Efficient Satellite Selection Method for Instantaneous RTK-GNSS in Challenging Environments*

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The global navigation satellite system (GNSS) can potentially provide centimeter-level positioning using real-time kinematic (RTK) positioning. However, in static positioning, such as for surveying, receivers easily receive multipath signals continuously. Our goal was to improve the performance of instantaneous RTK-GNSS in multipath environments. Two conventional satellite selection methods based on the idea of correctly removing multipath signals, which allows more reliable solutions, were evaluated in this study. The first method is based on using signal-to-noise ratio (SNR) observations to mask measurements having degraded quality. In the second method, a mask of sky obstacles is generated using a fisheye view lens camera to detect non-line-of-sight (NLOS) signals. In this study, several static tests were performed to evaluate these conventional methods. The results show that both methods can efficiently improve availability. Furthermore, the performance when using a fisheye view mask was slightly better than that when using the SNR method, in particular for situations where a powerful reflected signal by NLOS was received. Based on these results, an improved SNR-based satellite selection method that uses the SNR fluctuation magnitude for a certain period is proposed. The results show that this method effectively improves the performance as compared with the conventional SNR mask.

Key Words: RTK-GNSS, Multipath, Satellite Selection, Surveying

1. Introduction

The global navigation satellite system (GNSS) positioning solution is widely used in many different application fields. The modernization of the Global Positioning System (GPS) and the use of multiple satellite constellations have facilitated an improvement in positioning accuracy.1) Furthermore, real-time kinematic (RTK) positioning based on relative positions using phase observations provides centimeter-scale positioning accuracy through real-time processing.2,3) In the RTK process, correct integer ambiguity resolution (AR) is the key for determining highly reliable fixed solutions.4)

However, GNSS positioning in urban areas still suffers both availability and reliability problems. Because of obstacles such as buildings, the GNSS signal is constrained by severe multipath errors and poor satellite geometry, in particular in dense urban areas.5) Strong multipath signals from obstacles degrade both the code and phase observation quality6) and these degraded observations decrease the accuracy of the float ambiguities and hinder correct integer AR. Incorrect fixes in the integer AR process can cause positioning errors greater than 10 cm. Thus, the integer AR is usually tested to validate the reliability of the solutions.7) The incorrect fixes caused by multipath errors frequently fail this validation test, since they affect both the number and quality of fixed solutions.

Multipath interference in urban areas is caused by the reflection and diffraction of signals from both line-of-sight (LOS) and non-line-of-sight (NLOS) satellites. An NLOS satellite signal blocked by high-rise buildings clearly contains multipath errors caused by the extended signal path. Several methods using 3D maps have recently been developed to effectively detect these satellites.8,9) Furthermore, methods that use fisheye view cameras and image processing allow LOS and NLOS satellites to be distinguished.10)

In addition, there are many techniques for mitigating the multipath errors that are based on the design of the receiver and antenna. A receiver that mitigates the narrow or strobe correlator can recognize the long delay of a multipath signal and remove it.11) Several types of antennas exist that mitigate the multipath signal, such as the choke ring antenna.12) Each of these methods has been adopted to achieve survey-grade receivers that can exclude multipath signals effectively. However, it is still difficult to exclude short delay multipath signals.

According to observation data, the multipath signal causes a reflection loss of the signal-to-noise ratio (SNR) of at least 5–10 dB-Hz.13) Based on this characteristic, SNR-based quality check method has been conventionally used for satellite selection.14) This method efficiently detects a multipath signal at no cost and requires no additional equipment.

The multipath effect in static conditions shows a different characteristic from that in kinematic conditions. In static conditions, strong multipath signals are continuously received,15) which causes incorrect fixing or the failure of the validation test over a long time, even if survey-grade receivers are used.

In this study, we aimed to improve both the availability and reliability of RTK-GNSS in static conditions, such as during geodetic surveying. First, we evaluated two conven-
tional satellite selection methods for mitigating the multipath errors in static conditions. The first method is based on SNR observations.\textsuperscript{14} The SNR is usually negatively influenced by a multipath signal.\textsuperscript{13} Conventionally, this SNR characteristic is applied for masking the satellites. The second method, which uses fisheye view images, is based on the density of sky obstacles. NLOS satellite exclusion masks use fisheye view images to reject NLOS signals.\textsuperscript{10} A procedure to generate a mask by using a fisheye view lens has been introduced. We conducted a test in a severe multipath environment under static conditions to evaluate the effects of the methods in terms of mitigating multipath and NLOS effect.

Four locations were selected such that the antenna would receive reflected and diffracted multipath signals. The results show that both methods effectively obtained reliable solutions and increased the availability. However, the results of these two methods differ: at several locations, the results of the fisheye view mask show a slightly better performance than those of the conventional SNR mask.

Based on these results, the SNR measurements remaining after applying the conventional SNR mask were compared with those of the fisheye view mask, and the characteristics of the SNR measurements were investigated. The weakness of the conventional SNR mask was revealed, and occasionally we observed incorrect fixed solutions. The conventional SNR mask cannot detect the multipath signal perfectly when a reflection signal is dominant. According to these results, an improved method using the magnitude of the fluctuation of the SNR for a certain period is proposed. Test results show that this improved SNR method is effective for improving the detection performance as compared with the conventional SNR mask.

This paper is organized as follows. First, the RTK process using multiple constellations is briefly introduced. Then, two conventional methods for satellite selection are described. We performed several tests to validate the conventional methods in severe multipath environments. The results showed that the conventional methods were able to improve the performance and we found the weakness of the conventional SNR mask method. Finally, an improved SNR mask method is proposed.

2. Real-time Kinematic Positioning for GNSS

The RTK-GNSS uses a double difference (DD) code and phase observation. The DD measurements efficiently cancel receiver- and satellite-dependent biases. In addition, the atmospheric reflection errors of two receivers located close together are similar and can be canceled in DD measurements. Meanwhile, the phase ambiguities that based on an unknown integer number of times the carrier wave length should be resolved.\textsuperscript{8} The LAMBDA method is a well-known and efficient integer AR method based on the least-squares method\textsuperscript{9} and is used to determine the optimal integer ambiguities. After the integer ambiguities have been determined, the validation test is performed.\textsuperscript{16} We used the ratio test for the validation test based on the residuals with fixed values.

2.1. Multipath effects in RTK-GNSS

In dense urban areas, such as those surrounded by high-rise buildings, signals are reflected or diffracted by obstacles. These signals can interfere with the reception of the signals received directly from the satellites, a phenomenon known as multipath interference, or simply multipath, because the signal is received via multiple paths. However, cases also occur where the direct signal is blocked and only a strong reflected signal is received. This NLOS reception is particularly common in dense urban areas where high-rise buildings block many of the signals.

A multipath signal usually takes a longer path than a direct one. In particular, multipath signals with short delays caused by reflection and diffraction are difficult to mitigate. When the antenna is installed in a static situation, strong multipath signals are easily received for a long time. In this case, frequently multipath contaminated signals are continuously received.

Multipath interference degrades the observation quality. The error in code observations is of the order of several meters. Phase and Doppler observations are considerably less influenced than code observations.\textsuperscript{31} However, multipath errors in the phase observation cause serious problems in the integer AR process for RTK-GNSS. In the integer AR process, the multipath contaminated phase observations make it difficult to determine the correct integer ambiguities. This situation occurs in two significant situations, one of which is where the ratio value does not exceed the threshold value of the verification test. In this situation, availability is decreased. The second situation is where the ratio value exceeds the threshold value of the verification test accidentally and incorrect fixed solutions are obtained. In this situation, reliability is decreased. Under static conditions, a strong multipath effect occurs in both situations.

Satellite selection methods are applied for excluding the multipath contaminated signals of satellites, to resolve these problems.

2.2. Satellite number requirements for multiple constellation RTK-GNSS

The RTK process using only GPS satellites requires a minimum of four satellites for linearizing the rank.\textsuperscript{31} When only four satellites were used for positioning, many incorrect fixed solutions were obtained because of the difficulty in distinguishing the correct integer ambiguity. Thus, a minimum of five satellites is required to obtain a highly reliable solution.

When multiple constellations are used, improved satellite geometry and positioning availability are provided, in particular in dense urban areas. However, expanding the RTK process to use multiple constellations produces inter-system biases (ISBs). In the DD process using different satellite systems, ISBs are not cancelled. Two concepts to resolve this problem exist: estimating and calibrating these ISBs, named combined positioning,\textsuperscript{17} or computing DD with the same satellite systems to cancel ISBs, named mixed positioning.\textsuperscript{18} Both concepts need one or more surplus received satellites to linearize the rank for solving the integer AR.
In this study, DD was employed with the same satellite systems for mixed positioning. As the primary satellites for taking a DD measurement, one satellite from each system is selected. Thus, at least two satellites for each satellite system are required for DD measurement. The minimum number of receiving satellites required with multiple constellations is as follows.

—One satellite system requires at least five satellites.
—Two satellite systems require at least six satellites in total and at least two satellites for each system (e.g., four GPS and two BeiDou).
—Three satellite systems require at least seven satellites in total and at least two satellites for each system (e.g., two GPS + two BeiDou + three GLONASS).

Note that QZSS satellites are designed to conform to GPS, — Three satellite systems require at least seven satellites in total and at least two satellites for each system (e.g., four GPS and two BeiDou). and therefore, are regarded as one system.

3. Conventional Satellite Selection Methods

In this section, we describe two conventional satellite selection methods, one based on SNR and one based on fisheye view images. Each of the masks is generated to select satellites that allow good quality measurements.

3.1. SNR-based satellite selection method

The strength of the SNR is basically related to the satellite elevation angle. However, a multipath signal causes a reflection loss of at least a few dB-Hz and usually more than 6 dB-Hz,13) losing at least half the amplitude of the direct path. Based on these characteristics, the elevation-dependent SNR values are estimated to check the SNR quality. The threshold line for the mask is set to detect the multipath dominant signal. Margins of several dB-Hz are taken from the elevation-dependent estimated line in parallel to the threshold line. If the observed SNR does not exceed the mask line, the satellite is removed from consideration in the positioning.

The value of the SNR as a function of elevation is calculated in advance from a rover receiver and an antenna in a multipath-free environment. Raw observation data of 24 h are used to produce the estimated SNR line. Based on these statistical raw data, the estimated line is generated for each satellite system and frequency by using quadratic fitted curves.

Figure 1 shows the elevation-dependent average SNR of GPS, QZSS of L1, BeiDou of B1, and GLONASS of G1 for the estimated line for each satellite system and orbit.

According to our many experimental results, this simple detection method is very efficient for removing multipath contaminated signals.14)

3.2. Fisheye view image-based satellite selection method

An approximate density of obstructions can be obtained by using fisheye view images. In this study, the MADOKA 180 fisheye view lens for the Sony E Mount (E) produced by Yasuhara Co. Ltd. was used. The lens calibration value was obtained by applying a simple procedure using a checkerboard for the initialization.19)

In this method, the azimuth-dependent elevation mask is used to determine the NLOS satellites. When a satellite’s position determined by ephemeris is located in the obstruction mask, it is not used for positioning. The steps for creating the mask are as follows. An image is captured using the fisheye view lens camera installed horizontally at the same location as the GNSS antenna. To allow the mask and satellite positions to be compared, they are expressed using the same coordinates.

1. Azimuth adjustment
   The image is rotated to adjust the azimuth such that north is upward, and flipped.
2. Projection adjustment
   For each projection, the image and satellite position are arranged to the same coordinates. The image is transformed to an equidistant projection, which lends calibration value.
3. Mask creation
   In this study, masks were expressed for every 1 degree of the azimuth for elevation with a resolution of 0.1 degrees.

These procedures are performed using the open source software RTKLIB,20) version 2.4.3. Using this software, the fisheye view images are stretched to transform the projection, because the observation data are shown as an equidistant projection.

Figures 2, 3, and 4 show the fisheye view images with the observation data. A 12-h static test was performed in a location between a mid-rise and a high-rise building. After the experiment, a fisheye view image was captured from the same location as the antenna. Observation data were obtained using a GNSS antenna and receiver. The image on the lower layer is a fisheye view image; the upper layer is an equidistant projection of the satellite track with a heat map indicating the SNR for the GPS, QZSS, GLONASS (L1-C/A), BeiDou (B1), and Galileo (E1) satellites. Figure 2 shows the adjusted azimuth of the original fisheye view image with the observation data. We adjusted the azimuth by using Google maps to adapt for the placements and the edges of the buildings for post-processing. Figure 3 shows the projection transform of the results of the fisheye view image. The gaps between the degraded line of the SNR and the edges of buildings are reduced as compared with those in Fig. 2. Figure 4 shows the binarized fisheye view image. The red line shows the threshold mask to exclude NLOS satellites. The mask is expressed as the azimuth-dependent elevation, as is the satellite position. Thus, it is easy to compare the position of each satellite and determine whether it is
NLOS or LOS. To optimize the resolution of this mask, careful calibration is required in the prior adjustments. Because of the mask’s expression and resolution, it is difficult to express the complex shape of buildings perfectly.

4. Testing and Results

Static positioning tests were performed in severe multipath environments to examine the effects of the conventional satellite selection methods. We chose four location points in different situations surrounded by buildings. These locations are on the campus of TUMSAT in Tokyo.

4.1. Experimental setup

A GNSS antenna was installed on a tripod for surveying purposes, as shown in Fig. 5. The tripod was adjusted horizontally. The test environments and each fisheye view image are presented in Figs. 6–9. The fisheye view images are presented with the north side upward, together with the orthographic projection.

The rover consisted of a Trimble NetR9 multi-constellation GNSS receiver and a NovAtel GPS-703-GG antenna. The reference station for RTK-GNSS was installed within 200 m of the rover’s location and the same receiver was used. A Trimble Zephyr Geodetic antenna was used for the reference station. The true positions of each reference and rover were obtained by post-processed RTK-GNSS using GEO-NET data and the F3 solution was provided by the Geospatial Information Authority of Japan (GSI). F3 solutions are the final solutions provided by the GSI each day. Figure 10 shows the satellite sky views in each test. These are equidistant projections of the observed satellite positions with a heat

Fig. 2. Original image after the azimuth adjustment with observation data.

Fig. 3. Image projection transform to equidistance with observation data.

Fig. 4. Binarized image and mask (red line) with observation data.

Fig. 5. Test components for rover receiver and antenna.

Fig. 6. Test environment and fisheye view image at Point 1, between two mid-rise buildings of almost the same height. 12 h, 1 Hz, April 8, 2016. The maximum angle of obstacles for the fisheye view mask was 68.3°. In this case, many LOS signals are expected to be degraded.

Fig. 7. Test environment and fisheye view image at Point 2, surrounded by one high-rise and one mid-rise building. 12 h, 1 Hz, February 13, 2016. The maximum angle of obstacles for the fisheye view mask was 72.5°. The influence of a strong signal reflected by the high-rise buildings is expected because of the different heights of the buildings.
map indicating the SNR for the GPS, QZSS, GLONASS (L1-C/A), and BeiDou (B1) satellites.

4.2. Analysis conditions

The details of the analysis conditions are briefly described in this section. GPS, QZSS, BeiDou, and GLONASS measurements were used to verify the conventional methods.

Instantaneous dual-frequency RTK-GNSS was performed using the LAMBDA method for integer AR. The basic conditions for the positioning are described below. The parameters were determined empirically based on our past experiments. For the verification test, a ratio test with a fixed threshold value was used. The threshold value of the ratio test was set to 3. When the ratio value satisfies the ratio test, fixed solutions are obtained, whereas when the ratio value does not satisfy the ratio test the solution for that epoch is abandoned. The main focus of this study was to improve the instantaneous RTK-GNSS positioning without using any type of filtering method. The data of the four static points were processed using the RTK-GNSS software developed in our laboratory.

Basic conditions.
—SNR of L1 over 30 dB-Hz (GNSS)
—SNR of L2 (GPS, QZSS, GLONASS), and B2 (BeiDou) over 15 dB-Hz
—Satellite elevation angle is greater than 15°
—Maximum horizontal dilution of precision (HDOP) is 10.

The conventional satellite selection methods were applied before the generated DD measurements were implemented. The threshold value for the elevation-dependent SNR mask was set to 6 dB-Hz for each estimated line for GPS, QZSS L1, BeiDou B1, and GLONASS G1. We compared the observed SNR and mask line for each measurement independently. Each mask based on fisheye view images was generated by RTKLIB in post-processing.

4.3. Results

The average number of valid satellites after applying the basic conditions is shown in Table 1. The results for the following conditions are compared in Table 2. As for the normal RTK-GNSS, we applied the basic conditions described in 4.2.

1. Normal RTK-GNSS
2. Normal RTK-GNSS with SNR mask
3. Normal RTK-GNSS with fisheye view mask.

The solution availability and reliability, and the standard deviation for both each horizontal error and each vertical error in the fixed solution were evaluated for each point. Availability is defined as the ratio of the number of fixed solutions to the number of whole epochs. Reliability is defined as the ratio of the number of reliable solutions to the number of fixed solutions. In this study, a reliable solution is defined as one that is within the 95% probability ellipse that is set to have the origin at each true position based on the covariance matrix. The standard deviation value of measurement errors for the probability ellipse was set at a fixed value, 5 cm.
To validate the accuracy of the fixed solution, the standard deviations of the reliable solution for the horizontal and vertical direction were compared, as shown in Table 2. We used the probability ellipse to remove incorrect fixed solutions.

At Point 1, the availability was considerably improved and reliability was also improved by applying the two conventional satellite selection methods. Since the height of the two buildings surrounding the rover antenna was the same, the frequency of receiving both LOS and NLOS signals was not high. The reason for this large improvement is that both conventional selection methods could detect the diffracted signal caused by the blockage of buildings. As shown in Figs. 6 and 10, diffracted signals were received frequently. The performance difference between the SNR mask and the fisheye view mask was similar.

At Point 2, the performance of the fisheye view mask was better and even the SNR mask was effective for improving both availability and reliability. In fact, the availability in the normal RTK solutions was only 17%. The reason for this is that the number of valid satellites was not sufficient and the effect of NLOS signals caused the RTK solutions to be unfixed. As shown in Figs. 7 and 11, the height of the two buildings was different and it was easy to receive the NLOS signals from the north-west direction. In addition, strong signals reflected by the high-rise buildings were received because of the difference in their height. Figure 12 shows the histogram of the horizontal error in reliable solutions as fixed solutions at Point 2 based on the probability ellipse. The results of applying each satellite selection method and normal RTK-GNSS are compared. This figure shows that both satellite selection methods were able to increase availability at the cost of increasing the number of solutions with a horizontal error larger than 10.0 cm.
The obstacle density at Points 3 and 4 was almost the same and the building height was slightly greater at Point 3 than at Point 4. The number of valid satellites at Point 4 was greater than that at Point 3. These results were dependent on the deflection of the satellite visibility in Japan. In the Northern Hemisphere, the satellite density is higher on the south than on the north side. In addition, the BeiDou satellites are located to the south-west of Japan. This means that many BeiDou satellites can be observed if the sky is clear in the south-west direction. At Point 3, the antenna was located close to the wall of the high-rise building. It was easy to receive multipath contaminated signals from LOS satellites with a short-delay multipath (less than 10 m). These short delay multipath negatively influence the quality of the phase measurement and it is difficult to reduce the multipath errors by using conventional techniques, even when survey-grade receivers are used. The negatively influenced phase measurements made it difficult to obtain correct integer ambiguities and fixed solutions. Point 4 was assumed to have many multipath contaminated signals, similarly to Point 3. However, in this situation, the number of uncontaminated signals was also relatively high, consisting mainly of those from the BeiDou satellites. This is why the fixed rate and reliability of Points 3 and 4 differed. It also shows that the redundancy in the number of valid satellites under multipath environments is quite important to the success of the integer AR.

5. Improved SNR-based Satellite Selection Method

To generate fisheye view masks, an additional process is required, which is not currently practical. In this section, the measurements remaining after the conventional SNR mask is applied are compared with those of the fisheye view mask. The data and results obtained at Point 2 were used, because at this location the effect of the NLOS signals was strong. Finally, our improved SNR-based satellite selection method is newly proposed and validated.

Figure 13 shows the SNR distribution of all the satellites in the sky view after applying the conventional SNR mask. It includes the signals from the GPS, QZSS (L1-C/A), GLONASS (G1), and BeiDou (B1) satellites. The red line represents the outline of the fisheye view mask. As compared to the results of the fisheye view mask, signals received from clearly NLOS satellites in the northwest area still remain.

One NLOS satellite that remained after the conventional SNR mask was selected at Point 2 to confirm the effect of an NLOS satellite for RTK-GNSS. Figure 14 shows the GPS PRN-06 satellite track in the sky view from 19:00 to 22:00 GPS time. In this situation, the GPS PRN-06 satellite rose from the north-west side. This satellite remained behind the northwest buildings until approximately 20:30 GPS time (at the edges of the building) and a signal that was both diffracted and reflected by the southeast building was continuously received.

Figure 15 shows the results of SNR time series for L1 and L2 signals of the GPS PRN-06 satellite. The epochs for the SNR eliminated by the conventional SNR mask are shown in gray. The SNR observation was disrupted and fluctuated widely until approximately 20:30. Although approximately half of the contaminated observations were removed by the conventional SNR mask, the rest of the epochs remained. In the lower graph in Fig. 15, it can be seen that the SNR for L2 also exhibits the behavior of a contaminated signal. According to these results, the L2 signal check using the conventional SNR mask will improve the performance.

Based on these results, an improved satellite selection method focused on the variation in the SNR is proposed. In this method, the dispersion in wave patterns for the
SNR is utilized, because the pattern of the signals fluctuates and is disrupted in the case of static conditions. Based on this characteristic, the SNR standard deviation from the elevation-dependent estimated line is newly used to exclude satellites having signals that are multipath contaminated. The standard deviation in elevation-dependent SNR. The standard deviation in SNR is expressed as

\[ V(t_e) = \sqrt{\frac{1}{N} \sum_{i=0}^{N-1} (v(t_i))} \]  

(2)

where \( N \) is the averaging window size.

The results of the new indicator for detecting the multipath in the different \( N \) for GPS PRN 06 are shown in Fig. 16. The gray line represents the new indicator in the case where \( N \) is set at 100. The black line shows the new indicator in the case where \( N \) is set at 300.

The observation data were investigated to determine the most suitable threshold empirically using a moving standard deviation over the 300 epochs for the window size. We set 7 dB-Hz as the threshold of the indicator for these data. If the SNR fluctuates widely, the indicator exceeds the threshold on the north-west side was effectively reduced. However, it can be seen that a threshold of 3 dB-Hz is too strict to obtain sufficient availability.

To verify the proposed method, we applied it for each point with normal RTK-GNSS. The test results using the proposed SNR mask are shown in Table 3. The improved SNR-based satellite selection method uses a moving standard deviation over the 300 epochs for window size, with 7 dB-Hz as the threshold of the indicator.

As can be seen from the results for Point 2, the proposed method improved both availability and reliability and its performance almost reached the level of that of the fisheye view mask. Other results for each point are almost the same as those of both conventional satellite selection methods. The proposed method is able to improve the accuracy as compared with the conventional SNR mask.

Figure 17 shows the SNR distribution of all the satellites in the sky view after applying the proposed SNR mask.

### Table 3. New test results of solution availability and reliability for each point.

| Point | Availability | Reliability |
|-------|--------------|-------------|
| 1     | 33186/43200  | 76.8%       |
|       | 33137/33186  | 99.9%       |
| STD [cm] | \( H = 2.20 \) \( V = 1.71 \) |
| 2     | 21813/43200  | 50.5%       |
|       | 21640/21813  | 99.2%       |
| STD [cm] | \( H = 2.34 \) \( V = 3.78 \) |
| 3     | 14316/43200  | 33.1%       |
|       | 14184/14316  | 99.1%       |
| STD [cm] | \( H = 1.72 \) \( V = 2.49 \) |
| 4     | 39695/43200  | 91.9%       |
|       | 39688/39695  | 100.0%      |
| STD [cm] | \( H = 1.22 \) \( V = 2.15 \) |

6. Conclusion

This study evaluated conventional satellite selection methods for improving the RTK-GNSS performance in terms of solution availability and reliability. Experiments were performed at four different locations in severe multipath environments. A dual-frequency instantaneous RTK-GNSS was applied in these conditions using the GPS, QZSS, BeiDou, and GLONASS satellites. Several basic quality checks were applied to the observation data. We evaluated the conventional elevation-dependent SNR satellite selection method.
and it was shown that it can remove multipath contaminated signals. The fisheye view mask was evaluated and was shown to effectively detect NLOS satellites. Using these two methods, the RTK-GNSS performance was certainly improved considerably.

During the procedure to generate the fisheye view mask, we noticed that it required precise calibration. Therefore, the remaining SNR measurements based on the conventional SNR mask were compared with those of a fisheye view mask. We realized that the SNR-based satellite selection method still leaves room for improvement. The performance using the fisheye view mask was better than that using the SNR information in the case where long NLOS signals were received. Therefore, a new SNR-based satellite selection method was proposed. The proposed method uses the magnitude of the fluctuation in the SNR for a certain period as an indicator to detect NLOS satellites. Using these methods, the performance was improved using this new indicator and was comparable to that of the fisheye view mask.

The era of multi-GNSS is coming. It will be possible to receive more than 100 satellites in the near future. Thus, the satellite selection method proposed in this study will be of significant importance, because it can provide better positioning solutions, in particular in the case of RTK-GNSS.

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