공학석사학위논문

Improvement of DGPS Positioning Accuracy Using FKP Correction message

FKP 보정정보를 이용한 DGPS 위치정확도 향상 연구

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이 논문을 공학석사 학위논문으로 제출함

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ABSTRACT

Improvement of DGPS Positioning Accuracy Using FKP Correction Message

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The typical augmentation system for pseudorange measurement is DGPS (Differential GPS). DGPS improves commercial single frequency GPS (Global Positioning System) receivers. However, in the DGPS, bias error remains due to spatial decorrelation. Therefore, in this paper, the method have been researched to eliminate spatial decorrelation in conventional DGPS by using FKP correction message which is correction for CDGPS based on carrierphase measurements.

In DGPS, the correlation of the errors experienced at the reference station and the user location is largely dependent on the distance between them. As the separation of the user from the reference station increases so does the probability of significant differing ionospheric and tropospheric conditions at the two sites.

Similarly, the increasing separation also means that a different geometrical component of the ephemeris error is seen by the reference station and the user. This is commonly referred to as “Spatial Decorrelation” of the ephemeris and atmospheric errors.

In the DGPS based on pseudorange measurements, positioning error caused by spatial decorrelation is under noise level of pseudorange measurement. That is why it is treated as minor error source and just a few researches to deal with spatial decorrelation are in progress. Up to the present time, on basis of pseudorange measurements, there are typically RAAS (Regional Area Augmentation System) and WADGPS (Wide Area Differential GPS) as research considering spatial decorrelation to improve positioning accuracy. But, they are not complete system, are developing. Thus, in present, there is no way to eliminate spatial decorrelation in Korea.

Bias error due to spatial decorrelation is also present in CDGPS which is the augmentation system for carrierphase measurements. Compared to pseudorange measurements, carrierpahse measurements have got much smaller noise about centimeter level which is much smaller than bias error due to spatial decorrelation. It is very important error source which can affect integer ambiguity resolution in CDGPS. Therefore, many research to deal with spatial decorrelation in CDGPS have been carrying out more briskly rather than in DGPS. Typically, there is Network-RTK (Network Real Time Kinematics) method for spatial decorrelation in CDGPS.

FKP is ‘Flaechen Korrektur Parameter’ in German. It is one of Network-RTK (Network-Real Time Kinematic) methods such as VRS (Virtual Reference Station), MAC (Master-Auxiliary Concept) and it means ‘Area Correction Parameters’. It is an information to deal with spatial decorrelation in CDGPS based on carrierphase measurements. According to RTCM standard, it can be easily modified to the correction for pseudorange measurements. In Korea, FKP has been being broadcasted since 2012. Thus, to use FKP correction for pseudorange measurement, it is not necessary to add more hardware system and to construct infrastructure.

In this paper, with broadcasted FKP correction in real-time, FKP-DGPS algorithm has been designed and the static/dynamic tests have been carried out to verity its feasibility and performance. In the real-time static test, FKP-DGPS has 21% less 1CEP and 76% less bias error rather than DGPS. Also, in the dynamic test, FKP-DGPS has better positioning accuracy than DGPS. It has 19% improved 1CEP and 31% less bias error. Considering these results, FKP correction can eliminate bias error due to spatial decorrelation in DGPS and it can be utilized for commercial single-frequency GPS receivers effectively.

Keywords: DGPS, CDGPS, Spatial Decorrelation, FKP, FKP-DGPS

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1. Introduction

1.1 Motivation and Purpose

Nowadays, people are getting their own location information by using a car navigation or smartphone. This is operated based on GPS (Global Positioning System) which is based on GPS satellites. Users with a module that can received GPS signals from more than 4 GPS satellites can calculate their own positions by trigonometry regardless of the weather conditions, anywhere and anytime. It is an ideal system can determine the position at high accuracy of about several meter. It is a navigation system for military initially, the U.S Department of Defense has been developed for the guidance and accurate locating of such aircraft of missile. After several civil accidents, it has been open to civilians and we can now easily access the location information with any device that GPS receiver is mounted.

However, in case of standalone positioning with single-frequency GPS receiver which is equipped in relatively inexpensive devices such as car navigation or smartphone, positioning error could be 10~30 meters because of various error factors. This positioning error cannot give the location information to users exactly who use the map application on their smartphones. In addition, in the case of car navigation, it does not have a enough positioning accuracy to provide users quickly to perceive that they run following the instruction exactly at the crossroads or travel with a wrong path. Therefore, the user's request for more accurate location information has increased.

To solve these problems, there is a method to use GNSS (Global Navigation Satellite System) augmentation systems. The GNSS augmentation systems can be separated into DGPS (Differential GPS) and CDGPS (Carrierphase Differential GPS) on the basis of the measurements. In both systems, there is a reference station and its location is known exactly. When user is close enough to reference station, in user's measurements and reference station's measurements from identical GPS satellites, there are common errors in both measurements such as ionospheric delay, tropospheric delay, satellite's orbit and clock errors. At that time, references station can estimates exact common errors in measurements with its known position and make them in form of correction message. Thus, users can get more precise their location information by eliminating GPS error sources which cause positioning error by using broadcasting reference station's correction message. Commercial single-frequency GPS receivers are operated based on pseudorange measurements and can have 1~3 meter positioning accuracy using DGPS correction. However, there is remaining bias form error due to spatial decorrelation which is caused by the difference in the space between user and reference station. It is considered to be an error that cannot be eliminated using just DGPS correction.

In this study, in order to effectively compensate for the spatial decorrelation, FKP-DGPS algorithm has been designed using FKP correction information being broadcast for CDGPS. To use FKP correction, it is not necessary to add more hardware system and to construct infrastructure. Then, in this study, we have made real-time program based on designed FKP-DGPS algorithm and have done experiment to verify its performance.

1.2 Literature Survey

In GNSS augmentation system, the difference in the space between reference station and user causes spatial decorrelation. In DGPS, positioning error caused by it is under noise level of pseudorange measurement. That is why just a few researches for dealing with spatial decorrelation are in progress.

Up to the present time, on basis of pseudorange measurements, there are typically RAAS (Regional Area Augmentation System) and WADGPS (Wide Area Differential GPS) as research considering spatial decorrelation to improve positioning accuracy. In the case of RAAS, a network is formed by multiple reference stations and estimates GPS error sources in area of the network. Thus, it can be possible to broadcast more suitable corrections to users with consideration of where they are [25]. In Korea, DGPS transmission through DMB (Digital Multimedia Broadcasting) have been constructing which is known to take advantages of RAAS. In the case of WADGPS, as shown in Figure 1, WRS (Wide Area Reference Stations) which are spread regionally collect GPS signal data and transmit it to WMS (Wide Area Master Stations). WMS calculate the GPS correction information of the wide region and transmit corrections to geostationary satellites as well as integrity information. Finally, users can get correction information and integrity information from geostationary satellites and improve positioning accuracy. WADGPS have advantages such as being able to cover wider region and alerting fault GPS satellites signal (integrity) to user quickly. However, it is necessary to spend lots of money and time to construct WADGPS infrastructure. From this year, Korean WADGPS have been beginning on the development and it is expected to start civilian service in 2020.

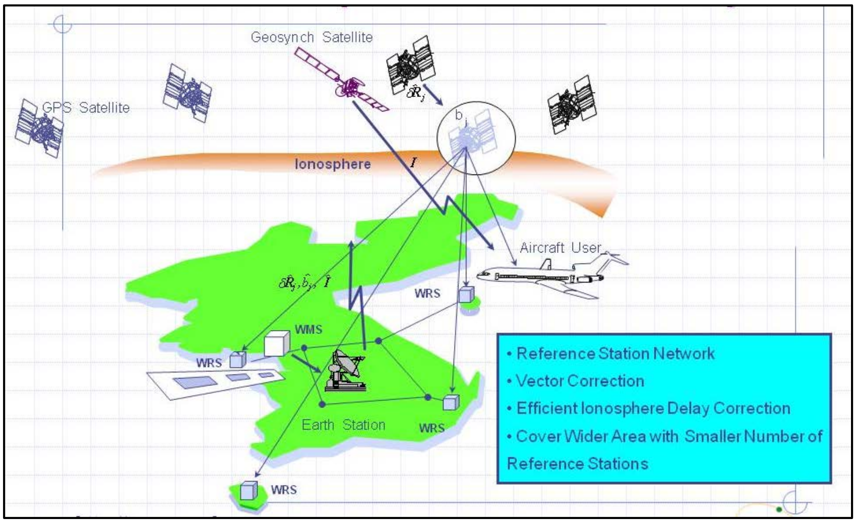

Figure 1 WADGPS (Wide Area Differential GPS)

Bias error due to spatial decorrelation is also present in CDGPS which is the augmentation system for carrierphase measurements. Compared to pseudorange measurements, carrierpahse measurements have got much smaller noise about centimeter level which is much smaller than bias error due to spatial decorrelation.

It is very important error source which can affect integer ambiguity resolution in CDGPS. Therefore, many research to deal with spatial decorrelation in CDGPS have been carrying out more briskly rather than in DGPS. Typically, there is Network-RTK (Network Real Time Kinematics) method for spatial decorrelation in CDGPS.

RTK (Real Time Kinematics) is similar to CDGPS and it is possible to calculate the position with an accuracy of centimeter level when determining integer ambiguity exactly. In RTK, if user is far from reference station, possibility of integer ambiguity resolution can decrease because of spatial deccorelation. Thus, reference station could cover just 10~20 km distance. In other words, service area is very small for RTK users. In order to complement this small service area, similarly to RAAS, a network is formed by nearby multiple reference stations and estimates error sources in area of network. It is called Network-RTK. The advantage of Network-RTK is feasibility to give valid correction information to users who is more far from reference station rather than RTK. Network-RTK can eliminate spatial decorrelation effectively by estimating error sources in area of network. According to method of estimation or broadcasting information, Network-RTK methods are classified into VRS (Virtual Reference station), MAC (Master-Auxiliary Concept), FKP (Flaechen Korrektur Parameter).

1.3 Content and Method

In this study, in order to improve single-frequency GPS receiver’s positioning accuracy based on pseudorange measurement, conventional DGPS is basically used. Furthermore, FKP correction for CDGPS based on carrierphase measurement is modified to apply to single-frequency GPS receiver. In other words, FKP-DGPS algorithm is designed by combining conventional DGPS correction information and FKP correction information to eliminate error sources effectively which cause bias error.

FKP correction can be easily modified to apply for pseudorange measurements. It has been already constructed in and it is open service to user in this time. It is broadcasted through NTRIP (Network Transport of RTCM via Internet Protocol) server in RTCM version 3.1 standard format. In this study, using this broadcasting FKP correction in RTCM version 3.1 via Internet, FKP correction for pseudorange measurements is generated by following the method in RTCM standard document. With this generated FKP correction, FKP-DGPS correction is constructed by combining conventional DGPS correction which is broadcasted in RTCM version 2.3. FKP correction is to compensate spatial decorrelation effectively. Therefore, this paper have confirmed validity of the FKP correction to improve DGPS positioning accuracy by eliminating spatial decorrelation.

In the case of commercial single-frequency GPS receivers which are interested in this paper, they have interface for acquiring and applying DGPS correction in

RTCM version 2.3 format and they have got an accuracy of 1~3 meter in real-time. Therefore, this paper have verified performance of generated FKP-DGPS correction formed in DGPS correction format in RTCM version 2.3 to apply single-frequency GPS receivers in real-time based on Visual C++. In addition, before real-time program, post processing program was made for confirmation of designed FKP-DGPS algorithm's feasibility.

1.4 Contributions

As previously stated, the methods for spatial decorrelation in DGPS based on pseudorange measurements are RASS (Regional Area Augmentation System) and WADGPS (Wide Area Differential GPS). In present, both methods are developing in Korea and there is no effective way to compensate spatial decorrelation in DGPS.

However, FKP correction have been already broadcasting in 2012 and it is open service to users who have got any devices for CDGPS based on carrierphase measurements. FKP correction can be easily modified to use for pseudorange measurement by following mathematical methods and this paper use it to compensate spatial decorrelaion in DGPS.

Therefore, the contribution of this paper is improvement of DGPS positioning accuracy of single-frequency GPS receivers by just utilization of broadcasting FKP correction for CDGPS without no need to construct infrastructure and to add more hardware**.**

2. GPS (Global Positioning System)

2.1 GPS overview

GPS is U.S. Global Navigation system fully operational and meets the criteria established in the 1960s for an optimum positioning system. The system provides accurate, continuous, world-wide, three-dimensional position and velocity information to users with the appropriate receiving equipment. GPS also disseminates a form of Coordinated Universal Time (UTC). As shown in Figure 2, the satellite constellation nominally consists of 24~32 satellites arranged in 6 orbital planes with 4 satellites per plane.

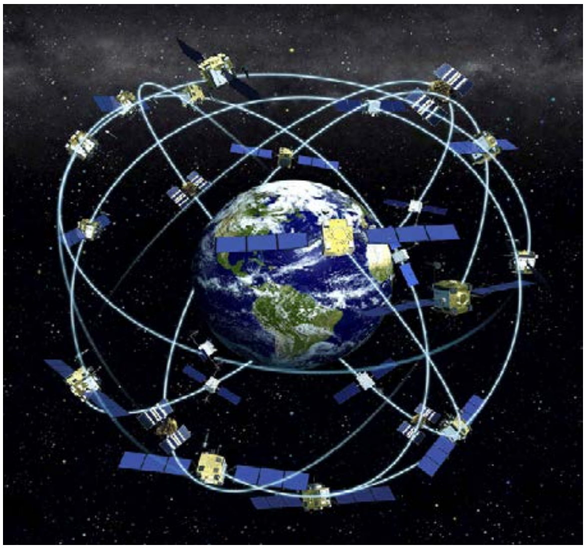

Figure 2 GPS Constellation

A worldwide ground control/monitoring network monitors the health and status of the satellites. GPS can provide service to an unlimited number of users since the user receivers operate passively. The system utilizes the concept of one-way time of arrival (TOA) ranging. Satellite transmission are referenced to highly accurate atomic frequency standards onboard the satellites, which are in synchronism with a GPS time base. The satellites broadcast ranging codes and navigation data on two frequencies using a technique called code division multiple access (CDMA). In other words, there are only two frequencies in use by the system, called L1 (1,575.42MHz), L2 (1,227.6MHz). Each satellite transmits on these frequencies, but with different ranging codes than those employed by other satellites. These codes were selected because they have low cross-correlation properties with respect to one another. The navigation data provides the means for the receiver to determine the location of the satellite at the time of signal transmission, whereas the ranging code enables the user's receiver to determine the transit time of the signal and thereby determine the satellite-to-user range. This technique requires that the user receiver also contain a clock. Utilizing this technique to measure the receiver's three-dimensional location requires that TOA ranging measurements be made to four satellites, as shown in Figure 3.

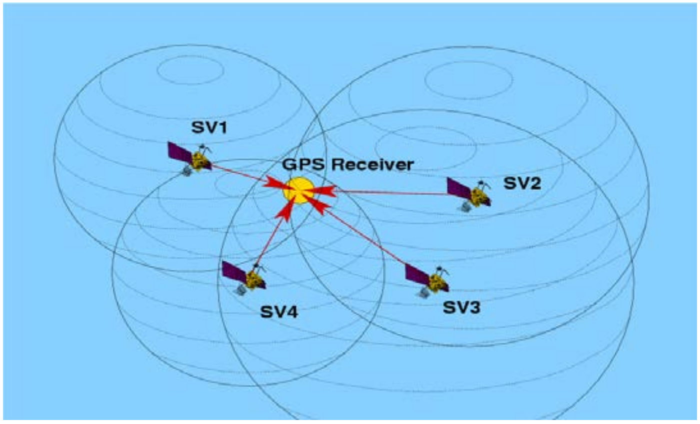

Figure 3 Concept of calculating Position in GPS

If the receiver clock were synchronized with the satellite clocks, only three range measurements would be required. However, a crystal clock is usually employed in navigation receiver to minimize the cost, complexity, and size of the receiver. Thus, four measurements are required to determine user latitude, longitude, height, and receiver clock offset from internal system time. If either system time of height is accurately known, less than four satellites are required.

2.2 Error sources in GPS

In Figure 4, there are many sources of possible errors that will degrade the positioning accuracy computed by a GPS receiver.

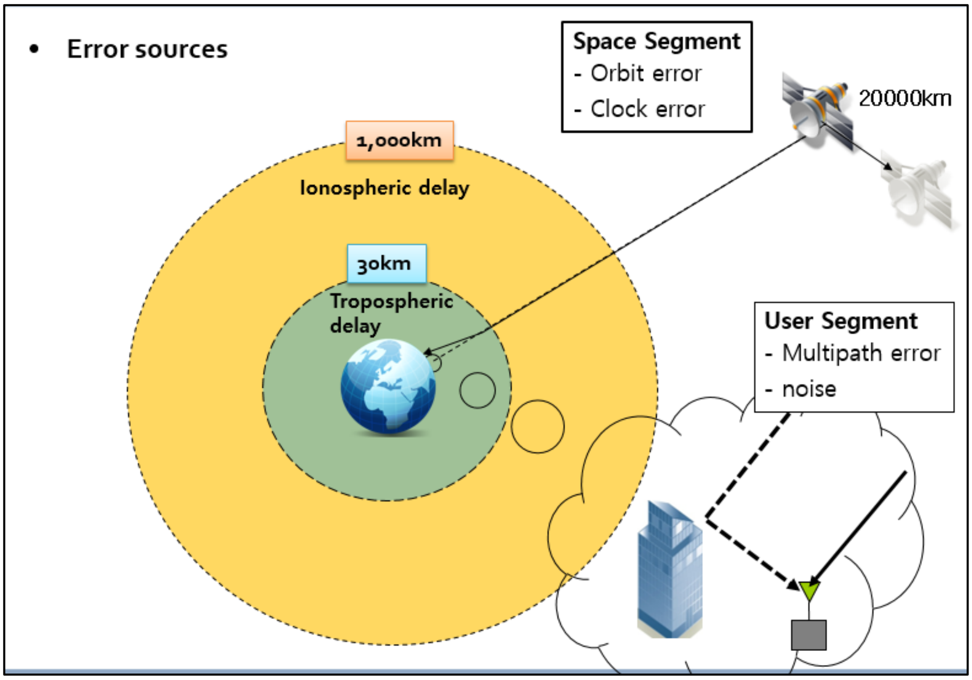

Figure 4 GPS Error sources

While traveling from satellite and user, the travel time of GPS satellite signals can be altered by atmospheric effects. When a GPS signal passes through the ionosphere and troposphere it is refracted, causing the speed of the signal to be different from the speed of a GPS signal in space. About space segments, error in the ephemeris data (the information about satellite orbits) will also cause errors in computed positions, because the satellites weren't really where the GPS receiver thought they were when it computed the positions. Small variation in the atomic clocks on board the satellites can translate to large position errors. A cock error of 1 nanosecond translates about 0.3 meters user error on the ground. About user segment, multipath effects arise when signals transmitted from the satellites bounce off a reflective surface before getting to the receiver antenna. When this happens, the receiver gets the signal in straight line path as well as delayed path. Another source of error is measurement noise, or distortion of signal caused by electrical interference or errors inherent in the GPS receiver itself [30].

In general, users with commercial single-frequency GPS receiver can often attain better than 10m, 95% positioning accuracy and 20-ns, 95% timing accuracy worldwide. In other words, positioning accuracy can be affected by various GPS error sources mentioned above. Without any correction information, calculation of position is called 'Standalone' and its accuracy is about 5~10m. In this paper, methods have been researched to decrease positioning error effectively for civilians using single-frequency GPS receivers based on pseudorange measurements [3].

2.3 DGPS (Differential GPS)

As explained before, satellite navigation system can provide far higher accuracy than any other current long and medium range navigation system. Specifically, in the case of GPS, differential techniques have been developed which can provide accuracies comparable with current landing systems.

DGPS (Differential GPS) was developed to meet the needs of positioning and distance-measuring application that required higher accuracies than 5~10 standalone positioning that single-frequency GPS receiver could deliver. DGPS involves the use of a control or reference receiver at a known location to measure the systematic GPS errors. Also, by taking advantage of the spatial correlation of the errors, the errors can then be removed from the measurement taken by moving or remote receivers located in the same general vicinity. There have been a wide variety of implementations described for affecting such a DGPS system. In present, two general categories of differential GPS systems can be identified such as those that rely primarily upon the pseudorange measurements and those that rely primarily upon the carrierphase measurements. Using carrierphase measurements, high accuracy can be obtained in centimeter lever called CDGPS, but the solution suffers from integer ambiguity and cycle slips. Whenever a cycle slip occurs, it must be corrected for, and the integer ambiguity must be re-calculated. The pseudorange solution is more robust, but less accurate 2~5 meter and it is called DGPS. It does not suffer from cycle slips and therefore there is no need for reinitialization [22]. In this paper, improvement of positioning accuracy of single frequency GPS-receiver is focused on and it can be just operated by using pseudorange measurements. Therefore, DGPS would be treated in this paper.

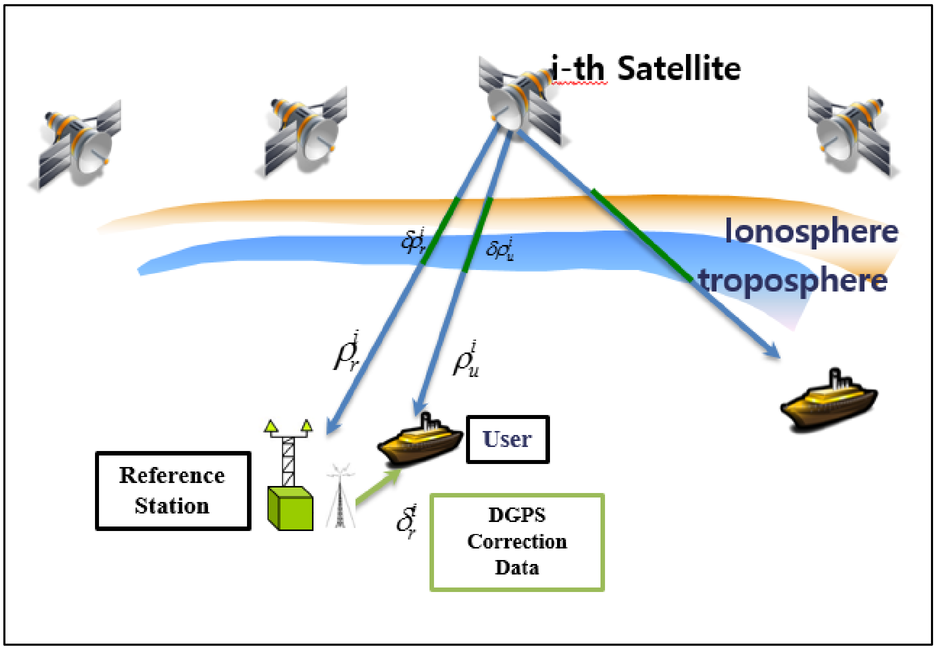

Figure 5 Differential GPS (DGPS) Concept

A typical DGPS architecture is shown in Figure 5. The system consist of a reference station located at a known location that has been previously surveyed, and one or more DGPS user. DGPS is based on the principle that receivers in the same vicinity will simultaneously experience common errors on a particular satellite ranging signal [3].

As shown in Figure 5, when both receivers of reference station and user receive GPS signal from i-th satellite, pseudorange measurements calculated by both receivers are expressed in below Equation (1).

$$\rho_r^i = d_r^i + B_r + (I_r^i + T_r^i + \delta R_r^i - b^i) + \varepsilon_\rho^i$$

$$\rho_u^i = d_u^i + B_u + (I_u^i + T_u^i + \delta R_u^i - b^i) + \varepsilon_u^i \tag{1}$$

ρ^i: code measurement to the i-th satellite

d^i: distance to the i-th satellite

b^i: satellite clock bias of i-th satellite

B: clock bias of receiver

I: ionospheric delay

T: tropospheric delay

δR: orbit error

ε_ρ^i: pseudorange noise of i-th satellite

r, u: reference station, user

In both signals, GPS error sources such as ionosphereic delay, tropospheric delay, orbit error, and satellite clock bias are highly correlated over space and time. DGPS exploit these correlation to improve overall system performance. For example, in a simple local-area DGPS system with a single reference station, the errors in the reference station's pseudorange measurements for visible satellites are expected to be very similar to those experienced by a nearby user. In other words, there is common error in both GPS signal between reference station and nearby user. Therefore, if the reference station estimates the errors by leveraging its known surveyed position and provides this information in the form of correction to the user, it is expected that the user's position accuracy will be improved as a result. Estimated and broadcasted DGPS correction information from reference station is expressed in Equation (2) [3].

$$\delta_r^i \equiv \rho_r^i - d_r{}^i = \delta\rho_r^i + B_r \qquad (2)$$

The method how users apply DGPS correction information and calculate DGPS position mathematically is expressed in Figure 6.

Pseudorange Meas. at Refrence stn.

$$\begin{aligned}\rho_r^i &= d_r^{\,i} + B_r + (I_r^i + T_r^i + \delta R_r^i - b^i)\\ &= d_r^{\,i} + B_r + \delta\rho_r^i\end{aligned}$$

Correction

$$\delta_r^i \equiv \rho_r^i - d_r^{\,i} = \delta\rho_r^i + B_r$$

Pseudorange Meas. at User

$$\begin{aligned}\rho_u^i &= d_u^{\,i} + (I_u^i + T_u^i + \delta R_r^i - b^i) + B_u\\ &= d_u^{\,i} + B_u + \delta\rho_u^i\end{aligned}$$

If user is near ref.stn,

$$\delta\rho_r^j \approx \delta\rho_u^j$$

$$\begin{aligned}\tilde{\rho}_u^i \equiv \rho_u^i - \delta_r^i &= (d_u^i + \delta\rho_u^i + B_u) - (\delta\rho_r^i + B_r)\\ &\approx d_u^i + B_u - B_r\\ &= d_u^i + \Delta B\\ &= (\bar{R}^i - \bar{R}_u)\cdot \hat{e}_u^{\,i} + \Delta B\end{aligned}$$

Navigation Solution

$$\begin{bmatrix}\hat{e}^1 & -1\\ \hat{e}^2 & -1\\ \vdots & \vdots\\ \hat{e}^m & -1\end{bmatrix}\begin{bmatrix}\vec{R}_u\\ \Delta B\end{bmatrix} = \begin{bmatrix}\vec{R}^1\cdot\hat{e}^1 - \tilde{\rho}_u^{\,1}\\ \vec{R}^2\cdot\hat{e}^2 - \tilde{\rho}_u^{\,2}\\ \vdots\\ \vec{R}^m\cdot\hat{e}^m - \tilde{\rho}_u^{\,m}\end{bmatrix} \Rightarrow H\cdot\vec{x} = \vec{z}$$

$$\vec{x} = (H^T H)^{-1}\cdot H^T\cdot\vec{z}$$

Figure 6 DGPS positioning method

As explained above, there are common errors in both GPS signal between reference station and user from the GPS satellite. That is why user can get position which of an accuracy of 1~3 meter with broadcasted DGPS correction information from reference station.

However, GPS error sources are highly correlated over space and time. In reality, they are just highly correlated, they are exactly not equal in both GPS signal to reference station and user. Therefore, there is spatial decorrelation that can cause position error in form of bias. The error due to spatial decorrelation is getting big when user is getting far from reference station. In this paper, it has studied that how to compensate spatial decorrelation effectively between reference station and nearby user in DGPS.

2.4 Spatial decorrelation

As already mentioned, the correlation of the errors experienced at the reference station and the user location is largely dependent on the distance between them. As the separation of the user from the reference station increases so does the probability of significant differing ionospheric and tropospheric conditions at the two sites. Similarly, the increasing separation also means that a different geometrical component of the ephemeris error is seen by the reference station and the user. This is commonly referred to as “Spatial Decorrelation” of the ephemeris and atmospheric errors. In general, the errors are highly correlated for a user within 350km of the reference station. In most cases however, if the distance is greater than 250km the user will obtain better results using correction models for ionospheric and tropospheric delay to eliminate the error due to spatial decorrelation. Spatial decorrelation between reference station and users increases if user are getting far from reference station and it can be confirmed in Table 1.

Table 1 Spatial Decorrelation depending on baseline length [22]

ERROR SOURCES	0 NM	100 NM	500 NM	1000 NM
Space Segment: Clock Errors	0	0	0	0
Control Segment: Ephemeris Errors	0	0.3	1.5	3
SA	0	0	0	0
Propagation Errors:				
Ionosphere	0	7.2	16	21
Troposphere	0	6	6	6
TOTAL (RMS)	0	9.4	17	22
User Segment:				
Receiver Noise	3	3	3	3
Multipath	0	0	0	0
UERE (RMS)	3	9.8	17.4	22.2

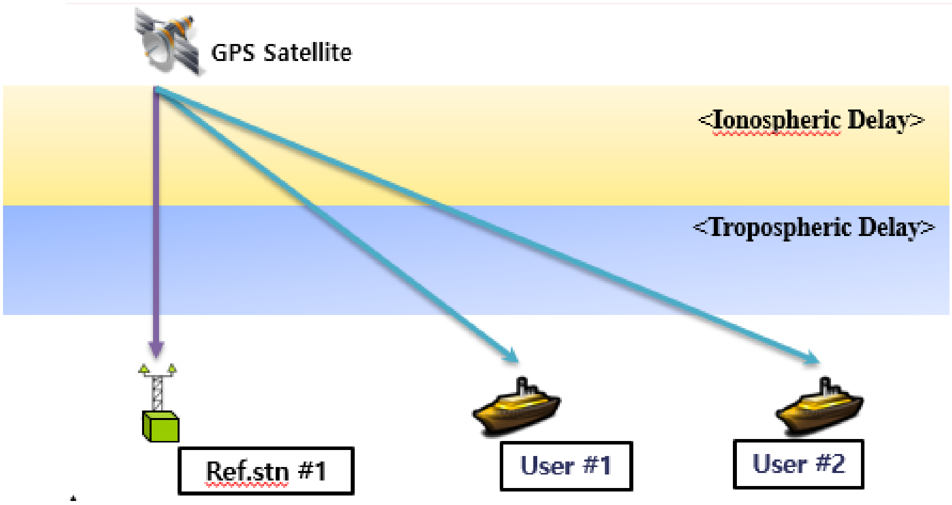

Figure 7 GPS signals from satellite to Reference station and Users

From Table 1, satellite's orbit error is respectively smaller than atmospheric errors such as ionospheric delay and tropospheric delay. Thus, in this paper, atmospheric errors have been considered as major error source. Figure 7 shows that GPS signals from the satellite to reference station and users pass through each own path. Thus, they experience different atmospheric delay and it can be shown in Figure 7.

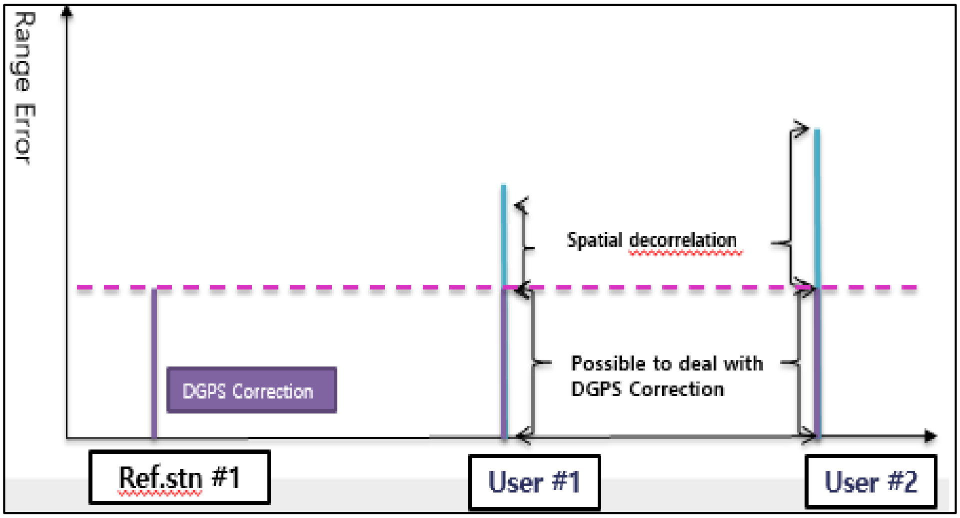

Figure 8 Spatial Decorrelation in DGPS

As explained before, spatial decorrelation cannot be eliminated in conventional DGPS because user generally is not able to be at same location of reference station, that is there is a difference of distance between reference station and user called 'baseline length'. Spatial decorrelation is directly proportional to baseline length. For example, in above Figure 8, User#2 suffers from bigger spatial decorrelation rather than User#1 owing to the longer distance. This spatial decorrelation causes positioning error in form of bias and it can be expressed in Equation (3).

$$
\begin{aligned}
I_u^i &= I_r^i - \delta I \\
T_u^i + \delta R_u^j &= T_r^i + \delta R_r^i + \delta T
\end{aligned}
\tag{3}
$$

δT : the distance dependent error for the geometric signal
δI : the distance dependent error for the ionospheric signal

In above Equation (3), both distance dependent errors for the geometric signal and ionospheric signal are caused by spatial decorrelation and it could be getting bigger if getting far from reference station. In addition, the distance dependent error for the geometric signal normally includes just tropospheric delay, not satellite orbit error because the orbit error is much smaller than tropospheric delay.

2.5 FKP (Flaechen Korrektur Parameter) [24][26]

FKP correction is 'Flaechen Korrektur Parameter' in German. It is one of Network-RTK (Network-Real Time Kinematic) methods such as VRS (Virtual Reference Station), MAC (Master-Auxiliary Concept) and it means 'Area Correction Parameters'.

In augmentation system for carrierphase measurements like DGPS base on pseudorange measurements, called RTK (Real Time Kinematic), it is a real time and precise positioning system with GPS satellites. The range to the GPS satellite from a user is determined by the phase measurement of the carrier wave from satellite with the precision of millimeters. Thus, the high precision position of the order of a few centimeters are easily available. However, it is well known that the baseline is limited to about 10~20km in RTK due to the non-uniformity of the ionosphere and the troposphere. In other words, there is also spatial decorrelation as mentioned before. This spatial decorrelation affects resolution of integer ambiguity which is necessary to be solved to calculate a location based on carrierphase measurements. For that reason, many researches have been doing about methods to deal with spatial decorrelation in RTK and Network-RTK is typical one of these methods.

Network-RTK is a kinds of network net. In order to give a chance to calculate locations to RTK users, it is necessary to estimate errors in carrierphase measurements exactly and broadcasts them to users. However, the coverage of one

RTK reference station is about 10~20km because of spatial decorrelation. It is not easy to estimate precisely the errors in the location outside of coverage as shown in Figure 9.

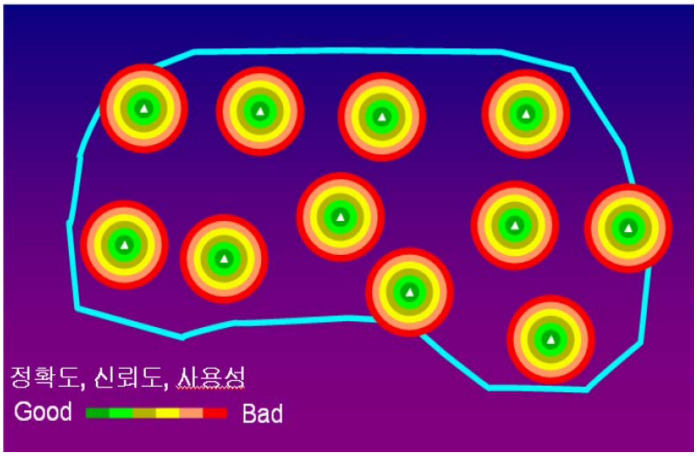

Figure 9 Coverage of RTK reference stations

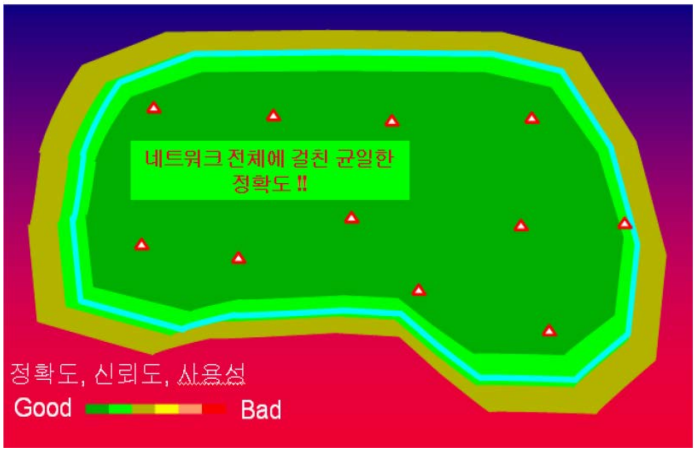

Figure 10 Concept of Network-RTK

The simple solution of this problem, that is to broaden service coverage, is installation of many reference stations in every 10~20km baseline. But, it is not practical solution as needs to spend lots of money and time. Thus, like RAAS (Regional Area Augmentation System), a network net have been composed by using conventional RTK reference stations and it is called ‘Network-RTK’. In the Network-RTK, estimation of errors anywhere in area of network could be much precise and spatial decorrelation could be almost exactly calculated. In addition, thereby estimating errors precisely at location outside of coverage of the RTK reference station, the coverage becomes wider up to about 100km as shown in Figure 10 [16]. Therefore, many research about how to improve Network-RTK performance have been carrying out as many advantages.

FKP means ‘Area Correction Parameters’ and it is one of the first methods that have been developed for the implementation of Network-RTK. In present, it is in complete implementation system in Korea and it has been open service to user from 2012. The technique employs information from the reference station of the network in order to derive linear parameters that will describe the effect of atmospheric and orbit errors. These parameters are then disseminated to users as gradients to be used for interpolating the network errors to their actual position. Figure 11 illustrates four reference station and their respective correction planes that are described by the computed parameters [26]. The x-axis defines the longitude, the y-axis the latitude while the z-axis corresponds to the magnitude of the correction that can be either for the phase or the pseudorange. The area of each plane that the corresponding parameters are valid for, is highlighted in a different color for each reference station in the Figure 11. The user that operates within the network receives the parameters from the closest reference station.

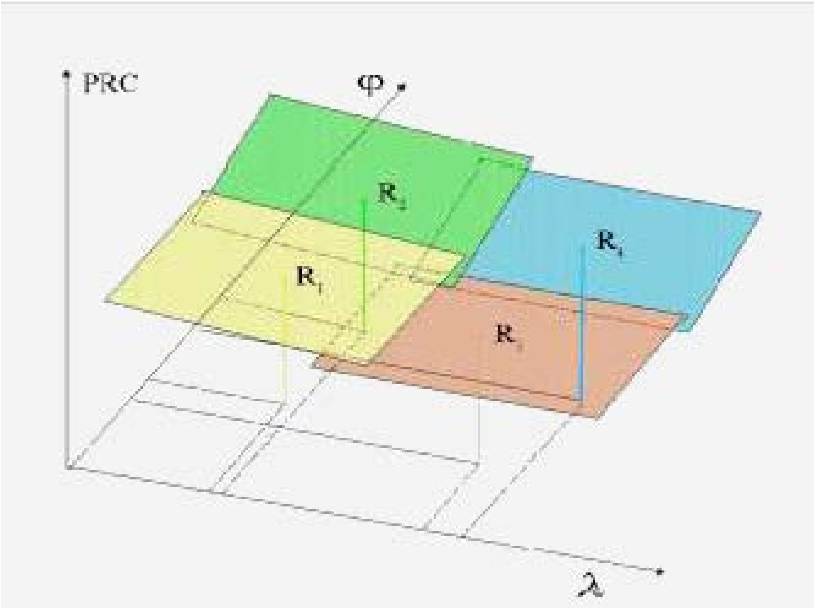

Figure 11 FKP correction planes

For the FKP method a linear interpolation is used in order to derive the parameters for each of the reference stations to describe the linear decorrelation of the error in the East-West and North-South directions respectively. The correction surface is defined as being parallel to the WGS84 ellipsoid at the height of the reference station. The parameters in FKP describe the horizontal gradient for the ionospheric and geometric signal components. These parameters are then transmitted to the users through the RTCM version 3.1.

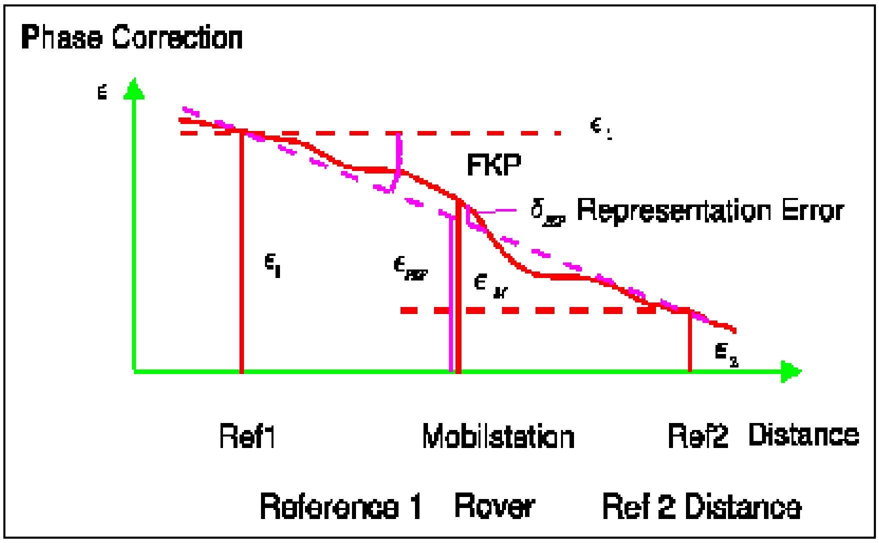

Figure 12 FKP correction information

As shown in Figure 12, the broadcasted information from FKP reference station is the gradient of estimated error surfaces. Users who use FKP correction receive it and can calculate precise error information at their location considering the difference of space between reference station and them.

FKP has advantage of give the service to infinite users as one-way communication. But, according to that its quality would be determined by provider, accuracy of error model could considerably affect the positioning accuracy of user.

In this paper, this FKP correction is applied for conventional DGPS method to eliminating remaining error due to spatial decorrelation in the DGPS. It can be used easily by making FKP DGPS program to implement without no extra hardware and infrastructure.

3. Post Processing FKP-DGPS Algorithm

Before verifying the applicability of FKP-DGPS message for single-frequency GPS receiver in real-time, it is necessary to make sure of feasibility of FKP correction to improve positioning accuracy. Thus, as shown in Figure 13, post processing FKP-DGPS algorithm have been designed and the program has been made based on the post processing FKP-DGPS algorithm in MATLAB. For test to verify this algorithm, real GPS measurements have been received using commercial single-frequency GPS receiver and FKP information has been collected from NTRIP server via internet. Utilizing post processing MATLAB program with the correction and GPS data, the feasibility of FKP correction has been confirmed by comparing static user's positioning accuracy with just DGPS or without any corrections.

The post processing FKP-DGPS algorithm consist of 4 steps as shown in Figure 13. Firstly, GPS measurements and correction information are acquired. After that, using acquired data, tropospheric delay is generated and FKP correction at user position is calculated. Finally, FKP-DGPS navigation solution is solved and its result is compared to DGPS navigation solution and standalone navigation solution to confirm FKP-DGPS solution performance improved.

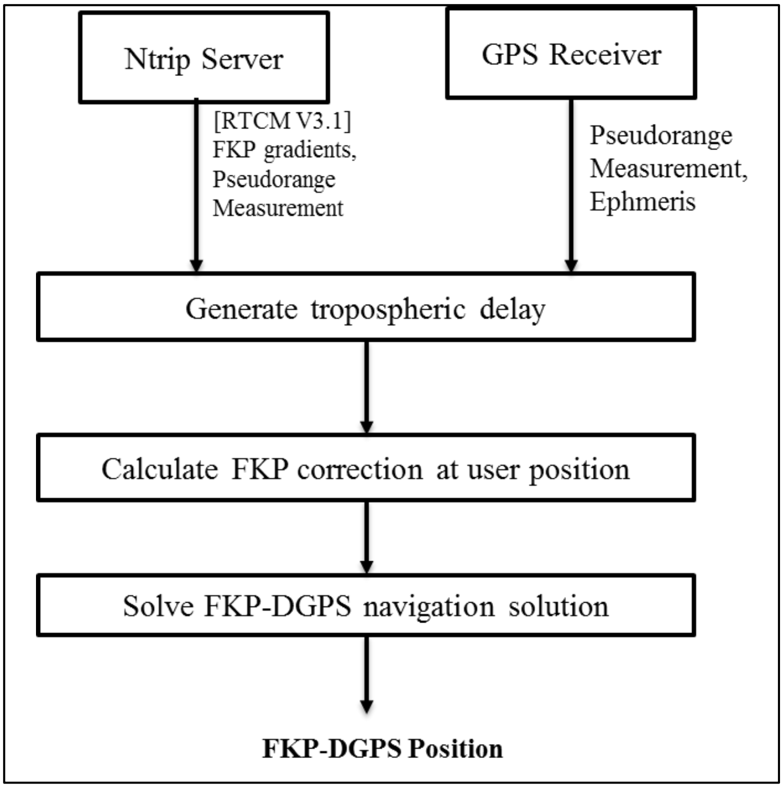

Figure 13 Post processing FKP-DGPS algorithm

3.1 Data Collection

First step of the post processing FKP-DGPS algorithm is the Data collection. As already explained, real GPS measurements have been received using commercial single-frequency GPS receiver and FKP correction information has been collected from NTRIP server via internet.

In terms of correction information, RTCM-104 DGNSS (Differential Global Navigation Satellite System) standards are used worldwide. Many popular GPS receivers accept RTCM-104 differential correction messages, and many special-purpose RTK receivers use the RTK messages. The RTCM SC-104 standards defines messages that contain reference station and system data. These messages are typically broadcast over a transmission link and received by mobile users, which then apply the information contained in the messages to achieve high-accuracy operation. The data can be transmitted over any number of communication channels such as via radio transmission, or via a mobile communication network, using different communication protocols. Nowadays, the data is being transmitted over internet as NTRIP (Networked Transport of RTCM via Internet Protocol)

In Korea, the correction data is broadcasting to users as RTCM standard messages from NDGPS reference stations of the Ministry of Maritime Affairs and Fisheries and reference stations of National Geographic information institute. In this paper, those correction data from reference stations of the latter is collected.

In the case of FKP, this correction messages are broadcasted in RTCM version 3.1 in Korea. It is basically a kind of information for RTK user. Figure 14 shows all kinds of message type in RTCM version 3.1.

Group Name	Sub-Group Name	Message Type
Observations	GPS L1	1001
		1002
	GPS L1 / L2	1003
		1004
	GLONASS L1	1009
		1010
	GLONASS L1 / L2	1011
		1012
Station Coordinates		1005
		1006
Antenna Description		1007
		1008
Receiver and Antenna Description		1033
Network RTK Corrections	Network Auxiliary Station Data Message	1014
	GPS Ionospheric Correction Differences	1015
	GPS Geometric Correction Differences	1016
	Combined GPS Geometric and Ionospheric Correction Differences	1017
	GPS Network RTK Residual Message	1030
	GLONASS Network RTK Residual Message	1031
	GPS Network FKP Gradient Message	1034
	GLONASS Network FKP Gradient Message	1035
	GLONASS Ionospheric Correction Differences	1037
	GLONASS Geometric Correction Differences	1038
	Combined GLONASS Geometric and Ionospheric Correction Differences	1039

Figure 14 Message type of RTCM Version 3.1

As shown in Figure 14, RTCM version 3.1 is consist of information about RTK. Thus, it contains the messages about VRS, MAC which are methods of Network RTK. No.1034 message is FKP message of visible satellite from reference station.

In the first step, data collection, of post processing FKP-DGPS algorithm, No.1034 message is collected and decoded to get FKP gradient of error surfaces. At the same time, No.1005 message which is about station coordinates is also collected. It is used to calculate FKP correction for user who has got single-frequency GPS receiver. Furthermore, in post processing FKP-DGPS algorithm, conventional DGPS message hasn't used and No.1001 which contains GPS L1 observables such as pseudorange measurements is replaced to produce DGPS correction.

In terms of GPS receiver data, Evaluation kit equipped in U-blox LEA-6 GPS receiver which is a kind of typical single-frequency GPS receivers has used for this researched. Using the GPS receivers, user's pseudorange measurements and ephemeris data (satellite orbit information) are collected.

Figure 15 Ublox LEA-6 Evaluation kit (GPS Receiver)

3.2 Calculation of FKP correction

With the collected data, generation of tropospheric model delay should be done before calculation of FKP correction for pseudorange measurements. As the standard document of RTCM version 3.1, it is stated that ‘For the geometric gradient a standard troposphere model has to be applied before computing the difference. It is recommended to use the Niell mapping function and the Saastamoinen troposphere zenith delay model [24]. Thus, in this paper, tropospheric delay has been generated by using the Niell mapping function and the Saastamoinen troposphere zenith delay model according to the standard document and the tropospheric delays in the pseudorange measurements of reference station and user have been eliminated before solving navigation solution.

After that, calculation of FKP correction for pseudorange measurements have been done by following the RTCM standard. As mentioned before, FKP correction is about information of the gradients of error surfaces estimated by reference station. No.1034 FKP messages consists of following Figure 16.

DATA FIELD	DF NUMBER	DATA TYPE	NO. OF BITS	NOTES
GPS Satellite ID	DF009	uint6	6	
GPS Issue of data ephemeris (IODE)	DF071	bit(8)	8	Issue Of Data (GPS broadcast) Ephemeris to reference the geometric gradients
N0: Geometric gradient (North)	DF242	int12	12	
E0: Geometric gradient (East)	DF243	int12	12	
NI: Ionospheric gradient (North)	DF244	int14	14	
EI: Ionospheric gradient (East)	DF245	int14	14	
TOTAL			*66*	

Figure 16 No. 1034 message of RTCM version 3.1 (FKP)

These gradients information and the difference in space from reference station are required to calculate FKP corrections for ionosphere and troposphere as Equation (4).

$$
\begin{aligned}
\delta\rho_o(\triangleq \delta T_{FKP}) &= 6.37\cdot(N_o(\varphi-\varphi_R)+E_0(\lambda-\lambda_R)\cos(\varphi_R)) \\
\delta\rho_I(\triangleq \delta I_{FKP}) &= 6.37\cdot H\cdot(N_I(\varphi-\varphi_R)+E_I(\lambda-\lambda_R)\cos(\varphi_R))
\end{aligned}
\tag{4}
$$

$\delta\rho_o$: Geometric term

$\delta\rho_I$: Ionospheric term

N_I, E_I : north, east ionospheric gradient [ppm]

N_o, E_o : north, east geometric gradient [ppm]

$\varphi, \lambda : lat, lon$ of user / $\varphi_R, \lambda_R : lat, lon$ of Ref.stn

E : elevation angle

$H = 1 + 16(0.53 - E/\pi)^3$

3.3 FKP-DGPS Navigation Solution

The purpose of this paper is that FKP-DGPS algorithm is designed to improve DGPS positioning accuracy by using FKP correction and to verify the feasibility of FKP correction to compensate spatial decorrelation in pseudorange measurements. Figure 17 shows how to apply FKP correction to conventional DGPS method mathematically and how to get FKP-DGPS navigation solution.

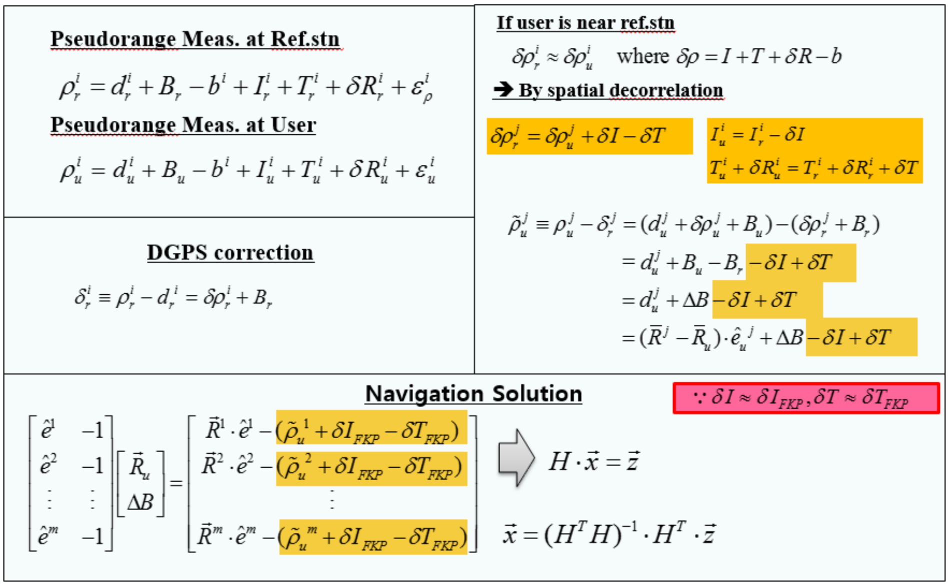

Figure 17 FKP-DGPS Navigation Solution

It is confirmed that bias error due to spatial decorrelation can be eliminated by FKP correction. In addition, the common errors which causes bias error can be eliminated DGPS correction. Therefore, that is why there is no bias error in FKP-DGPS.

3.4 Experimental Result

To verify the post processing FKP-DGPS algorithm, we have constructed experiment. It was static user test. As shown in Figure 18, User was Bldg. 312

reference station in Seoul National University with Ublox receiver (Figure 15) as commercial single frequency GPS receiver and trimble zephyr geodetic 2 antenna (Figure 19) at 24th September in 2013. It was carried out an hour and time interval was 1 sec. Also, as FKP reference station, Yang-Pyung station was selected which is 50km east of user and received FKP information data using GNSS Internet Radio Program (Figure 20)

Figure 18 Static User (Bldg. 312 at Seoul National University)

Figure 19 Trimble Zephyr Geodetic 2 Antenna

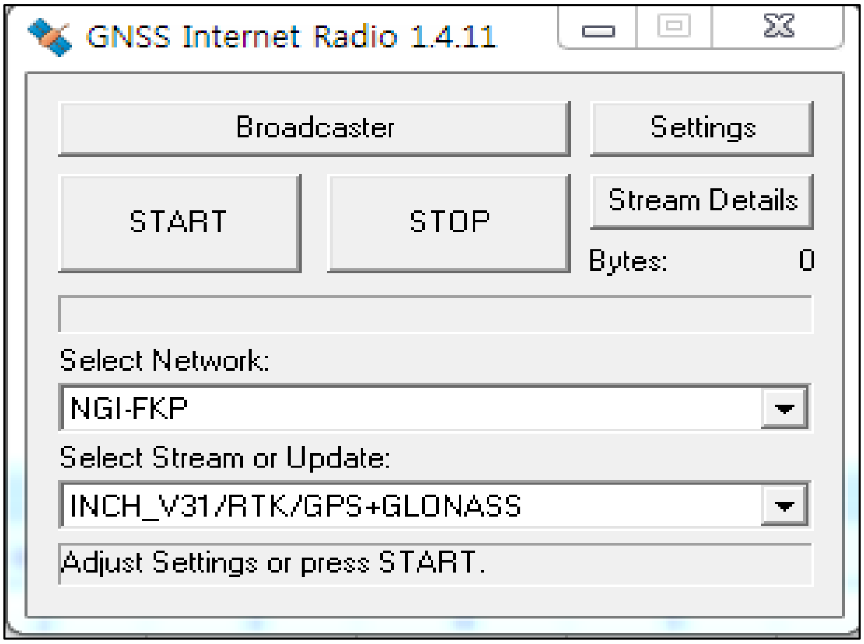

Figure 20 GNSS Internet Radio Program

With this configuration of experiment, all data was collected and MATLAB was used for post processing to analysis.

Figure 21 shows Skyplot and Figure 22 shows the elevation angle of visible satellites while the experiment. As shown in Figure 21, Identical set of visible satellite was using when standalone, DGPS, FKP-DGPS navigation solution were calculated to prevent different condition which could affect position results.

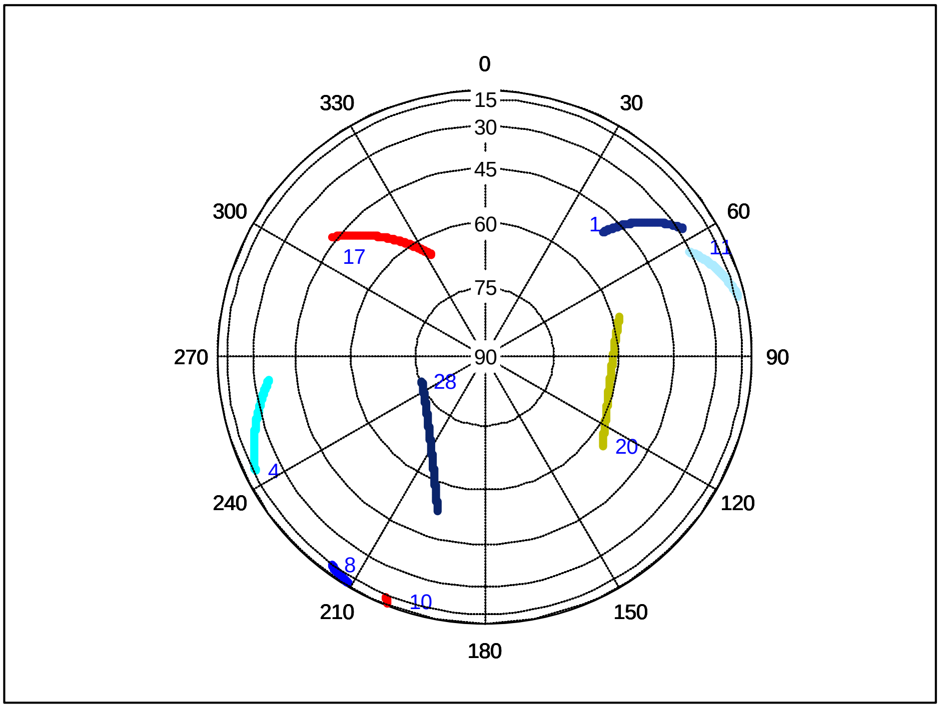

Figure 21 Skyplot (Static test, Post processing)

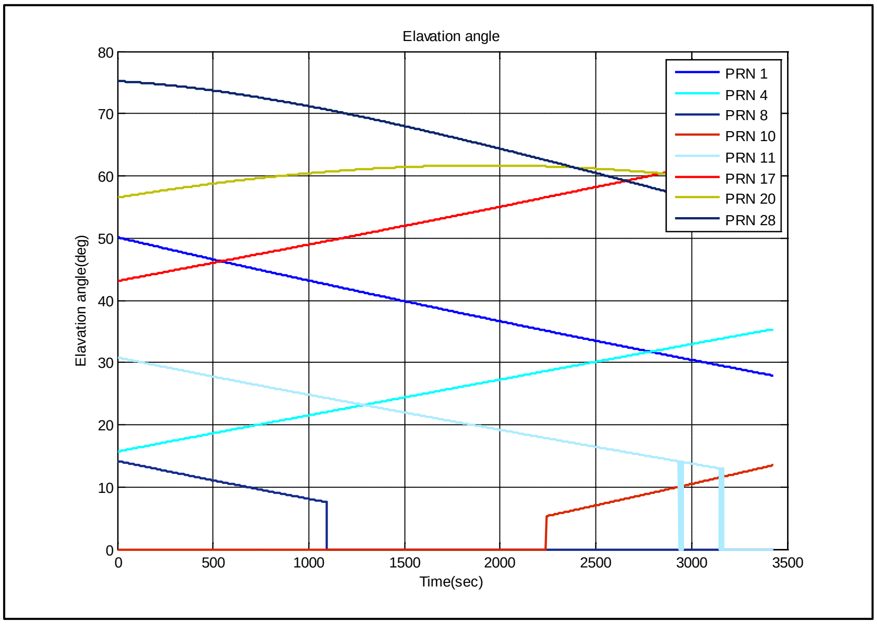

Figure 22 Elevation Angle (Static test, Post processing)

The results are present in ENU coordinate (East-North-Up Coordinate) compared to the exactly known location of Bldg. 312 reference station.

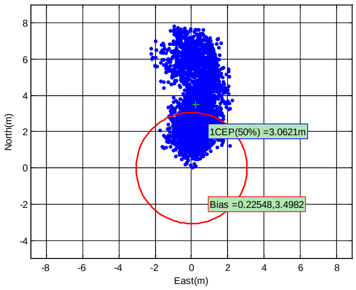

Figure 23 Standalone

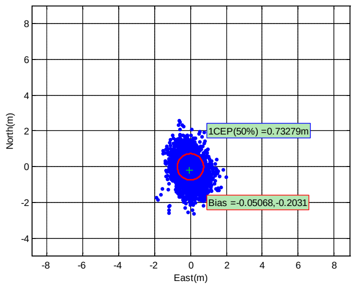

Figure 24 FKP-DGPS

Figure 23 shows the standalone positioning accuracy in ENU coordinate and Figure 24 shows the FKP-DGPS positioning accuracy. In the standalone position, much more biased result is confirmed than in FKP-DGPS. It can be explained that the common error such as ionospheric delay, tropospheric delay, and satellite orbit error are not eliminated in standalone. They affect the standalone positioning accuracy as bias error. However, in FKP-DGPS, they are eliminated respectively and almost zero bias error exists in the result. Also, the both results are compared numerically as shown in Table 2.

$$*Bias = \sqrt{Error_{east}^{\ 2} + Error_{north}^{\ 2}}$$

Table 2 Positioning Accuracy of Standalone, FKP-DGPS

	1CEP(50%)	*Bias
Stand-alone(m)	3.0621	3.5054
FKP –DGPS(m)	**0.7328**	**0.2093**

In the case of standalone, bias error is about 3.5 meters and FKP-DGPS has 0.21 meters bias error which is 15 times smaller than the result of standalone. Also, according to smaller bias error, FKP-DGPS has 0.73 meters positioning accuracy for 1CEP (50%) which is 4 times smaller than the standalone.

This research is to improve DGPS positioning accuracy by using FKP correction to eliminate effectively remaining bias error in DGPS due to spatial decorrelation and, in this stage, the feasibility of FKP correction is to be verified by post processing FKP-DGPS algorithm. Therefore, it is important to make sure that FKP-DGPS positioning accuracy is better than DGPS positioning accuracy respectively. The following figures show DGPS (Figure) and FKP-DGPS positioning results.

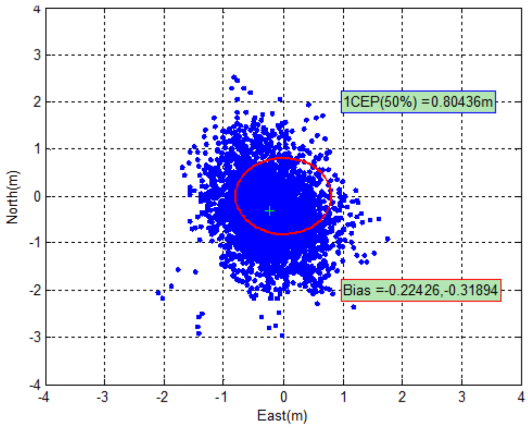

Figure 25 DGPS

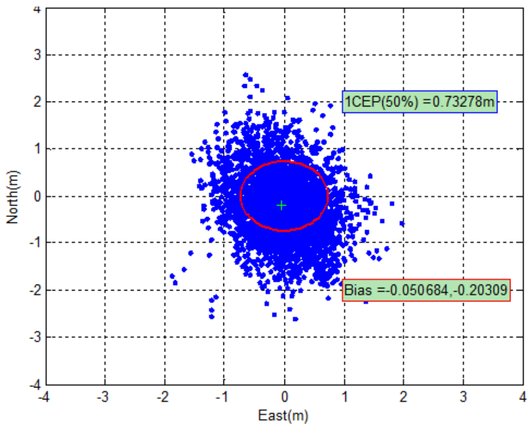

Figure 26 FKP-DGPS

Compared to the DGPS result, FKP-DGPS result looks like similar. However, having a close look, it is confirmed that DGPS is biased slightly in the direction of 7 o'clock and FKP-DGPS has bias error that is closer to zero than DGPS. Also, the both results are compared numerically as shown in Table 3.

Table 3 Positioning Accuracy of DGPS, FKP-DGPS

	1CEP(50%)		*Bias	
DGPS (m)	0.8044	10% reduced	0.3899	60% reduced
FKP –DGPS(m)	**0.7328**		**0.2093**	

In the case of DGPS, bias error is about 0.4 meters and it has 0.8 meters 1CEP positioning accuracy. However, FKP-DGPS has 0.2 meters bias error and 0.73 meters 1CEP positioning accuracy. In other words, FKP-DGPS has 10% less 1CEP and 60% less bias error. Therefore, the feasibility of FKP correction for pseudorange measurements has been verified.

4. Real-Time FKP-DGPS Algorithm

In real-time FKP-DGPS algorithm, in contrast with the post processing FKP-DGPS algorithm which make DGPS correction by using pseudorange measurements and known coordinate of reference station, real-time broadcasted DGPS correction in RTCM version 2.3 has applied for the real-time algorithm. Furthermore, it is not necessary to solve navigation solution. FKP-DGPS correction is encoded in No.1 message format in RTCM version 2.3 to apply for GPS receiver directly. The GPS receiver can calculate navigation solution and give the solution as output result. Therefore, the post-processing algorithm is changed as shown in Figure 27.

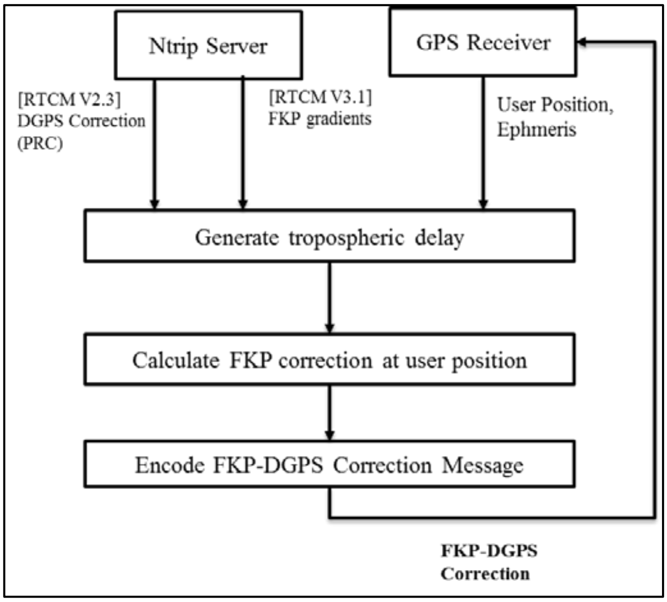

Figure 27 Real-Time FKP-DGPS algorithm

4.1 Data Collection

As mentioned before, real-time FKP-DGPS algorithm is different from the post processing algorithm in just usage of broadcasted DGPS correction information in RTCM version 2.3 and encoding FKP-DGPS correction to format of No.1 messages in RTCM version 2.3 and applying it to GPS receiver directly which can calculate FKP-DGPS navigation solution itself. Thus, it is required to look see the messages in RTCM version 2.3 which includes in DGPS correction messages. The following Figure 28 shows the message types in RTCM version 2.3. Basically, DGPS correction is included as No.1 which is information about the common errors such as ionospherical and tropospherical delay, and satellite orbit error. Also, many other messages included like delta DGPS correction as No.2 and GPS reference station parameters as No.3 and so on.

MESSAGE TYPE NO.	CURRENT STATUS	TITLE
1	Fixed	Differential GPS Corrections
2	Fixed	Delta Differential GPS Corrections
3	Fixed	GPS Reference Station Parameters
4	Tentative	Reference Station Datum
5	Fixed	GPS Constellation Health
6	Fixed	GPS Null Frame
7	Fixed	DGPS Radiobeacon Almanac
8	Tentative	Pseudolite Almanac
9	Fixed	GPS Partial Correction Set
10	Reserved	P-Code Differential Corrections
11	Reserved	C/A-Code L1, L2 Delta Corrections
12	Reserved	Pseudolite Station Parameters
13	Tentative	Ground Transmitter Parameters
14	Fixed	GPS Time of Week
15	Fixed	Ionospheric Delay Message
16	Fixed	GPS Special Message
17	Fixed	GPS Ephemerides
18	Fixed	RTK Uncorrected Carrier Phases
19	Fixed	RTK Uncorrected Pseudoranges
20	Fixed	RTK Carrier Phase Corrections
21	Fixed	RTK/Hi-Accuracy Pseudorange Corrections
22	Tentative	Extended Reference Station Parameters
23	Tentative	Antenna Type Definition Record
24	Tentative	Antenna Reference Point (ARP)
25-26	--	Undefined
27	Tentative	Extended Radiobeacon Almanac
28-30	--	Undefined
31	Tentative	Differential GLONASS Corrections
32	Tentative	Differential GLONASS Reference Station Parameters
33	Tentative	GLONASS Constellation Health
34	Tentative	GLONASS Partial Differential Correction Set ($N > 1$) GLONASS Null Frame ($N \leq 1$)
35	Tentative	GLONASS Radiobeacon Almanac
36	Tentative	GLONASS Special Message
37	Tentative	GNSS System Time Offset
38-58	--	Undefined
59	Fixed	Proprietary Message
60-63	Reserved	Multipurpose Usage

Figure 28 Message Types in RTCM Version 2.3 [23]

In this real-time FKP-DGPS algorithm, broadcasted RTCM version 2.3 data via internet is acquired and decoded to get PRC (Pseudorange Correction) as DGPS correction information.

4.2 Generation of FKP-DGPS correction message

In this real-time FKP-DGPS algorithm, the method of generation of FKP correction is equal in the post processing algorithm as following Equation (5). Generated geometric and ionospheric term in Equation (1) can be modified to the FKP correction for L1 pseudorange measurements as Equation (6). Finally, it is simple to make FKP-DGPS correction by combining FKP correction and PRC (DGPS correction).

$$\begin{aligned} \delta\rho_o(\triangleq \delta T_{FKP}) &= 6.37 \cdot (N_o(\varphi - \varphi_R) + E_0(\lambda - \lambda_R)\cos(\varphi_R)) \\ \delta\rho_I(\triangleq \delta I_{FKP}) &= 6.37 \cdot H \cdot (N_I(\varphi - \varphi_R) + E_I(\lambda - \lambda_R)\cos(\varphi_R)) \end{aligned} \tag{5}$$

$\delta\rho_o$: Geometric term

$\delta\rho_I$: Ionospheric term

N_I, E_I : north, east ionospheric gradient [ppm]

N_o, E_o : north, east geometric gradient [ppm]

$\varphi, \lambda : lat, lon$ of user $/ \varphi_R, \lambda_R : lat, lon$ of Ref.stn

E : elevation angle

$H = 1 + 16(0.53 - E/\pi)^3$

$$\boxed{\delta\rho_{r,f} = \delta\rho_o - (\frac{f_1}{f})^2 \delta\rho_I} \tag{6}$$

f_1 : L1 frequency / f : meas. frequency

In the case of commercial single-frequency GPS receivers, they have interface to be applied No.1 DGPS correction message in RTCM version 2.3 to improve its standalone position. Therefore, if FKP-DGPS correction is modified in the form of No.1 DGPS correction message, it is possible to apply FKP-DGPS correction to GPS receiver directly. FKP-DGPS correction is generated easily as following Equation (7) and is called FKP-DGPS PRC.

$$\boxed{PRC_{FKP-DGPS} = PRC_{DGPS} + \delta\rho_{r,f}} \tag{7}$$

$PRC : Pseudorange\ Correction$

$\delta\rho_{r,f} = FKP\ Correction$

In order to make this FKP-DGPS PRC in the form of No.1 message in RTCM version 2.3, it is necessary to look into overall configuration of it. As explained before, various messages are broadcasted in RTCM version 2.3. This RTCM message consist of two main parts, a header and the rest remaining words of the message. The header consist of two words. The second part contains up to 31 words (usually it does not extend the length of 12 words) [21]. The scheme of the structure of RTCM message is presented in the Figure 29.

HEADER		THE REST OF WORDS			
WORD 1	WORD 2	WORD 3	WORD 4	...	WORD 33

Fig. 2. The structure of RTCM message

Figure 29 The Structure of RTCM version 2.3 message

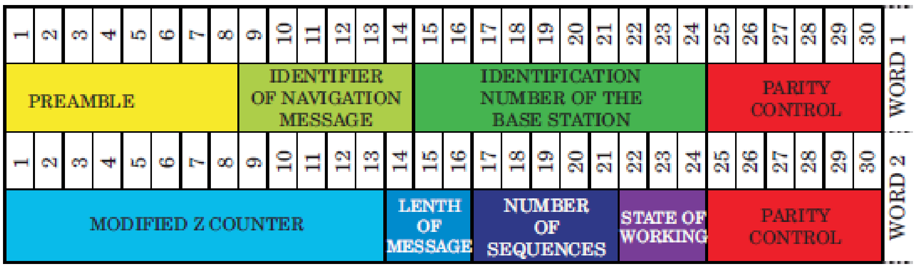

Figure 30 The header of RTCM version 2.3 message

The header is constructed by the two first words in each message they are identical for every type of message. The main function of the header is to maintain the timing of receipt the corrections by means of a modified counter Z. Also it provides the identification number of the station which is important information because it needs to be same as in RTCM version 3.1 to make valid FKP-DGPS correction.

Among second parts of RTCM messages following header, No.1 message is the most significant because it contains DGPS correction (PRC). As shown in Figure 31, this is the primary message type which provides the pseurdorange correction for any user. There are an Issue of Data (IOD – the age of data) parameter and UDRE which is a one-sigma estimate of the uncertainty in the pseudorange correction as estimated by the reference station, and combines the estimated effects of multipath, signal-to-noise ratio, and other effect.

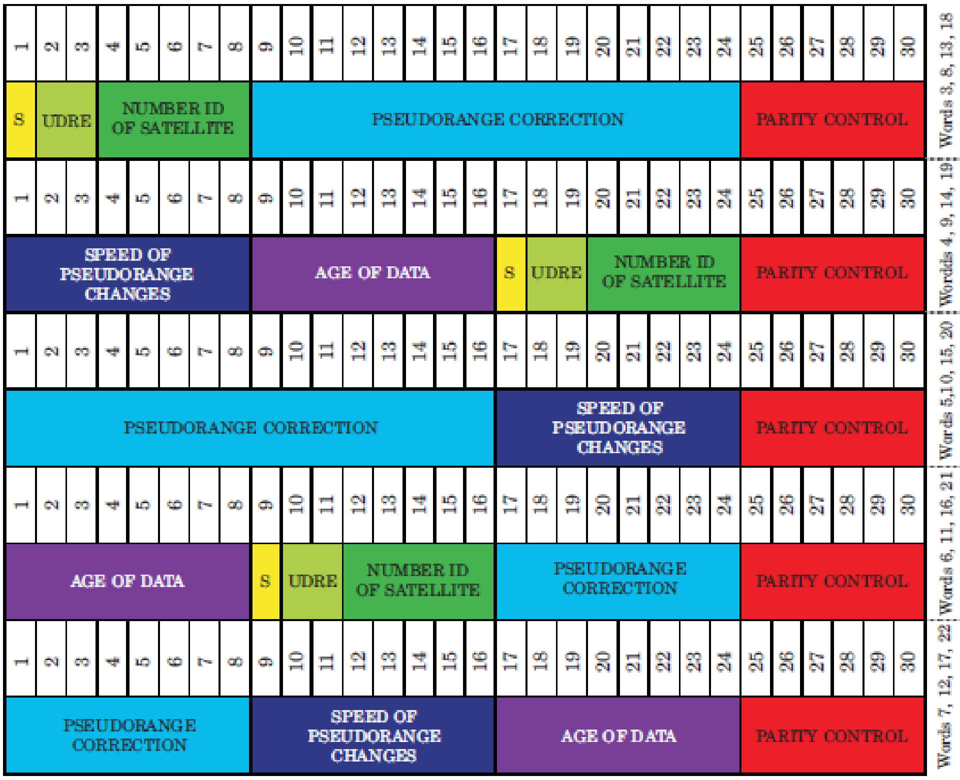

Figure 31 Structure of RTCM version 2.3 Message No.1

Consequently, in real-time FKP-DGPS algorithm, generated FKP-DGPS correction is encoded in No.1 message format to look like PRC in RTCM version 2.3.

5. Real-Time Experimental Result

In order to verity the real-time FKP-DGPS algorithm, the test program has made based on MFC as shown in Figure 32. The program consists of three steps such as data collection, generation of FKP correction, and encoding FKP-DGPS message as explained before.

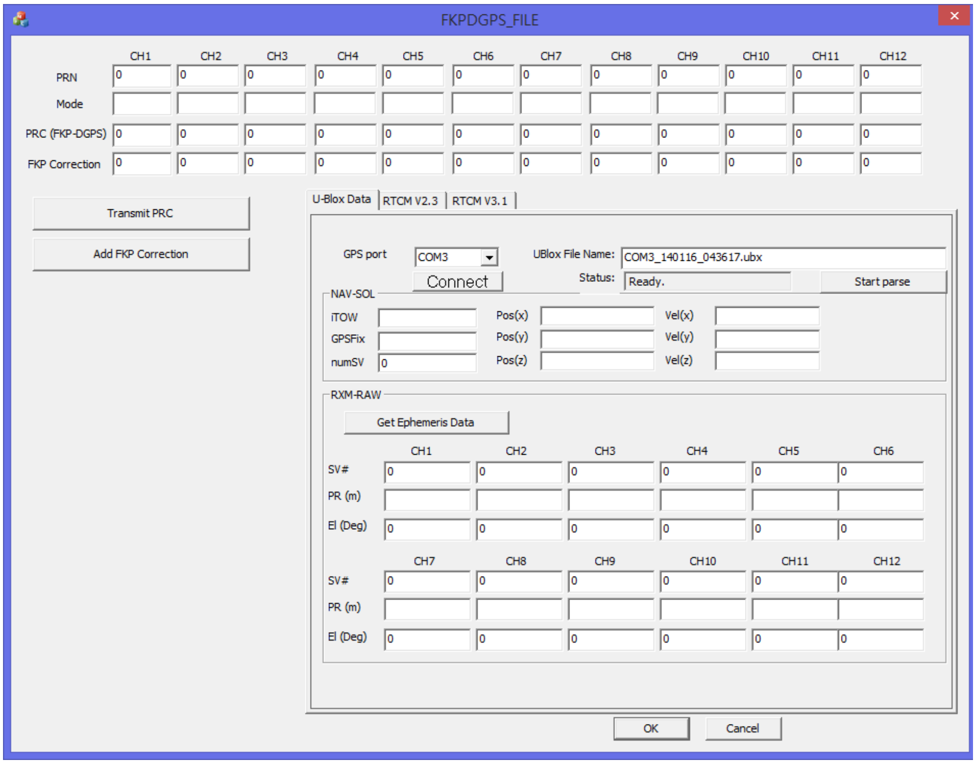

Figure 32 Real-Time Experimental Program (MFC)

The experiments have been done for static and dynamic user. The following Figure 33 shows the configuration of the experiments.

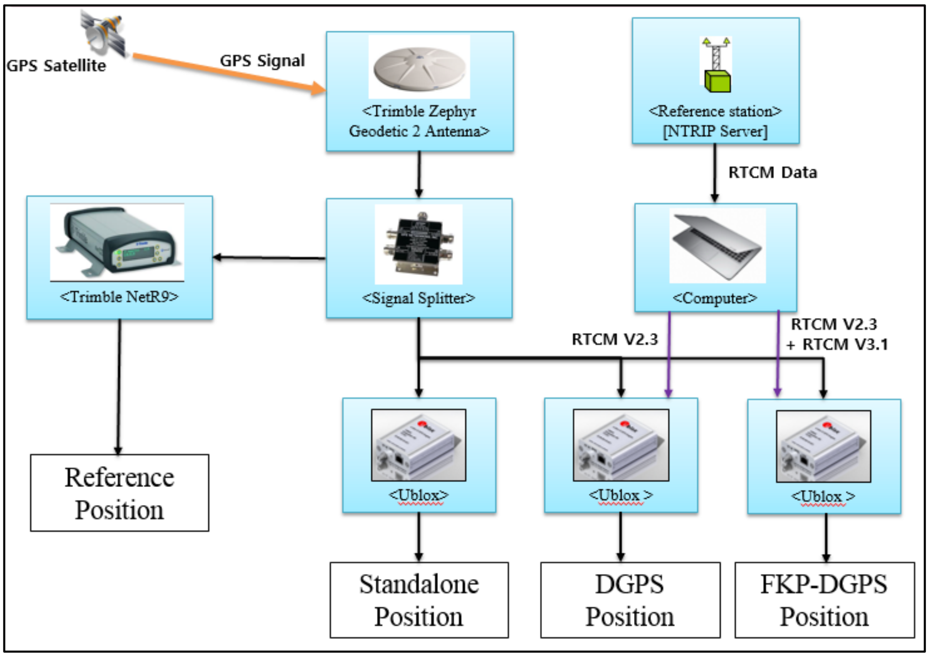

Figure 33 Configuration of experiment

Similarly to the post-processing test, trimble zephyr geodetic 2 antenna is used as antenna to acquire GPS signals which are passed on to three GPS receivers equally through signal splitter. Each of three GPS receivers is operated as standalone, DGPS, and FKP-DGPS mode. Also GNSS Internet Radio Program is used to get DGPS and FKP correction information via Internet.

5.1 Static Test Result

In the case of static user, similarly to the test in post-processing, user was Bldg. 312 reference station in Seoul National University with Ublox receiver at 17th May in 2014. It was carried out an hour (10p.m ~ 11p.m in local time) and time interval was 1 sec. Also, as FKP reference station, Yang-Pyung station was selected which is 50km east of user and received FKP information data using GNSS Internet Radio Program.

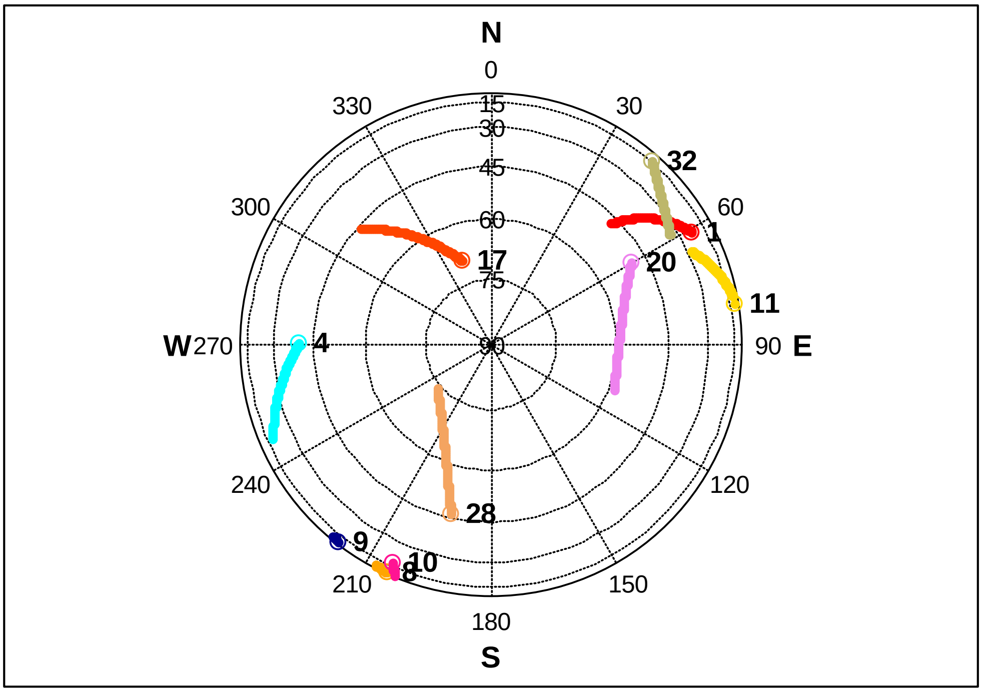

Figure 34 Skyplot (Real-time Static test)

As mentioned before, without solving navigation solution, FKP-DGPS correction messages were delivered to GPS receivers in real-time. Thus, the positioning results have been confirmed in the outputs from GPS receivers. The following figures show the results of standalone, DGPS, FKP-DGPS in sequence.

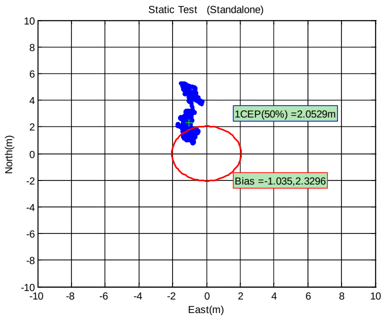

Figure 35 Standalone Result (Real-time Static test)

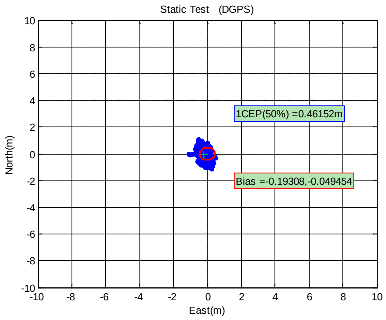

Figure 36 DGPS Result (Real-time Static test)

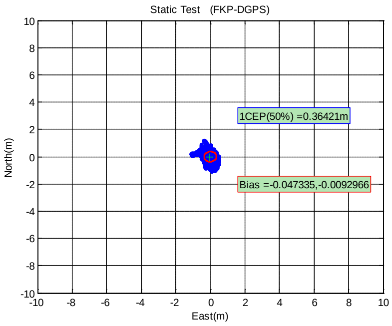

Figure 37 FKP-DGPS Result (Real-time Static test)

The results has been calculated in ENU coordinates. In the result of standalone, it is easily seen that position has bias error. Standalone position is affected by the common errors such as ionospheric, tropospheric delay and satellite orbit error without any collection. However, in the results of DGPS, FKP-DGPS, it is difficult to see bias error and they contain just noise. The following figures are expanded to check the difference between DGPS and FKP-DGPS in details.

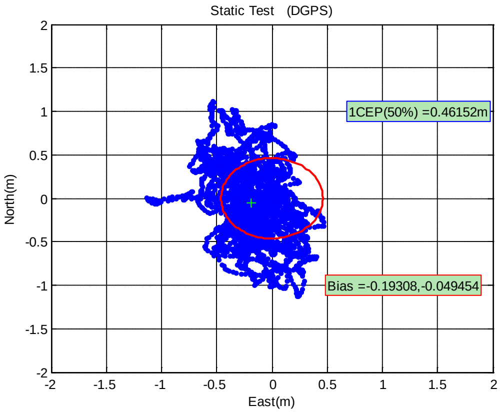

Figure 38 DGPS Result in expansion

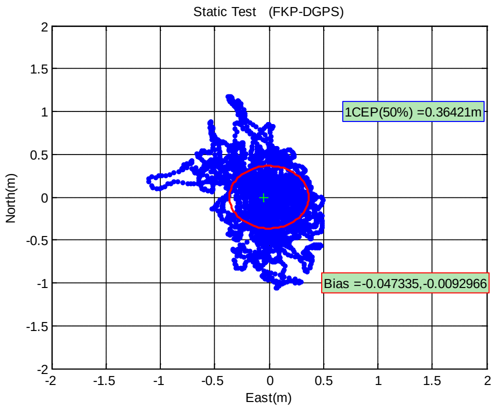

Figure 39 FKP-DGPS Result in expansion

In the case of DGPS, the average of position is biased slightly in the west. Compared to DGPS, FKP-DGPS has almost zero bias. The results are compared numerically as shown in Table 4.

Table 4 Positioning Accuracy of Real-time static test

	1CEP(50%)	*Bias
Standalone (m)	2.0529	2.5492
DGPS (m)	0.4615	0.1993
FKP–DGPS (m)	**0.3642**	**0.0482**
	21% reduced	76% reduced

Compared to standalone, DGPS, FKP-DGPS results are much better. In the case of DGPS, bias error is about 0.2 meters and it has 0.46 meters 1CEP positioning accuracy. However, FKP-DGPS has 0.04 meters bias error and 0.36 meters 1CEP positioning accuracy. In other words, FKP-DGPS has 21% less 1CEP and 76% less bias error in real-time static test. Therefore, the feasibility of FKP correction for pseudorange measurements has been verified in static user.

5.2 Dynamic Test Result

Utilizing the real-time FKP-DGPS algorithm, the dynamic test has been carried out to verity the feasibility of the FKP correction for dynamic user. In the dynamic test, at 21th May in 2014, the user was the vehicle (Figure 41) and it was driven 15 rounds in the parking lot of Seoul grandpark shown in Figure 40. The vehicle's speed was about average 35km/h. It was carried out during 11 minutes (3:05p.m ~ 3:16p.m in local time). The following Figure 42, 43 show the mounted antenna on the roof of the land vehicle and the configuration of experimental equipment.

Figure 40 Parking lot of Seoul Grand Park


Figure 41 Land Vehicle (Dynamic User)


Figure 42 Mounted Antenna on the roof of the land vehicle

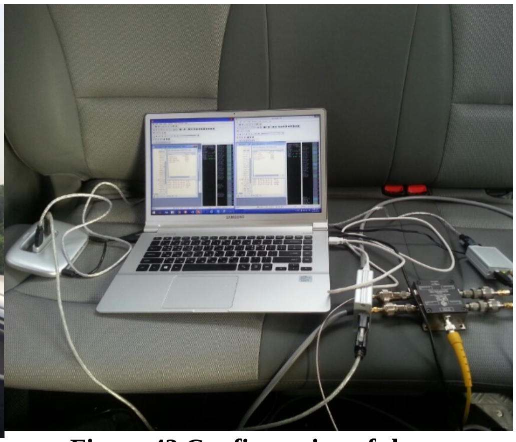
Figure 43 Configuration of the experimental equipment

The configuration of the dynamic test is same as in the static test. The analysis of the results also was carried out equally. The following Figure 44 show the skyplot while dynamic test.

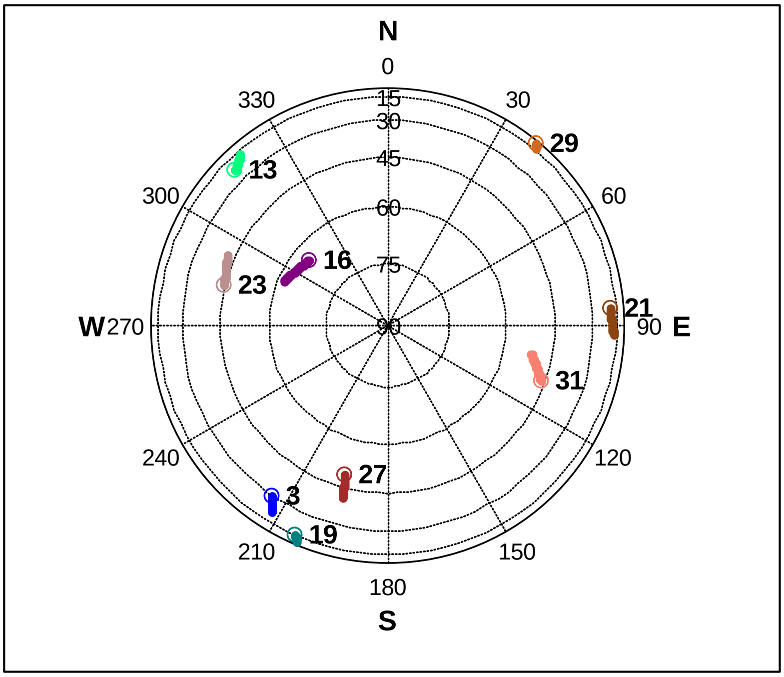

Figure 44 Skyplot (dynamic test)

The following figures show the results of standalone, DGPS, FKP-DGPS in the dynamic test.

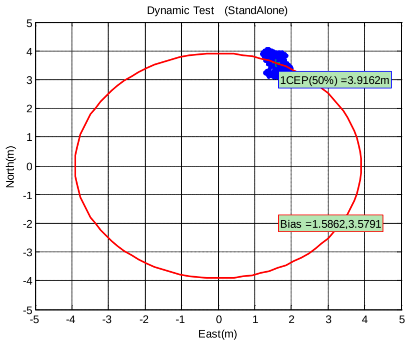

Figure 45 Standalone Result (Dynamic test)

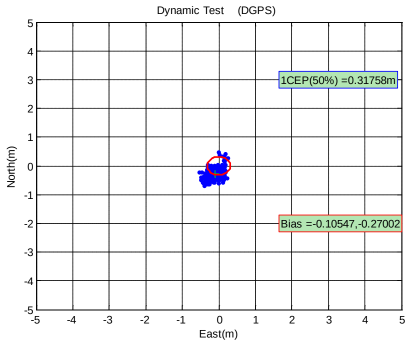

Figure 46 DGPS result (Dynamic test)

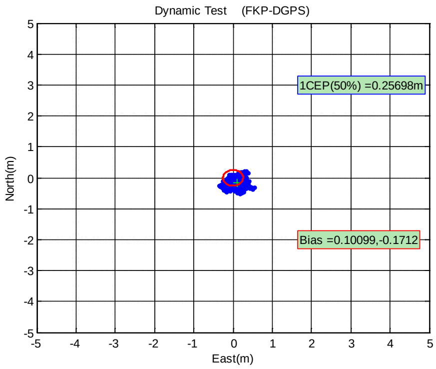

Figure 47 FKP-DGPS Result (Dynamic test)

The results are similar to the results of static test. In the standalone result, it is easy to see bias error. Compared to it, in the DGPS, FKP-DGPS results, it is difficult to see bias error. The following figures show DGPS, FKP-DGPS in the close look.

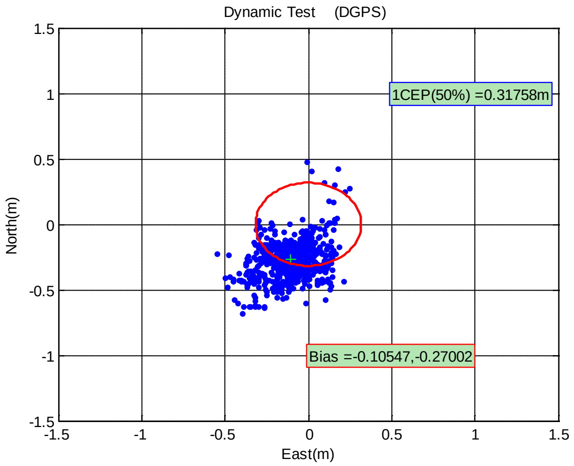

Figure 48 DGPS Result in expansion

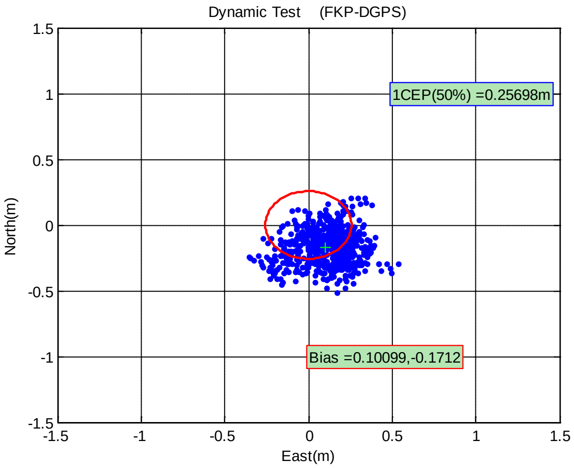

Figure 49 FKP-DGPS Result in expansion

The FKP-DGPS result has smaller bias error rather than the DGPS result. It is also confirmed numerically in Table 5.

Table 5 Positioning Accuracy of Real-time dynamic test

	1CEP(50%)	*Bias
Standalone (m)	3.9162	3.9148
DGPS (m)	0.3176	0.2899
FKP–DGPS (m)	**0.2570** 19% reduced	**0.1988** 31% reduced

As shown in Table 5, FKP-DGPS has much better positioning accuracy rather than standalone. Also, it has 19% less 1CEP and 31% less bias error. In the conclusion, the feasibility of FKP correction for pseudorange measurements has been verified in static and dynamic user. In other words, it is possible to improve conventional DGPS positioning accuracy using FKP correction message.

6. Conclusion

In this paper, in order to improve the positioning accuracy of commercial single-frequency GPS receiver equipped in smartphone or car navigation, FKP-DGPS algorithm has been designed by using FKP correction which is broadcasted for CDGPS to eliminate influence of spatial decorrelation that remains in conventional DGPS augmentation system based on pseudorange measurements.

FKP correction is one of the Network-RTK methods and it is an information to deal with spatial decorrelation in CDGPS based on carrierphase measurements. It can be easily modified to the correction for pseudorange measurements. In Korea, FKP has been being broadcasted since 2012. Thus, to use FKP correction for pseudorange measurement, it is not necessary to add more hardware system and to construct infrastructure.

Up to now, the researches to verify the feasibility of FKP correction for pseudorange measurements have not been done. Thus, before test with real-time FKP-DGPS algorithm, post-processing FKP-DGPS algorithm has been designed and the static test has been carried out to verity its feasibility and performance. In the result, FKP-DGPS has 10% less 1CEP positioning accuracy and 60% less bias error compared to conventional DGPS. In the end, utilizing the real-time FKP-DGPS algorithm, the real-time program has been made based on MFC and static and dynamic tests have been carried out in real-time. In the real-time static test, FKP-DGPS has 21% less 1CEP and 76% less bias error rather than DGPS. Also, in the dynamic test, FKP-DGPS has better positioning accuracy than DGPS. It has 19% improved 1CEP and 31% less bias error. Considering these results, FKP correction can eliminate bias error due to spatial decorrelation in DGPS and it can be utilized for commercial single-frequency GPS receivers effectively.

In the future, additional tests would be carried out to verify the performance of FKP-DGPS algorithm in the condition with various factors cause spatial decorrelation.

요 약

본 논문은 저가의 단일주파수 GPS (Global Positioning System) 수신기의 위치정확도를 보다 향상시키기 위해 기존 의사거리 측정치 기반의 DGPS (Differential GPS) 보강항법을 이용하고 또한 DGPS 에서 처리할 수 없는 공간이격오차에 의한 잔여 바이어스 오차를 반송파위상 측정치 기반의 CDGPS(Carrierphase Differential GPS)를 위한 FKP 보정정보를 이용하여 처리하는 방법에 대해 연구하였다.

공간이격오차(Spatial decorrelation)는 보정정보를 제공하는 기준국과 사용자의 거리가 멀어짐에 따라 공간상의 상관성이 떨어지게 되고 이로 인하여 측정치 사이에 존재하는 전리층, 대류층, 위성관련 오차와 같은 공통오차 또한 차이가 나게 되는 것을 말한다. 상대적으로 공간이격오차가 유발할 수 있는 오차의 크기가 의사거리 측정치 기반의 시스템에서는 측정치의 잡음수준보다 작기 때문에 중요성 또한 크게 부각되지 않고 있었으며, 이를 보상하는 시스템에 대한 구축은 아직까지 완성된 것은 없으며 광역보정시스템(WADGPS, Wide Area Differential GPS)나 지역적 보강항법시스템(RAAS, Regional Area Augmentation System)와 같은 시스템이 개발 중이거나 구축 중이다. 반면, 상대적으로 반송파위상 측정치 기반의 시스템에서의 공간이격오차는 미지정수를 결정하는데 영향을 줄 수 있고 이에 따라 위치정확도가 크게 영향을

받을 수 있다. 따라서 이를 보상하는 연구가 보다 활발하며 시스템 또한 구축된 것이 많다. 대표적으로 반송파위상 측정치 기반의 CDGPS 보강항법의 공간이격오차를 제거하기 위한 연구는 VRS (Virtual Reference System), MAC (Master-Auxiliary Concept), FKP (Flaechen Korrektur Parameter)와 같은 Network RTK(Real-Time Kinematics)방식이 있으며 현재 국내에서 구축되어 상용 서비스가 진행되고 있는 경우가 많다.

위와 같은 Network RTK 방식 중, FKP 는 이론적으로 의사거리 측정치에 대한 활용이 가능하다고 알려져 있으며 현재 국내에서 2012 년도부터 상용화된 서비스이다. 또한 FKP 보정정보는 단방향 통신으로 사용자 수의 제한이 없다는 단점이 있으며 반송파위상 측정치를 기반으로 하는 보정정보로 낮은 잡음을 가진다는 장점이 있다. 따라서 본 논문에서는 기존 DGPS 보강항법의 공간이격오차를 효과적으로 보상하기 위해서 현재 국토지리원에서 인터넷(TCP/IP)를 통해 방송하고 있는 FKP 보정정보를 이용하여 기존 DGPS 보강항법을 단일주파수 GPS 수신기에서 사용하기 위한 방식에서 추가적인 하드웨어 구성이나 인프라 구축 없이 GPS 수신기에 적용할 수 있도록 실시간 FKP-DGPS 알고리즘을 구성하여 실제로 정적, 동적 실험을 통해 성능을 검증하였다.

본 논문의 FKP-DGPS 알고리즘의 결과, 정적 사용자의 경우에 기존 DGPS 에 비해 76% 작은 바이어스 오차와 21% 향상된 1CEP 위치정확도를 가지는 성능을 확인하였으며, 동적 사용자의 경우에

마찬가지로 31% 작은 바이어스 오차와 21% 향상된 1CEP 위치정확도를 가지는 것을 확인하였다.

본 논문의 내용은 현재 일반 사용자들에게 많이 이용되고 있는 스마트폰이나 차량용 네비게이션에 장착된 저가 GPS 수신기에 적용하여 사용자들에 보다 높은 위치 서비스를 제공해 줄 수 있을 것을 기대할 수 있다.

주요어: DGPS, CDGPS, Spatial Decorrelation, FKP, FKP-DGPS

학번: 2012-23160

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