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Performance Analysis of Real-Time Kinematic GPS Positioning using Continuous Operating Reference Station

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ABSTRACT

Continuously Operating Reference Stations (CORS) provides GPS measurements to support high accuracy GPS positioning. The CORS improves GPS positioning productivity by eliminating the requirement for GPS users to operate two receivers. Previously, this is achieved by providing data from CORS to users in post-mission mode.

However, the efficiency of the CORS will be maximized by upgrading it in real-time operation using RTK-GPS surveying because users can obtain centimeter-level accuracy in real-time without operating their own reference stations.

In this research, authors extracted the arbitrary point's coordinate which is using GPS CORS data, now served in RINEX FORMAT via Internet, with observation network of the existing triangulation and GPS CORS data. And then, RTK GPS was performed with this arbitrary point as reference station.

Keywords : RTK-GPS, CORS, VRS-GPS, triangulation

요 약

상시관측소는 GPS 측량에서 높은 정확도를 제공하며, GPS 사용자가 두 대의 수신기를 사용해야하는 필요를 제거함으로써 GPS 측위를 향상시킨다. 이전에는, 사용자에게 상시관측소로부터 제공된 자료를 후처리함으로써 수행되어졌다.

그러나 RTK-GPS 측량을 이용한 실시간 처리로 향상될 때 상시관측소의 능률은 최대가 될 것이며, 그 이유는 사용자가 기준점을 이용하지 않고서도 실시간으로 cm급의

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정확도를 획득할 수 있기 때문이다.

본 연구에서는 인터넷을 통해 RINEX 형태로 제공되는 GPS 상시관측소 자료와 기존의 삼각점을 이용해 관측망을 형성하고 임의점의 좌표를 추출하였다. 또한, 기준점으로써 추출된 임의점을 이용해 RTK GPS를 수행하였다.

주요어 : RTK-GPS, 상시관측소, 가상기준점, 삼각점

1. INTRODUCTION

Nowadays, GPS Surveying is remarkable as a core technology of 4S, i.e. GNSS (Global Navigation Satellite System), ITS(Intelligent Transportation System), SIIS(Spatial Image Information System) and GSIS(Geo-Spatial Information System). GPS is widely used in the field of civil, ocean, also geodesy. The existing GPS surveying method has two representative techniques. The one is static method which is testing with adjustment of network in triangulation. Though it has high precision, it is not real time. It can resolve the solution by pre-processing. And the other is Real Time Kinematic.

In this research, authors will research and test with Virtual Reference Station GPS (VRS-GPS). This technique is not necessary to climb some triangulation, thus it could save time and manpower for operating reference station.[1)]

It is an alternative plan to improve popularity and efficacy that GPS CORS would be the reference station of DGPS and Network RTK in VRS-GPS.

The author extracted the arbitrary point's coordinate which is using GPS CORS data, now served in RINEX FORMAT via Internet, with observation network of the existing triangulation and GPS CORS data. Then, with this arbitrary point as reference station, RTK GPS was performed. Lastly, the result of RTK GPS based on this arbitrary point have been compared and analyzed with those of static GPS surveying.[2)]

2. GPS SURVEYING

2.1 GPS Observation.

The basic GPS observations are pseudoranges, carrier phases and phase rates (Doppler). The basic observation equations for these observations are

$$P = \rho + c(d_t - d_T) + d_{ion} + d_{trop} + d_\rho + \varepsilon_P \quad (1)$$

$$\Phi = \rho + \lambda N + c(d_t - d_T) + d_{ion} + d_{trop} + d_\rho + \varepsilon_\Phi \quad (2)$$

$$\dot{\Phi} = \dot{\rho} + c(\dot{d}_t - \dot{d}_T) - \dot{d}_{ion} + \dot{d}_{trop} + \dot{d}_\rho + \varepsilon_p \quad (3)$$

where,

P : Pseudorange observation (m)

Φ : Carrier phase observation (m)

$\dot{\Phi}$: Doppler observation (ms^{-1})

λ	: Carrier wavelength (m $cycle^{-1}$)
N	: Carrier phase integer ambiguity (cycle)
c	: Speed of light (ms^{-1})
$\rho, \dot{\rho}$	: Satellite-receiver geometric range and range rate (m, ms^{-1})
$d_t, \dot{d}_t$	: Satellite clock error and error drift, respectively (m, ms^{-1})
$d\tau, d\dot{\tau}$	: Receiver clock error and error drift, respectively (m, ms^{-1}),
$d_{ion}, \dot{d}_{ion}$	: Ionospheric delay and delay drift, respectively (m, ms^{-1}),
$d_{trop}, \dot{d}_{trop}$	: Tropospheric delay and delay drift, respectively (m, ms^{-1}),
$d_\rho, \dot{d}_\rho$	: Orbital error and error drift, respectively (m, ms^{-1}),
ϵ	: Measurement noise and multipath (m)

In equations (1) and (2), the satellite-receiver geometric range is calculated as $\rho = \|r^s - r^r\|$, where r^r is the unknown ECEF (Earth-Fixed Earth-Centered) position vector of the receiver in WGS-84 and r^r is calculated from parameters included in the satellite ephemeris.

2.2 Differential Positioning

Differential positioning with GPS, abbreviated by DGPS, is a technique where two or more receivers are used. One receiver, usually at rest, is located at the reference site A with Known coordinates and the remote receiver namely usually roving The reference or base station calculates pseudorange corrections (PRC) and range ratecorrections (RRC) which are transmitted to the remote receiver on near real time. The remote receiver applies the corrections to the measured pseudoranges and performs point positioning with the corrected pseudoranges. The use of the corrected pseudoranges improves the positional accuracy.

2.2.1 DGPS with code ranges

The code range at base station A measured at epoch t_0 may be modeled by Eq (4).

$$R^j_A(t_0) = \rho^j_A(t_0) + \Delta\rho^j_A(t_0) + c\delta^j(t_0) - c\delta_A(t_0) \quad (4)$$

where the radial orbital error $\Delta\rho^j_A(t_0)$ has been added. Note that range $\Delta\rho^j_A(t_0)$ is known. The code range correction for satellite j at reference epoch $t_{0)}$ is given by

$$\begin{aligned} PRC^j(t_0) &= -R^j_A(t_0) + \rho^j_A(t_0) \\ &= -\Delta\rho^j_A(t_0) - c\delta^j(t_0) + c\delta_A(t_o) \end{aligned} \quad (5)$$

From a time series of range corrections, the range rate correction $PRC^j(t_0)$ can be evaluated by numerical differentiation. Thus, the code range correction at an arbitrary epoch t is approximated by

$$PRC^j(t) = PRC^j(t_0) + RRC^j(t_0)(t - t_0) \quad (6)$$

where the latency $(t - t_0)$ is essential for the best accuracy.

The code range at the remote station B measured at epoch t can be modeled analogously to Eq. (4) by

$$R^j_B(t_0) = \rho^j_B(t_0) + \Delta\rho^j_B(t_0) + c\delta^j(t) - c\delta_B(t) \quad (7)$$

Applying the range correction, cf. Eq. (6), to the measured pseudorange yields

$$R^{j}_{B}(t)_{corr} = R^{j}_{B}(t) + PRC^{j}(t) = \rho^{j}_{B}(t) + (\Delta\rho^{j}_{B}(t) - \Delta\rho^{j}_{A}(t)) - (c\delta_{B}(t) - c\delta_{A}(t)) \quad (8)$$

where the satellite clock error disappears. For moderate length baselines, the radial orbital errors at the base and the remote station are highly correlated or even equivalent. Neglecting the difference of the radial orbital errors, Eq. (8) may be rewritten as

$$R^{j}_{B}(t)_{corr} = \rho^{j}_{B}(t) - c\Delta\delta_{AB}(t) \quad (9)$$

where $\Delta\delta_{AB}(t) = \delta_{B}(t) - \delta_{A}(t)$ is the combined error of the receiver clocks. Note that the disturbing effects due to SA (dithering of the satellite clock, degradation of the orbit) have been virtually eliminated. The same holds for other disturbing effects like ionospheric or tropospheric refraction. Point positioning at B is performed with the corrected code pseudorange leading to improved positional accuracies. The code range corrections are transmitted in the RTCM format (version 2.0) and the technique is sometimes denoted RTCM differential GPS.

2.2.2 DGPS with carrier phases

The pseudorange derived from carrier measured at the base station A at epoch t_0 can be modeled by

$$\lambda\Phi^{j}_{A}(t_0) = \rho^{j}_{A}(t_0) + \Delta\rho^{j}_{A}(t_0) + \lambda N^{j}_{A} + c\delta^{j}(t_0) - c\delta_{A}(t_0) \quad (10)$$

where N^{j}_{A} is the (unknown) phase ambiguity. Consequently, the phase range correction at reference epoch t_0 is given by

$$PRC^{j}(t_0) = -\lambda\Phi^{j}_{A}(t_0) + \rho^{j}_{A}(t_0) = -\Delta\rho^{j}_{A}(t_0) - \lambda N^{j}_{A} - c\delta^{j}(t_0) + c\delta_{A}(t_0) \quad (11)$$

and the phase range correction at an arbitrary epoch t follows from

$$PRC^{j}(t) = PRC^{j}(t_0) + RRC^{j}(t_0)(t - t_0) \quad (12)$$

with $PRC^{j}(t)$ being the range rate correction at reference epoch. Following the same procedure as before, the corrected phase range at the remote receiver at epoch t are obtained by

$$\lambda\Phi^{j}_{B}(t)_{corr} = \rho^{j}_{B}(t) + \lambda\Delta N^{j}_{AB} - c\Delta\delta_{AB}(t) \quad (13)$$

where $\Delta N^{j}_{AB} = N^{j}_{B} - N^{j}_{A}$ is the combined integer ambiguity. As before, disturbing effects due to SA have been virtually eliminated. Point positioning at B is performed with the corrected phase range corrections are transmitted in the RTCM format (version 2.1) or in a receiver dependent format.3)

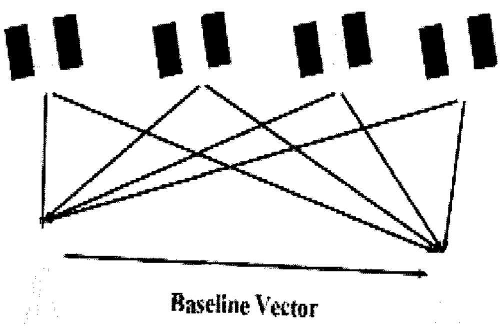

Figure 1. Differential GPS

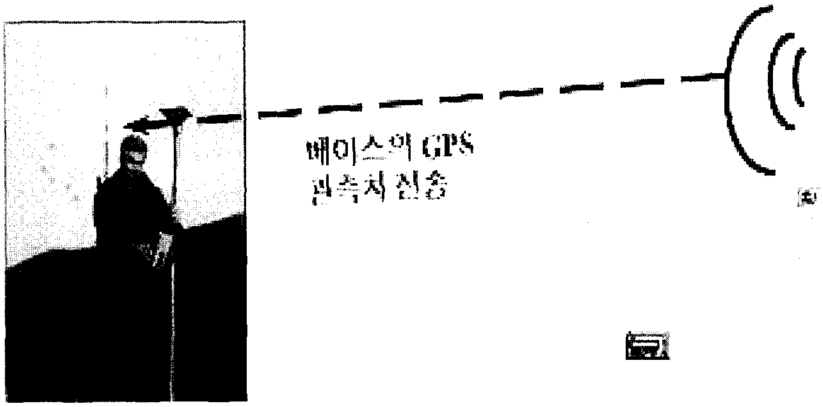

Figure 2. The graphic overview of RTK Surveys

2.2.3. Real Time Kinematic GPS

The aim of using double differencing method with carrier phase in the Real-Time Kinematic Global Positioning System to obtain high accurate position. To ensure this purpose, the base station must send the information including raw pseudorange and carrier values or corrections to the rover station per 0.5 or 2 seconds. This is named as "Real Time Kinematic" in GPS surveying.

It is the reason restrict distance of 10km base station and rover station that Spatial decorrelation reduce the precise of double differential values. It has solution of inter ambiguity when moving and by float solution. When fixed inter ambiguity, It can obtain the precision of cms degree.

Since spatial decorrelation degrades the accuracy of double difference observation, the reference-rover separation should be limited to tens of kilometers (depending on whether single or dual receivers are used). The integer ambiguities can be fixed "on-the-fly"(OTF) or solved for as real numbers(float solution). Once the integer ambiguities have been fixed, centimeter level accuracy can be achieved. Alternatively, decimeter level accuracy is typically achieved using the floating ambiguity solution.

3. GPS CORS AND VRS-GPS

3.1 GPS CORS In Korea

3.1.1 Structure of GPS CORS in National Geographic Information Institute of Korea

Figure. 3. shows the inside and outside structure and photos of CORS operating in National Geographic Information Institute (NGII) and Table 1. contains the detailed information about inside of CORS and Institute.

Table 1. Contains of CORS

Antenna Pillar	Institute
GPS receiver (Dual-frequency) GPS antenna (Choke-ring antenna) Communication device (Modem and ISDN) Clinometer Power supply	Data processing software Control system of CORS Backup system Communication device Printer

Figure 3. Photos of CORS operating in NGII

3.1.2 Current Status and operation (application) of CORS Network

Currently, CORS Network consists of 70 or more, with managed and operated in a different purpose and way, respectively. And it is difficult to control and run all of CORS effectively in the absence of the competent authorities. All CORS information is served to users through Rinex format at NGII, Beacon type in Ministry of Maritime Affairs & Fisheries, and MBC(Munhwa Broadcasting Corporation) linking FM-DARC service in Korea Astronomy Observatory.

Table 2. lists CORS Networks held in

Table 2. List of CORS Network in each Institute

Network	Stations	Applications
National Geographic Information Institute	14	Precise Mapping, GPS Geodetic control point network
Ministry of Government Administration and Home affairs	32	GPS control point network for Land re-investigation Crustal movements Weather forecast Prevention of disasters
Ministry of Maritime Affairs & Fisheries	9	Earth rotation and crustal movements Applied Astronomy including realization of Earth Reference Frame, etc.
Korea Astronomy Observatory	4	Earthquake research

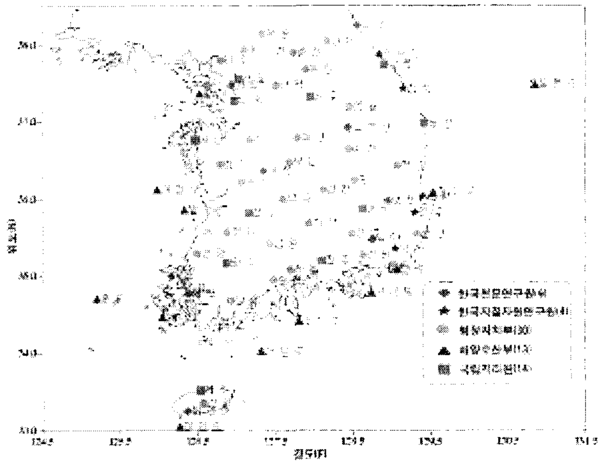

Figure 4. Distribution of CORS in Korea

each Institute and Figure. 4. presents the distribution of CORS all over the country.

3.2 VRS-GPS Surveys

The concept of "Virtual Reference Station" is based on having a network of GPS reference stations continuously connected via data links to a control center. A computer at the control center continuously gathers the information from all receivers, and creates a living database of Regional Area Corrections. These are used to create a Virtual Reference Station, situated only a few meters from where any rover is situated, together with the raw data, which would have come from it. The rover interprets and uses the data just as if it has come from real reference station. The resulting performance improvement of RTK is dramatic.[4)]

For the data transmission of VRS system, the requirement are as followings: i) Continuous acceptance of data, ii) no limit during rover moving iii) national scale's communication link iv) continuous supply positioning 24 hours a day, v) a low-priced rate (fare).

There are one-way and two-way communication link, and the data can be transferred via Internet, mobile phone or modem, and Beacon using microwave, FM-DARC.[5)]

With RTK GPS positioning, satellite clock errors, satellite orbit errors, ionospheric and tropospheric refraction are estimated using known coordinates of reference station, pseudo-range correction is transferred to rover via transmission device of data. In general, the separation-distance between reference stations is approximately limited to 10. It could be extended to 15km under best condition.

But, in VRS-RTK positioning, several errors

Table 3. Accuracy of surveying equipment

Surveying method	Accuracy
Static/Rapid Static GPS	Horizontal accuracy : 3mm+1ppm Vertical accuracy : 5mm+1ppm
RTK GPS	Horizontal accuracy : 10mm+1ppm Vertical accuracy : 20mm+1ppm

are estimated using virtual reference station instead of the known reference stations. Among these errors, ionospheric and tropospheric refraction errors are remarkable.

Considering the weighted-errors proportional to distance between fixed reference stations and virtual reference stations, the size of errors can be measured and estimated. To find a mean error close to user's position, an approximate size of errors must be known.

This method uses CORS Network for it, while traditional network adjustment is based on the fixed surveying marks.

4. EXPERIMENT AND ANALYSIS

In the GPS surveys using network of triangles, all stations are occupied for longer than 4 hours, and GPS data was recorded every 30 seconds. This interval is the same as that of Continuous Operating Reference System (CORS).

Two triangulation mark, namely Jeol-Yung-Do and Hwang-Lung, were selected as fixed stations in post-processing and network adjustment. The Position Dilution of Precision (PDOP) showed a good value of 2.0. And Root Mean Square Error (RMSE) in any component (in N, E, and U) were 37.0mm, 40.3mm, and 125.8mm, respectively.

Table 4 and Table 5 show local coordinates and results of stations from GPS static surveys, respectively.

4.1 Network Triangulation using Triangulation Point

Receiving times are 4 hours at each stations of triangulation net to obey the

Table 4. Announcement results of triangulations

Triangulation	Announcement results		
	N	E	Z
Kim Hae triangulation	191014.463	190956.388	24.590
Hwang Lung triangulation	184236.814	207407.778	427.630
Jul Yung triangulation	175947.421	204971.493	394.720

Table 5. Experienced results of triangulations

triangulation	experienced results		
	N	E	Z
	Base line length (m)		R.M.S.E (mm)
Kim Hae triangulation	191014.287	190956.344	24.756
Hwang Lung triangulation	184236.812	207407.779	427.778
	17797.368 (from Kim Hea)		14.3
Jul Yung triangulation	175947.450	204971.494	394.720
	20581.423 (from Kim Hea)		0.6

second order precision GPS Surveying Regulation in Korea. And epoch time is 30 seconds to coincide with that CORS, GPS data are post-processed using two fixed triangulation points, the first order triangulation in Jul Yung island and the fourth order triangulation in Hwang Lung mountain. And the value of PDOP (Position Dilution of Precision) is 2.0 in average, while indicates a good situation of satellite constellation. The RMSE of adjusted results are X (37.0mm), Y (40.3mm), and Z (125.8mm).

Table 4 shows the announcement results of triangulation in NGII and Table 5. shows the real experienced results of triangulations.

4.2 Network of CORS

Two CORS, held in NGII and one CORS, in KAO were employed in static surveys using network of CORS. All stations were occupied for 4hours, and GPS data was recorded every 30 seconds. Foregoing three CORS, namely DAEGU, JINJU, and MILYANG, were selected as fixed stations in post-processing and network adjustment. PDOP has a good value less than 2. Figure 5 presents the static GPS survey. Figure 6 presents the network consisted of three CORS and one triangulation point. RMSE in any component (in Northing, Easting, and Upward) were 12.1mm, 16.1mm, and 30.30.3 mm, respectively.

Figure 5. Static surveying using triangulation

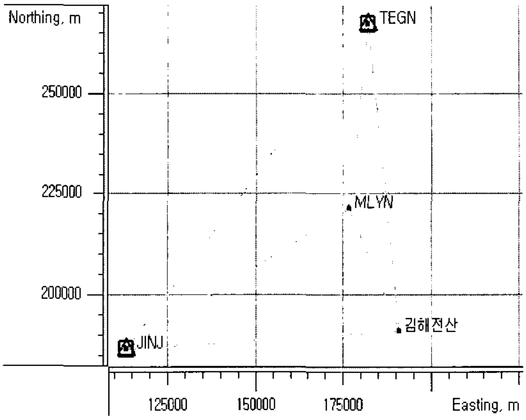

Figure 6. Network processing using triangulation

4.3 Comparison of RTK-Minus-Static surveys

At first stage, the post-processing and adjustment using CORS Network were reduced by commercially available software. One point, among several surveyed point, was selected as a reference station of RTK surveying. With this point, RTK surveying was conducted to calculate the coordinates of two unknown survey points. For the analyzing the accuracy of RTK surveying, static survey was also conducted for 2 hours and on that time, PDOP was a good value less than 2.0.

Figure 7 presents the photograph of field test of RTK surveying. And Figure 8 shows network of CORS and Triangulation Mark. Table 8 and 9 listed the final coordinate derived from both methods.

Average errors in any component (in Northing, Easting, and Upward) to CP-1 and CP-2 between two methods were 0.082mm, -0.229mm, and 0.218mm.

Figure 7. Real Time Kinematic GPS Surveying

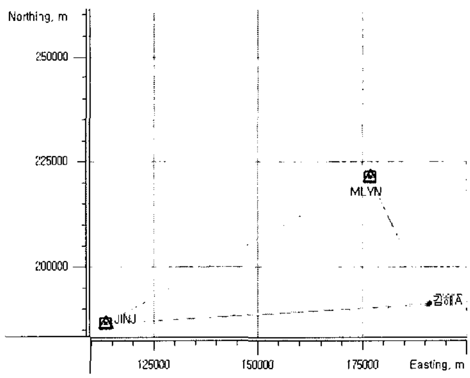

Figure 8. Network processing using CORS

Table 6. Known Coordinates of Several CORS and one Survey Marks

	Known Coordinates via Inter-net		
	N	E	
KIMHAE, Surveys Mark	191014.463	190956.388	24.590
CORS (DAEGU)	267666.710	182123.521	
CORS (JINJU)	186711.138	113428.224	
CORS (MILYANG)			

Table 7. Local coordinates of surveyed point from post-processing and adjustment using CORS Network

	N	E	Z
	Baseline Distance (m)		Residuals (mm)
KIMHAE, Surveys Mark	191014.842	190956.280	24.756
CORS (DAEGU)	267358.984	182075.914	59.493
	76860.0		3.000
CORS (JINJU)	186403.668	113379.425	77.288
	77721.1		18.3
CORS (MILYANG)	221332.408	176719.839	
	33497.8		

Table 8. Local coordinate of check point (in RTK-GPS surveying)

	RTK- results		
	N	E	Z
CP-1	190896.539	190842.535	-10.828
CP-2	191207.729	191299.604	-10.693

Table 9. Local coordinate of check point (using CORS)

	Static results		
	N	E	Z
CP-1	190896.275	190842.555	-10.967
CP-2	191207.911	191299.813	-10.772

5. CONCLUSIONS

In this paper, static surveying using CORS network and RTK surveying were selected to confirm the result of unknown surveyed point.

At first stage, triangulation and CORS network was selected to check the known result of one triangulation point. This results of test shows that RMSE in any components (Northing, Easting, and Upward) was 12.1mm, 16.1mm, and 30.3mm, respectively.

At second stage, one unknown point's coordinate was checked using RTK surveying and static surveying using CORS Network. The results showed that RMSE in any components (Northing, Easting, and Upward) was 0.082mm, -0.229mm, and 0.218mm, respectively.

Currently, CORS Network consists of 70 or more, with managed and operated in a different purpose and way. And it is difficult to control and run all of CORS effectively in the absence of the competent authorities. The integrated organization is needed to improve the efficiency of CORS. The test of Virtual Reference Station using CORS in National Geographic Information Institute had been experienced through first and second tests. The construction and service of this system help to improve GPS surveying greatly.

It is proved that Network RTK is more efficient and practical than existing RTK GPS in North Europe, Australia, U.S.A, and Japan.

So, It needs that more research of VRS GPS for suitable methods in Korea through other country and reference.

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