, the positioning accuracy would be further improved. It will speed up ambiguity resolution and extend baselines by permitting better ionospheric corrections over long distances (Fontana et al, 2001). However, it is expected that L5 would be in full operational by approximately 2015. Currently, we'll first concentrate on the efficacy of GG. For next step, we'll try to perform the same experiment as 3.2 but using a GG receiver, and investigate how it could help to improve the accuracy of RTK positioning.

4.3 Data Distribution

As mention in 2.1, we are now providing GPS rinex data to interested parties through ftp server. As GPS application is becoming more common in Macao, we'll target on providing daily raw data to other government departments, research groups and to the public through a web-based data distribution system. For the first phase, besides from data download via the Internet, the system will include user management, transaction management and statistics functions. For the second phase, we'll also consider automatic coordinate computation service, which allows the users to upload their own GPS data for static baseline computation with our GPS reference stations.

5. CONCLUSION

The paper starts with an introductory explanation of Macao Geodetic System and the evolution of GPS in Macao. The current development of Macao Geodetic Infrastructure consists of two GPS permanent reference stations, running to provide a single base RTK services. Several tests have been performed to investigate the efficiency of RTK positioning, by using different transmission methods and study the accuracy of single RTK within the target maximum service range. The test result has shown that UHF is not enough to cover the whole area of Macao and GSM could help to supplement those blind spots. With S/A off since 1 May 2000, ionospheric error becomes significant and it is a major source that degrades the positioning accuracy in RTK positioning over a long distance. We need to further investigate its affect with RTK coordinates during daytime. The paper finally gives a direction of the future development of Macao Geodetic Infrastructure base on the trend of GNSS technology and the findings in the tests. In future, we'll pay attention to the development of network RTK, GPS+Glonass and web-based data distribution, which aims to promote GPS technology and improve the quality of current RTK services in Macao.

REFERENCES

Chan H.P., 2002, Application and development of GPS in Macao, GNSS World of China, 2002 Volume 04 (in Chinese)

Fontana R.D., Cheung W. & Stansell T., 2001, The Modernized L2 Civil Signal - Leaping Forward in the 21st Century, GPS World 2001 Articles, available at www.navcen.uscg.gov/gps/modernization/ModernizedL2CivilSignal.pdf (access on 23-01-2007)

Law S.P., 2004, Initial research on RTK technology using different transmission medium in Macao, Proceedings of the 4th Across-the-Strait Geomatics Conference, Jilin Chang Chun, China (in Chinese)

Wanninger L., 2004, Introduction to Network RTK, IAG Working Group 4.5.1: Network RTK, available at http://www.network-rtk.info/intro/introduction.html (access on 23-01-2007)

BIOGRAPHICAL NOTES

Ka Man IU, graduated with bachelor's degree in survey engineering from Taiwan National Cheng Kung University, is now an MSc student of the Department of Land Surveying & Geo-Informatics in Hong Kong Polytechnic University. Currently, she is employed as a senior technician at Macao Cartography and Cadastre Bureau, and responsible for the maintenance of Macao geodetic control network, leveling network, participated in the construction of Macao GPS reference stations and the projects of Macao intelligent road network database and mobile GIS.

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