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# Analysis of Multi-Differential GNSS Positioning Accuracy in Various Signal Reception Environments

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## ABSTRACT

This study analyzed positioning accuracy of the multi-differential global navigation satellite system (DGNSS) algorithm that integrated GPS, GLONASS, and BDS. Prior to the analysis, four sites of which satellite observation environment was different were selected, and satellite observation environments for each site were analyzed. The analysis results of the algorithm performance at each of the survey points showed that high positioning performance was obtained by using DGPS only without integration of satellite navigation systems in the open sky environment but the positioning performance of multi-DGNSS became higher as the satellite observation environments degraded. The comparison results of improved positioning performance of the multi-DGNSS at the poor reception environment compared to differential global positioning system (DGPS) positioning results showed that horizontal accuracy was improved by 78% and vertical accuracy was improved by 65% approximately.

**Keywords:** GPS, GLONASS, BDS, multi-DGNSS

## 1. INTRODUCTION

As position-based services have been expanded around the world, new developments of global navigation satellite system (GNSS) have been rapidly progressed. In the early days, only global positioning system (GPS) of the US provided stable services. However, as GLObal NAvigation Satellite System (GLONASS) following the GPS services of Russia started to be provided, position-based services utilizing GPS and GLONASS simultaneously have been provided in various areas. In recent years, BeiDou Satellite System (BDS) in China has started its operation and utilized focusing on the Asia-Pacific region. Nations around the world have developed and utilized their own satellite navigation system such as Galileo in Europe, Quasi-Zenith Satellite System (QZSS) in Japan, and Indian Regional Navigation Satellite System (IRNSS) in India.

The satellite navigation system has a different level of accuracy depending on satellite observation environments. Accuracy of a few meters can be ensured in the open sky environment where satellite signals are not blocked as there are no terrain features nearby because there are few error making factors. In contrast, in urban canyon where there are many terrain features or buildings that block the field of view of satellites, the number of visible satellites may be reduced due to blocked satellite signals or multi-path errors may be induced due to the reflection of signals by buildings. Under such environment, positioning errors can be tens of meters to hundreds of meters, or positioning may be impossible due to the lack of visible satellites.

The multi-GNSS is a technology that utilizes currently operating satellite navigation systems such as GPS, GLONASS, and BDS. That is, more number of visible satellites can be ensured during positioning by integrating two or more systems rather than using a single system. Since the multi-GNSS can ensure a sufficient number of visible satellites even in urban canyon where satellite signals can be easily blocked, it can achieve more stable positioning

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**Table 1.** Difference of GNSS system.

| System | GPS | GLONASS | BDS |
|---|---|---|---|
| Coordinates System | WGS84 | PZ-90.11 | CGCS2000 |
| Time system | GPS time | GLONASS time | BDS time |
| Satellite type | MEO | MEO | GEO, IGSO, MEO |
| Ephemeris parameter | Keplerian orbital elements | Satellite position, velocity, Acceleration etc. | Keplerian orbital elements |
| Ephemeris updates | 2 h | 30 min | 1 h |

than using a single system. Tegedor et al. (2014) analyzed positioning results using GPS, GLONASS, Galileo, and BDS and conducted a study on precision orbit determination. Li et al. (2015) proposed an integrated positioning model after comparing satellite visibility, DOP, signal strength, multi-path errors, code and phase errors of GPS, GLONASS, BDS, and Galileo. In Korea, Choi et al. (2015) analyzed integrated positioning performance of GPS/GLONASS/BDS/QZSS in the Korean Peninsula while Tae et al. (2015) analyzed integrated positioning performance of GPS/GLONASS/BDS utilizing inexpensive receivers in open sky and urban canyon.

As a technology to improve positioning accuracy, differential GNSS (DGNSS) can be used. DGNSS is a method that reduces a positioning error by applying augmented information created from the reference station that knows the precise coordinates. Since DGNSS produces higher accuracy than other methods that calculate tropospheric and ionospheric delay errors using empirical models. The pseudo-range correction (PRC) information used in DGNSS positioning increases the effect of error correction because error correlation becomes larger as the distance between reference station and user becomes closer. The DGNSS positioning is capable of positioning accuracy up to sub-meter level depending on observation environments and positioning algorithm. Seo et al. (2014) proposed an algorithm that generated PRC information in Galileo and analyzed integrated GPS/Galileo positioning accuracy using the algorithm based on simulations. Yoon et al. (2016) validated positioning performance through the approach using a position domain technique for DGNSS positioning of GPS, GLONASS, and BDS in a smartphone. Hsu et al. (2016) validated mobile positioning of differential GPS/GLONASS in urban canyon.

This study utilized GPS, GLONASS, and BDS to ensure a sufficient number of satellites in various satellite observation environments. In addition, this study implemented multi-DGNSS by applying PRC of each system and improved positioning accuracy by applying a model that improved multi-path errors. To validate a performance of the algorithm developed in this study, experimental environments at various conditions were analyzed and positioning performances of the algorithm at various environments were compared.

## 2. MULTI–DGNSS

With the multi-DGNSS positioning, a large number of visible satellites can be secured because many satellite navigation systems such as GPS, GLONASS, BDS, Galileo, QZSS, and IRNSS are integrated and utilized in positioning. It can also improve positioning accuracy by applying PRC for each system. This section discusses the integration of GPS, GLONASS, and BDS used in this study and basic concept of DGNSS as well as multi-path error reduction technique applied in this study.

### 2.1 Multi-GNSS

Since GPS, GLONASS, and BDS are satellite navigation systems that are independently developed by the US, Russia, and China, each system is different in terms of coordinate and time systems. A process is needed to make a difference between systems to be matched based on a single standard or additional calculation is required to perform multi-GNSS positioning. The aforementioned systems employ different reference coordinate and time system as presented in Table 1, and a type of ephemeris provided to calculate satellite position and orbit type are different. Thus, a difference between systems must be taken into consideration to perform integrated positioning. A method that calculates a difference between systems and applies the difference can be found in the study of Tae et al. (2015).

### 2.2 DGNSS

DGNSS is divided into reference station and user parts. The reference station generates PRC information and the user receives and applies the generated correction information by the reference station to positioning. Since the reference station knows the accurate coordinate, it can calculate a geometric distance between satellite and reference station by calculating a coordinate of the satellite. The remaining error included in the code pseudo-range can be calculated by considering the satellite clock error calculated using broadcasting ephemeris received at the reference station from the satellite, the calculated geometric distance, as well as clock error of receiver calculated using navigation solution. The PRC information includes orbit error of satellite, ionospheric delay error and tropospheric delay error.

In the user part, accurate coordinate cannot be known because position information should be acquired in real time and position is flexible. Thus, it is impossible to eliminate error components included in the code pseudo-range of single frequency from the user part independently. An error can be corrected through modeling for ionospheric and tropospheric delay errors but error correction is limited because it is not a calculation of actual delay. In contrast, since the PRC information generated at the reference station is an error that is calculated through actual observation, it can offset an error more effectively than using a model thereby achieving highly accurate positioning.

If the error information included in the PRC information is completely matched with the error information included in the code pseudo-range received by the user and is offset, the positioning error is close to zero. However, since the reference station and user are not located in the same position generally, the paths of the troposphere and ionosphere where GNSS signals pass through are different. In addition, multi-path errors occur differently due to the different observation environment. Due to these factors, DGNSS positioning has a sub-meter level of accuracy in the open sky environment.

### 2.3 Multi-path Error Reduction Technique

When a user utilizes GNSS to obtain position information, it is possible to determine highly accurate positioning in an open sky environment where satellite observation conditions are good. However, satellite signals are blocked or multi-path errors occur in an urban canyon with many buildings or narrow alley, and this leads to a significant degradation of accuracy. Kim (2015) analyzed the characteristics of signal strength from GPS satellites thereby developing a multi-path error reduction model based on signal strength. Kim also verified that their model showed a superior performance of positioning accuracy compared to other existing multi-path error reduction models developed based on elevation angle or signal strength.

Kim (2015) claimed that when the Hye-in Kim (HK) model was applied to positioning, positioning error was reduced by half or more compared to cases not using the model at Teheran-ro in Seoul which was regarded as a poor reception environment. Compared with cases that applied

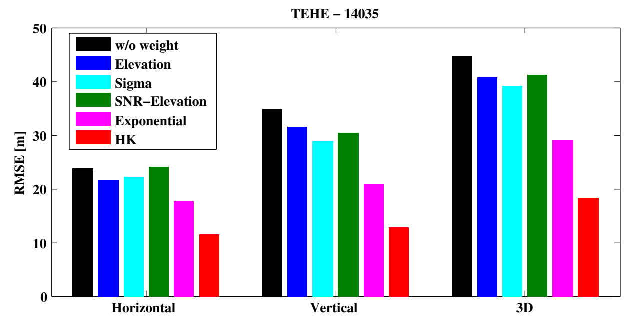


**Fig. 1.** GPS receiver structure

other models based on elevation angle or signal strength (signal to noise ratio; SNR), it verified a reduction in error nearly by half as shown in Fig. 1. This paper applied the HK model to positioning because it was judged as the most effective model that can correct multi-path errors among other weight-based models.

## 3. ANALYSIS ON GNSS SIGNAL OBSERVATION ENVIRONMENT

The experiments were designed by selecting various observation environments to evaluate positioning performance of multi-DGNSS according to observation environments. The following environments were selected: open sky environment where the field of view of satellite was rarely blocked, intermediate environment where the field of view of satellite was blocked by low-rise buildings, and poor reception environment where the field of view of satellite was severely blocked by high-rise buildings. The playground of Jungseok Aviation Science High School (hereafter referred to as JNSK) located in Yonghyeon-dong, Nam-gu, Incheon, Korea was chosen as an open sky environment. A crossway between 105, Inha-ro, Yonghyeon-dong and 30, Gyeonginnam-gil (hereafter referred to as YONH) and a shop alley located in 125, Songdo-dong, Yeonsu-gu, Incheon, Korea (hereafter referred to as SOND) were chosen as an intermediate environment. The apartment complex of Incheon SK Skyview (hereafter referred to as SKVW) located in Yonghyeon-dong was chosen as a poor reception environment.

Prior to the analysis on each of the observation environments, a quantitative basis that classified the locations was analyzed. Kim (2015) calculated a reception rate of data by using a program called Translation, Editing, and Quality Check (TEQC) from University NAVSTAR Consortium company to analyze a quantitative index of GNSS observation environment. A data reception rate refers


**Fig. 2.** Photographs by each observation environment: (a) JNSK, (b) YONH, (c) SOND, (d) SKVW.

**Table 2.** Data reception rate by observation environment.

| Test sites | JNSK | YONH | SOND | SKVW |
|---|---|---|---|---|
| Data reception rate (%) | 95 | 78 | 69 | 42 |

to a ratio between the number of data that are observable using observation data and ephemeris data at the survey point, and the number of data that are observed. It is deemed that higher data reception rate indicates better satellite observation environments.

Table 2 presents the results that calculate data reception rates when elevation cutoff angle is 10° using ephemeris and observation data acquired at each of the observation environments via TEQC. A data reception rate at JNSK selected as an open sky environment was the highest (95%) while data reception rates in other environments were relatively low. In particular, a data reception rate at SKVW, which was a poor reception environment, was the lowest (42%). The above results indicated that the field of view of satellite was most severely blocked in SKVW due to high-rise buildings. The data reception rates of YONH and SOND were 78% and 69%, respectively, which revealed a relatively good field of view of satellite due to low-rise buildings compared to that of SKVW. Based on the above results, the observation environments for testing in this paper were considered validly classified.

### 3.1 Comparison of Environments Surrounding Sites

Fig. 2 shows the comparison of surrounding environments of each survey point where the experiments were conducted. Fig. 2a shows the surrounding environment of JNSK which is the survey point of open sky environment. The field of view is rarely blocked because there are no nearby buildings. Fig. 2b shows the surrounding environment of YONH, which is one of the intermediate environments. Since the environment is surrounded by five-story low-rise buildings, the field of view is blocked. Fig. 2c shows the surrounding environment of SOND, in which blocking occurs as seven to 10-story buildings are located nearby. When comparing the surrounding environments of SOND and YONH, SOND had relatively higher surrounding buildings but a distance between buildings and survey point was relatively far. Since the walls of the surrounding buildings in SOND were made of glass, it was expected to have a large

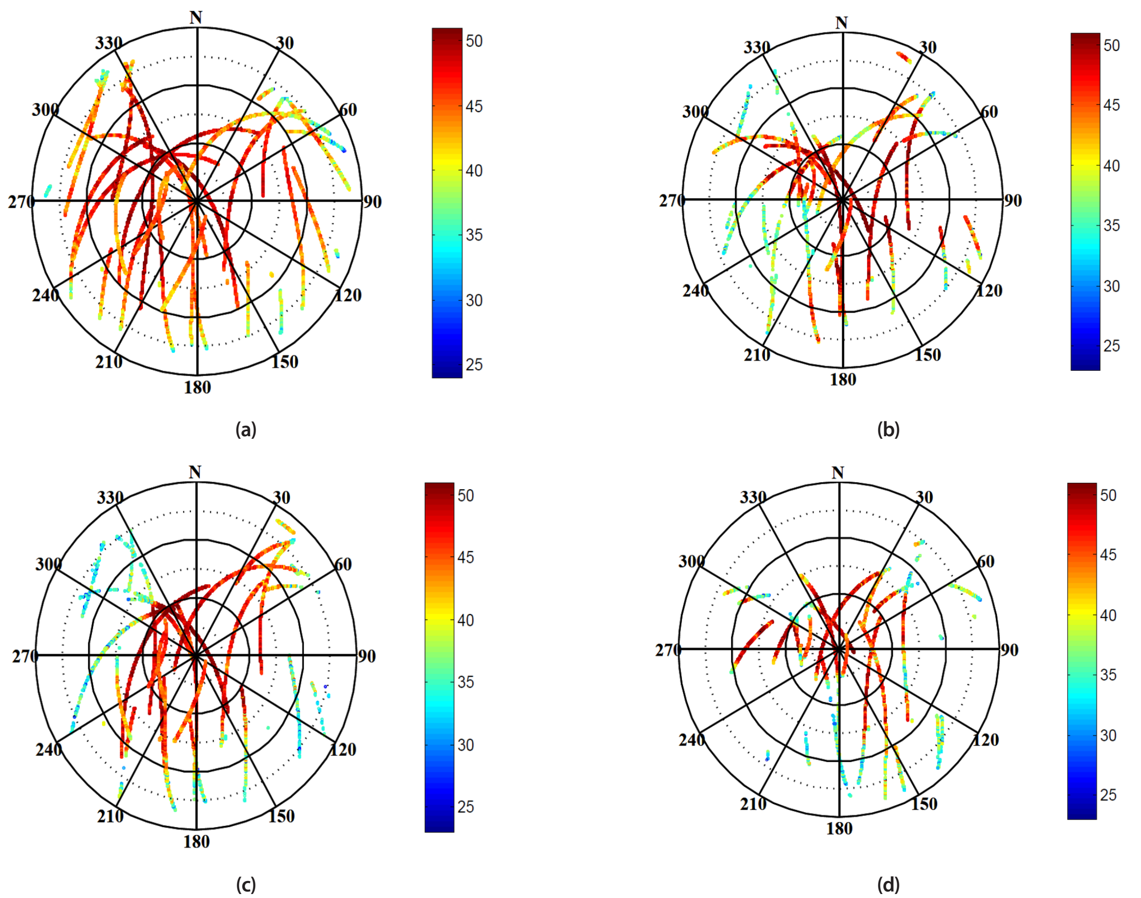


**Fig. 3.** SNR values on a skyplot by each observation environment: (a) JNSK, (b) YONH, (c) SOND, (d) SKVW.

multi-path error due to the reflection of satellite signals by the glass. Fig. 2d shows the surrounding environment of SKVW, which is a survey point of the poor reception environment. The figure shows that the field of view is severely blocked by the 40-story apartment nearby.

### 3.2 Comparison of Satellite Signal Strength and Visible Satellites

Fig. 3 shows the SNR and sky plot of GNSS satellites observed at each of the sites. An SNR is a measure to determine the quality of signals. Larger SNR indicates better signal quality. In other words, the smaller the SNR, the more the multi-path errors included in the signals. As shown in Fig. 3a, JNSK mostly had high SNR values except for satellites of which elevation angle were 15° or less. This was because multi-path error due to surrounding buildings or geographic features had little effect on JNSK. In addition, as it is observed that the moving trajectory of satellites was connected and rarely cut off in the sky plot, it is deemed that stable satellite signals were observed without being blocked.

Fig. 3b shows the SNR and sky plot of satellites observed at YONH. Compared to Fig. 3a in JNSK of open sky environment, there were satellites of which signal strength was weak. In particular, satellites observed between azimuths of 210° and 270° in the sky plot had low SNR values. These satellite signals contained many multi-path errors because of the reflection of signals from the surrounding buildings. In contrast, satellites observed in the northwest or south which were not blocked by the buildings had high SNR values.

Fig. 3c shows the SNR and sky plot of satellites observed at SOND. Despite that the fields of views of satellites observed at a low altitude below 45° in the northwest and southeast were blocked due to buildings, signals were recorded, indicating that signals were reflected from surrounding buildings. These signals contain multi-path errors, thus had low SNR values as shown in the figure.

Fig. 3d verifies that satellites are rarely observed due to the presence of high-rise apartments in the southwest direction in the SKVW survey point. Although data were collected at this survey point for about three hours as the

**Table 3.** Number of visible satellites at each test sites.

| | GPS | GPS/GLO | GPS/BDS | GPS/GLO/BDS |
|---|---|---|---|---|
| JNSK | 9.1 | 15.3 | 17.1 | 23.3 |
| YONH | 7.3 | 10.9 | 11.6 | 15.2 |
| SOND | 6.3 | 9.9 | 11.7 | 15.3 |
| SKVW | 3.4 | 5.1 | 5.3 | 9.0 |

same as other sites, observed data were relatively few because of severe satellite signal block due to buildings. Furthermore, low SNR values were verified despite of high altitude due to the effect of multi-path errors.

Table 3 presents the average number of visible satellites according to each combination of GPS, GPS/GLO, GPS/BDS, and GPS/GLO/BDS at each of the sites. Low-price GNSS reception modules that are currently available in the market such as u-blox cannot utilize all three systems including GPS, GLONASS, and BDS, and only two systems can be selectively combined and utilized up until now. Thus, this study conducted comparisons not only between GPS and GPS/GLO/BDS combination but also GPS/GLO and GPS/BDS combinations. Table 3 presents that JNSK represented as an open sky observed 9.1 satellite signals on average only with the use of GPS satellite, and 23.3 satellite signals were observed on average with the system of GPS/GLO/BDS. In contrast, SKVW represented as a poor reception environment was difficult to perform positioning using GPS only as it observed 3.4 satellite signals on average while 9 satellite signals were observed on average with the GPS/GLO/BDS system.

## 4. ANALYSIS ON POSITIONING ACCURACY

This section analyzed positioning accuracy of multi-DGNSS according to satellite observation environments. The precision coordinate was calculated to analyze the performance of the algorithm at each survey point prior to collecting observation data. For the survey point in JNSK, the precision coordinate was calculated using GPS Inferred Positioning System-Orbit Analysis and Simulation Software (GIPSY-OASIS), which was high precision data processing software with regard to collected observation data using Sigma receiver and GrAnt-G3T antenna from JAVAD Company, which were GNSS equipment for surveying. For YONH survey point, a closed traverse network was configured from the pre-acquired precision coordinate of JNSK in the above because it was close to the JNSK survey point. For SOND and SKVW sites, the precision coordinate was acquired through the virtual reference station (VRS) method using PolaRx3e receiver from Septentrio and

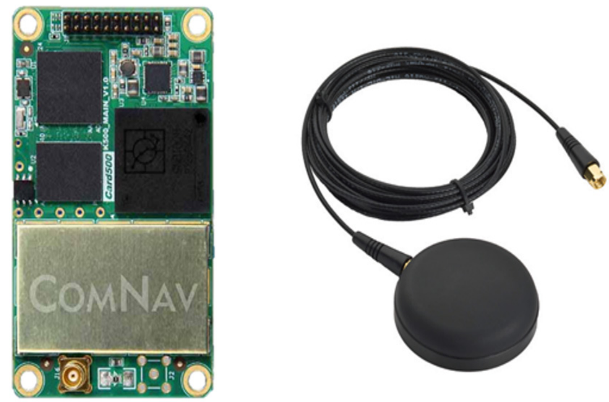


**Fig. 4.** Equipment used to receive GNSS observation.

GrAnt-G3 antenna from JAVAD. The collected observation data were processed using a least square method and ionospheric and tropospheric delay errors were corrected using simultaneously collected PRC information.

### 4.1 Collection of Observation Data

Observation data at each of the sites were collected to analyze positioning accuracy of the algorithm. To raise the reliability of the data through the collection of sufficient observation data at each of the experimental environments, a total of four observation environments acquired data for nine hours in every one second. To collect GNSS satellite observation data, K-500 receiver from ComNav and ANT-26C1GOA-196MNSB antenna from NovAtel were used as shown in Fig. 4. K-500 is an economic receiver that can receive GPS L1, GLONASS L1, and BDS B1 signals, and can receive signals of up to 80 satellites. ANT-26C1GOA-196MNSB is a small antenna of which diameter is 68.8 mm and can observe GPS L1, GLONASS L1, and BDS B1.

To perform DGNSS positioning, not only the collection of observation data but also the reception of PRC information from the reference station is required simultaneously. This study acquired PRC information from the regular observatory located in Ganghwa-gun, Incheon, Korea. The Ganghwa observatory observes GNSS satellites at a regular basis using Sigma-G3T of JAVAD and RingAnt-DM antenna as shown in Fig. 5. Since the Ganghwa regular observatory can generate not only PRC information of GPS and GLONASS but also that of BDS, it is appropriate to acquire data required in this study.

### 4.2 Analysis of the Experiment Results

A root mean square error (RMSE) of DGPS positioning, DGPS/DGLO integrated positioning, DGPS/DBDS

Fig. 5. GNSS receiver and antenna at Gang-Hwa reference station.

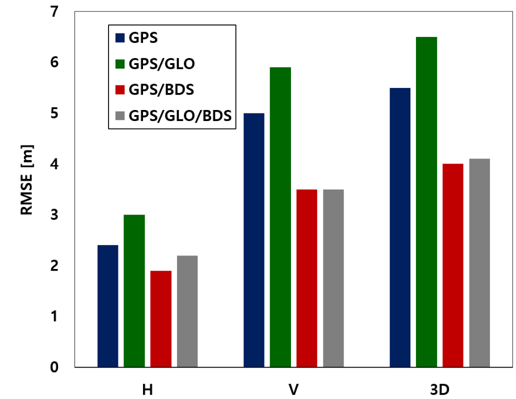


Fig. 7. Comparison of positioning accuracy by system at YONH.

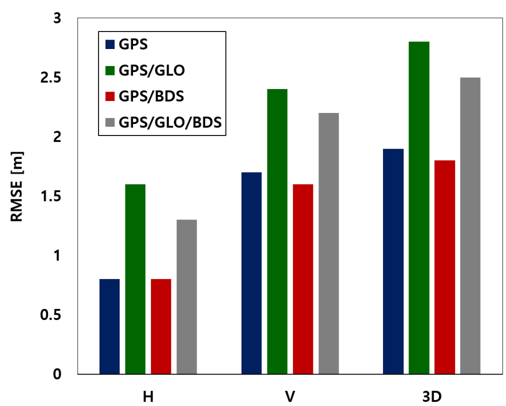


Fig. 6. Comparison of positioning accuracy by system at JNSK.

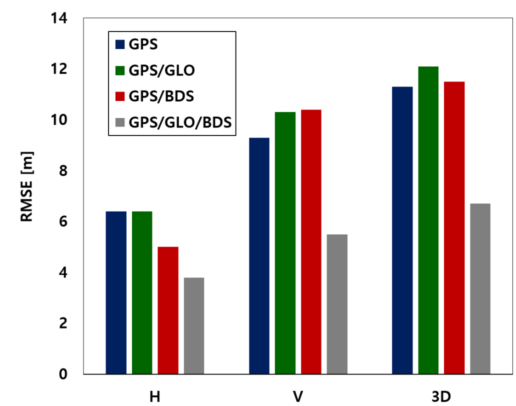


Fig. 8. Comparison of positioning accuracy by system at SOND.

integrated positioning, and DGPS/DGLO/DBDS integrated positioning was calculated and compared utilizing observation data to analyze multi-DGNSS positioning performance by sites.

Fig. 6 shows the graph that compares positioning results at JNSK for each system. As shown in the figure, an error of DGPS/DBDS integrated positioning was the smallest. The DGPS/DGLO/DBDS integrated positioning improved accuracy compared to that of DGPS/DGLO integrated positioning, but the error was larger than that of DGPS positioning. This result indicated that sufficiently high positioning performance can be achieved only using GPS in the open sky environment where few multi-path errors occurred. In addition, it was deemed that high positioning performance can be secured by excluding GLONASS observation data from the algorithm during positioning. This is due to the effect of noise included in the GLONASS code pseudo-range observation. More details can be found in the study of Cai et al. (2016) in which noises existed in the observation data of GPS, GLONASS, and BDS were compared through the zero base line double difference positioning. Cai et al. (2016) verified that standard deviations of L1 code pseudo-range noises of GPS and BDS were approximately 0.15 m and 0.16 m, respectively, compared to 0.25 m of GLONASS, which was larger.

Fig. 7 shows a graph that compares positioning performance at YONH for each system. The DGPS/DGLO/DBDS integrated positioning effect was larger than that of DGPS, which was in contrast with that in JNSK. However, when GLONASS was integrated and used, errors were generated more than that using the BDS integrated system due to the effect of the noise included in the GLONASS code pseudo-range observations as the same as revealed in JNSK. Since a size of horizontal error in the open sky such as JNSK was small at approximately 1 m, the effect of GLONASS noise stood out significantly. In contrast, when observation environments were worse, errors became larger due to many reasons such as the effect of multi-path error and the number of visible satellites, thus the effect of the GLONASS noise was found to be relatively smaller.

Fig. 8 shows the positioning results by system combination in SOND. As presented in Table 3, the number of visible satellites in SOND was similar to that of YONH but the signal blocking was more severe due to high-rise

**Table 4.** Comparison of positioning RMSE by system at SKVW.

| RMSE (m) | Horizontal | Vertical | 3-dimensional |
|---|---|---|---|
| DGPS | 22.3 | 17.8 | 28.6 |
| DGPS/DGLO | 8.2 | 11.7 | 14.3 |
| DGPS/DBDS | 5.9 | 8.7 | 10.5 |
| DGPS/DGLO/DBDS | 4.8 | 6.1 | 7.8 |

**Table 5.** Improvement rate of Multi-DGNSS positioning accuracy compared to DGPS at SKVW.

| Improvement rate of Multi-DNGSS (%) | Horizontal | Vertical | 3-dimensional |
|---|---|---|---|
| DGPS/DGLO | 63.2 | 34.3 | 50.0 |
| DGPS/DBDS | 73.5 | 51.1 | 63.3 |
| DGPS/DGLO/DBDS | 78.5 | 65.7 | 72.7 |

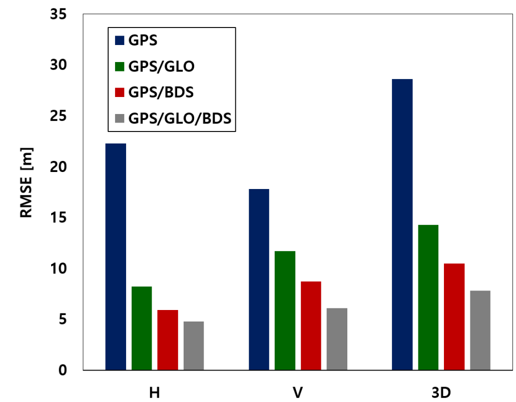


**Fig. 9.** Comparison of positioning accuracy by system at SKVW.

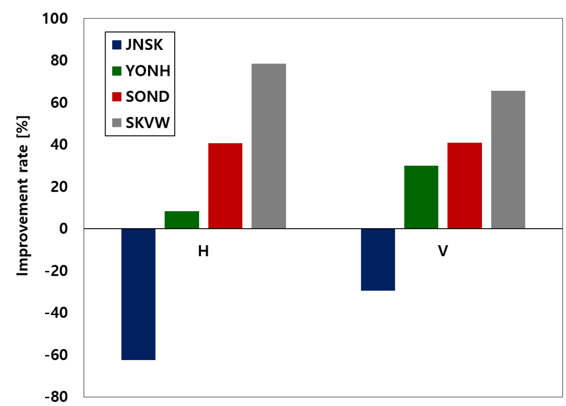


**Fig. 10.** Improvement rate of Multi-DGNSS positioning accuracy compared to DGPS.

buildings. Thus, the figure verified that the effect of multipath signal was larger thereby generating larger positioning errors. However, a mean number of visible satellites was increased from 6.3 to 15.3 satellites, which was more than two-fold increase, when using GPS/GLO/BDS integrated positioning thereby significantly increasing the accuracy.

Table 4 and Fig. 9 show the comparison of positioning errors according to system combination at the SKVW, which represents the poor reception environment. In the case of SKVW, a data reception rate was just 42% as presented in Table 2 and the number of observation satellites was 3.4 on average, which was very small, as presented in Table 3. Thus, as for the DGPS positioning performance utilizing GPS only, large errors of 22.3 m horizontal error and 17.8 m vertical error were identified. In contrast, in the case of DGPS/DGLO and DGPS/DBDS that utilized GLONASS and BDS additionally, the numbers of visible satellites was increased to 5.1 and 5.3 on average, respectively, and their horizontal errors reduced to 8.2 m and 5.9 m, respectively, indicating higher accuracy. In particular, the number of visible satellites in DGPS/DGLO/DBDS integrated positioning was significantly increased to 9.0 on average, and the horizontal, vertical, and 3D errors were 4.8 m, 6.1 m, and 7.8 m, indicating significantly improved accuracy. Although considerably large errors occurred in DGPS positioning to the extent that positioning determination was difficult, DGPS/DGLO/DBDS integrated positioning reduced the horizontal error to 5 m or lower, which was similar positioning result with that of SOND.

Table 5 presents the accuracy improvement rates of DGPS/DGLO, DGPS/DBDS, and DGPS/DGLO/DBDS integrated positioning compared to that of DGPS in SKVW. The table verified that horizontal accuracies were improved by 50% or more when combining two systems compared to that using a single system. Also, when three systems were integrated, horizontal and vertical accuracies were improved up to 78.5% and 65.7%, respectively.

Fig. 10 shows the accuracy improvement rate of DGPS/DGLO/DBDS positioning when compared with that of DGPS positioning at each of the experimental environments. Although the accuracy was degraded when systems were integrated in the open sky environment, positioning accuracies were improved more through system integration as the observation environments degraded to the intermediate and poor reception environments. In particular, horizontal accuracy in the poor reception environment was improved by nearly 80%. This may be because of the fact that the integration of systems that secured sufficient amount of visible satellites prevented significant degradation of positioning performance even if observation environment degraded.

Since visible satellites were sufficiently secured in the open sky environment already, the effect of increase in the number of visible satellites was not significantly noticeable. Rather, the effect of GLONASS code pseudo-range noise was noticeable. The effect of improvement in performance due to an increase in visible satellites was larger as the reception environment became poorer, and error values, which were a level of few meters, were much larger than the noise size of GLONASS code pseudo-range. This indicates that the effect of noise was minimal. In addition, since the multi-path errors, which were significant problems in the poor reception environment, were able to be corrected to some extent considerably through the HK model application mentioned in Section 2.3, the effect of increase in visible satellites could be clearly identified. If a new satellite navigation system such as Galileo that is being developed in addition to GPS, GLONASS, and BDS is integrated in the future, more visible satellites can be secured thereby further improving the algorithm performance.

## 5. CONCLUSION

This study analyzed the positioning algorithm performance of multi-DGNSS to obtain position information of high accuracy by utilizing GNSS. Four locations in which satellite observation environments were different were selected for performance verification, and observation data of GPS, GLONASS, and BDS were received at each of the locations. Data were received in every three hours from each location, and a total of 36 observation data were used in the algorithm performance verification. In addition, positioning was conducted by receiving observation data as well as receiving PRC information simultaneously. The analysis results showed that high positioning performance can be ensured using DGPS only in the open sky environment where satellite observation condition was good. However, as the observation environment degraded in which, for example, satellite signals were blocked by buildings, positioning accuracy became higher when utilizing multi-DGNSS. At the poor reception environment where satellite observation condition was not good, horizontal error was decreased from 22.3 m to 4.8 m, indicating 78.5% improvement, and vertical error was decreased from 17.8 m to 6.1 m, indicating 65% or higher improvement. The results verified that positioning accuracy can be increased to some extent by applying the multi-path error reduction and multi-DGNSS technologies in downtown areas where satellite observation environment was inferior. Through the future study, positioning accuracy can be improved further by utilizing other satellite navigation systems in line with their development and stabilization in addition to GPS, GLONASS, and BDS.

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