Prediction of RTK-GNSS Performance in Urban Environments Using a 3D model and Continuous LoS Method

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Biography

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Abstract

To utilize RTK-GNSS in urban areas, it is important to predict areas in which it can be used. The performance of RTK-GNSS depends on the geometry and number of visible satellites and signal quality. These parameters can potentially be predicted using simulations that consider the relative geometry between the receiver and surrounding objects.

In this study, we first verified whether the GNSS signal quality can be correctly predicted using 3D models of buildings and measurement data. Subsequently, we verified whether the FIX status of RTK can be correctly predicted. The results show that the number of the measured and predicted satellites that have good signal quality was in agreement at least 87.8% of the time. We assessed and categorized the RTK-GNSS fixing status using the number of usable satellites. A comparison of the RTK fixed status estimation, using the actual measurements and those from the simulation, agreed within 83.9% of the total.

1. Introduction

In recent years, positioning techniques based on a global navigation satellite system (GNSS) have had widespread use in applications such as car navigation systems, smartphones, agriculture, unmanned aerial vehicles, and autonomous construction.

RTK-GNSS is commonly used in Japan for civil engineering such as dam construction. In japanese construction system of a dam, it is necessary to prove that it has been cut slant surface with a certain precision. For this reason, RTK-GNSS guided construction machinery is used at dam construction sites and civil engineering sites. However, sometimes RTK-GNSS cannot be used on civil engineering sites. The reason is that mountains and trees are shielded at civil engineering sites, and there are not enough GNSS satellites available for RTK-GNSS. At such civil engineering sites, a simple method to predict the performance of RTK-GNSS is expected. [1]

Furthermore, as the trend of RTK-GNSS in Japan, Softbank and DoCoMo, two of Japan's leading mobile phone network operators, launched a distribution service for RTK-GNSS correction information in late 2019. Therefore, various Japanese companies are considering using RTK-GNSS in various places. However, there are many mountains and tall buildings in Japan, and places where RTK-GNSS can be used are limited. To utilize RTK-GNSS in urban areas, it is important to know in advance where you can use RTK-GNSS. For the 3D terrain model in Japan, the Geographical Survey Institute distributes 10m mesh DEM data[2],3D building models are sold by Zenrin[3] and NTT Data [4].By using these 3D data, we can understand the shielding of buildings and terrain at any place in Japan.

As a requirement of RTK-GNSS, it is necessary to measure the carrier phase of satellites that are commonly observed by the rover and the reference station. For measurement of the carrier phase of a GNSS signal requires a strong signal with Line-of-

Sight between GNSS atellite and GNSS receiver. In addition, a continuous strong signal is required to estimate the half cycle ambiguity of GNSS Signal. The GNSS receiver receives the stable and continuous reference station correction information and uses the RTK-GNSS. As described above, since the commercial correction data distribution service has started, we will not focus on this research.

In this study, we predicted GNSS signal quality and RTK-GNSS availability using 3D models of buildings. In conventional research, radio wave propagation simulations with 3D building models are used to estimate the quality of GNSS signals in urban areas [5][6]. The calculation cost of estimating radio wave propagation simulations using 3D buildings depends on the number of building models, vertices, and faces, and it also depends on the number of reflections and diffractions in the radio wave propagation simulation settings. As the number of combinations of reflection and diffraction increases, calculation costs also increase. In contrast, the calculation cost of estimating Line-of-Sight(LoS) and None-Line-of-Sight(NLoS) states by 3D building simulation only depends on the number of buildings. Therefore, it is desirable to use the estimation results of LoS and NLoS states for signal quality estimation. In this research, We used GPS-Studio[*], a commercial GNSS numerical simulation software developed by the author in the past. GPS-Studio simulates the multipath propagation path and error of GNSS signal by satellite orbit information, 3D building data, date and time, receiver position using ray tracing method.In this study, we used only the LoS and its continuity.

Figure 1 shows the definition of LoS satellites and NLoS satellites; the only difference between the two being whether the line-of-sight between the satellite and the receiver is occluded NLoS or not LoS. In other words, the LoS state is defined as the situation where a building or other large object does not exist on the extended line that connects the satellite and the receiver in a straight line. The case where a building is shielding a transmission from a satellite is defined as an NLoS state. For a satellite in an NLoS state, only a signal whose propagation path is extended by reflection off or diffraction around a building, or the like, can reach the receiver. If an NLoS signal is tracked, the signal causes multipath errors. Even in LoS satellites, building reflections and diffractions can still reach the receiver, but the error is not so large because the direct wave of the signal is being tracked successfully.

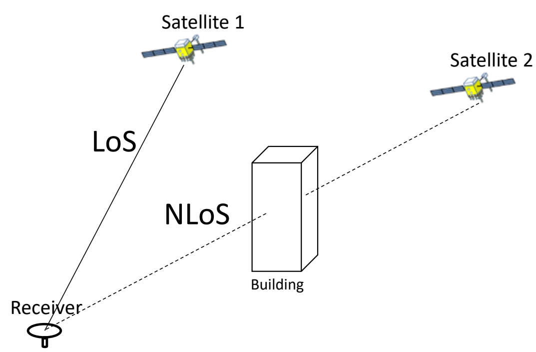

Fig.1 LoS and NLoS Satellites

2. RTK-GNSS performance quality prediction method using a 3D Building Model

In this study, we use the LoS status for the signal quality estimation of the GNSS using consumer 3D building models. Figure2 shows our los continuous method for RTK-GNSS prediction. We used GPS-Studio for Los estimation. In the prediction, the position of the receiver is specified by the user. The position of the satellite can be obtained from its navigation messages, for any particular date and time that is specified. The positional data that is broadcast by the satellite is known as ephemeris data, and it is this data that is used for this evaluation [7]. In the LoS simulation, even if an error occurs in the position of the satellite, the elevation angle and azimuth will not be significantly affected. Thus, the ephemeris can also be used for future prediction.

In our evaluation, a satellite with good signal quality, which can be used for RTK positioning, is defined as a satellite that can track the pseudo-range and carrier phase of dual frequencies. When the GNSS receiver is in the NLoS state, and the carrier phase is out of phase lock, the carrier phase half cycle cannot be obtained unless the LoS state continues for a certain period of time. To obtain a half cycle, it is necessary to determine whether the phase is positive or negative at the beginning of the navigation message. The period during which the top of this navigation message arrives is 6 s for GPS, QZS, and BDS, and 2 s for GLONASS. Therefore, for a GNSS receiver to output carrier phase observations with good signal quality, a stable signal with LoS for a specific time is required. In the simulation, we use the duration of the LoS state to evaluate the GNSS signal quality. When the signal in the LoS state is continuously received for more than a certain period of time, we define it as a good quality GNSS signal and define the satellite as a LoS continuation satellite. Once a satellite is identified as a continuation satellite, it continues to be so until it reaches an NLoS state. The time period threshold of the LoS-continuation status is determined by a measurement, as outlined in the next chapter.

RTK-GNSS positioning depends on the number of available satellites with good signal quality. Therefore, the availability of RTK positioning can be predicted by a simulation of the satellite signal quality. For RTK-GNSS to function effectively, the minimum requirement for the number of good-signal satellites needed is 5. Additionally, the number of required satellites increases in proportion to the number of satellite systems used. In later evaluations, we set the number of the RTK-GNSS FIXING required to 9 satellites.

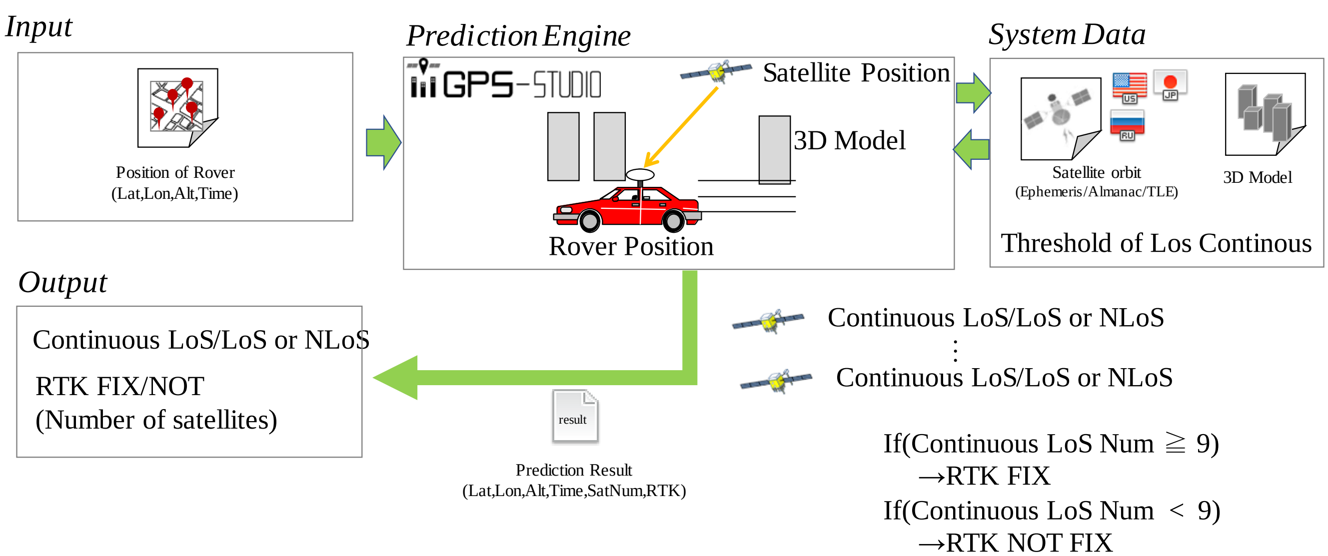

Fig.2 System of continuous LoS for RTK-GNSS prediction.

3. Evaluation

3.1 Evaluation setting

In this chapter, we compare the measured data in the real world with the results of the simulation. A high-accuracy GNSS receiver Trimble Net R9 [8], installed with the Position and Orientation Systems for Land Vehicles (POSLV) [9], is used to obtain measurement data for comparison with the emulated results.

Fig.3 Measurement Course and 3D Buildings Model for use in the Simulation

The actual GNSS measurements were collected in the Hibiya district of Tokyo, Japan, and the course of the vehicle is shown as a yellow line in Figure 2. In the following evaluation, we used 30 min of measured data, which comprised of 3 laps along the measurement route. For the evaluation of kinematic positioning, the GNSS reference station on the rooftop of the

Etchujima building was used. The gray polygon displayed on the aerial photograph along the course loop is the building considered in the calculation. It was created by removing and replacing a building in the commercially available 3D buildings model that seemed to have no effect on the calculation [3]. Rail and road overpasses were not included in the commercially available 3D buildings model; thus, by referencing the aerial photographs, we added and created them. The surface and lines of the main building under consideration were also simplified to improve the calculation speed. In the simulation, the topographic relief was not taken into account, and the building was placed on a level plane based on the elevation at the most southwestern point of the 3D buildings model. As has been stated, the building to be calculated is the building indicated by the gray polygon in Figure 3 at the southeastern end of the building model's and the center of gravity of this building is 600 m away from the receiver at its closest point in the course loop.

We set the height of the receiver to 1.5 m above the level plane in the simulation. The satellite systems for simulation were GPS, GLONASS, QZS, and BDS (BeiDou). Table 1 shows the simulation parameters. To verify the signal quality predicted by simulation, we defined a satellite estimation method with good signal quality in the measured data. We defined the good signal quality as that at which the high-accuracy GNSS receiver used in the experiment outputs all the pseudoranges and carrier phase observations of the L1, G1, B1, L2, G2, and B2 signals to each satellite.

3.2 Satellite signal prediction using LoS

Figure 4 shows a comparison between an LoS satellite estimated by simulation and a satellite that was determined to have good signal quality based on measurement. The number of the measured and predicted satellites that have good signal quality was in agreement at least 81.0% of the time. The trend of the graph shows that the signal quality is good with the LoS continuation state.

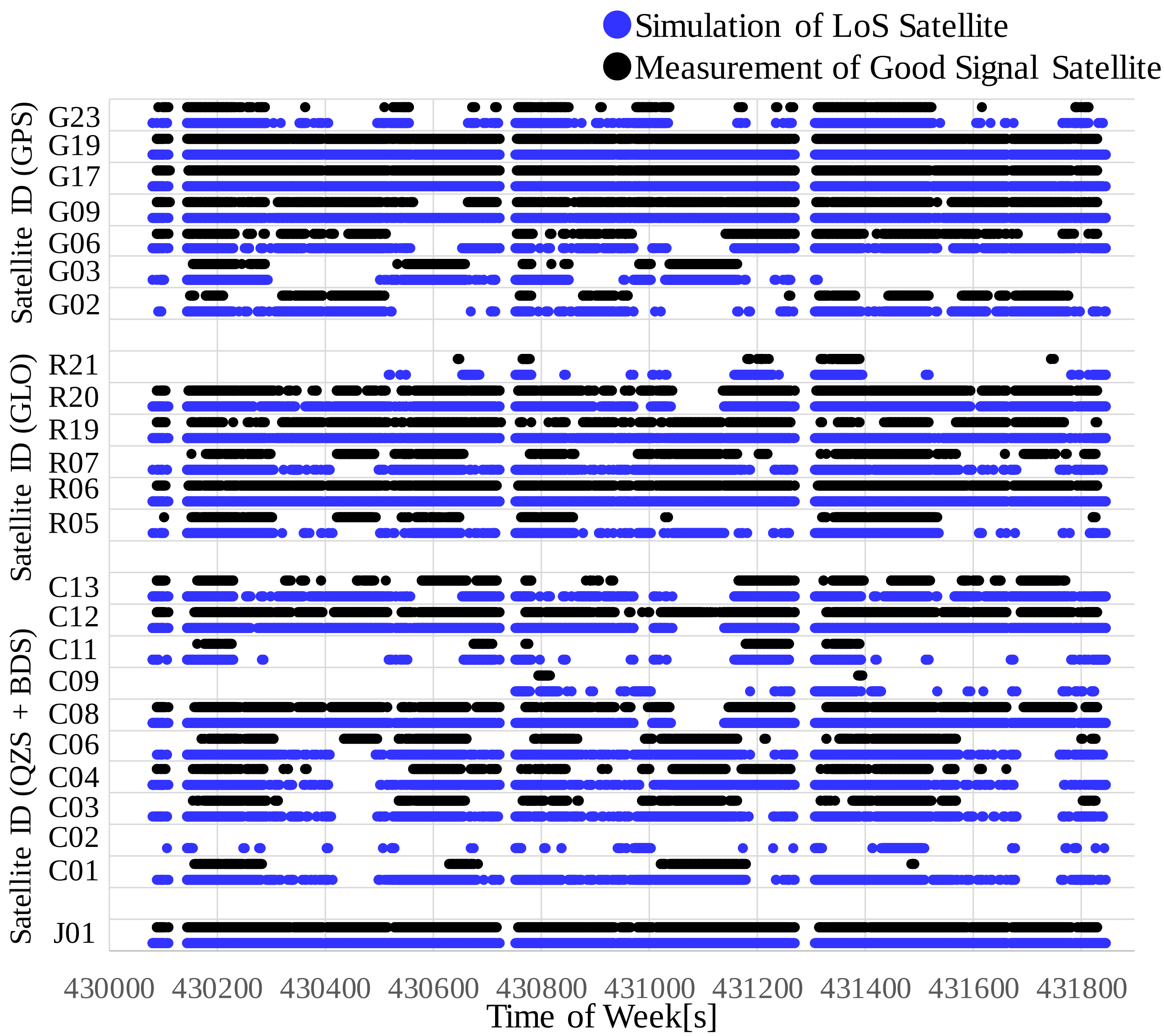

Fig.4 Good Signal Satellites and LoS Satellites

3.3 Improvement in satellite signal prediction using LoS continuation

To determine the duration of the LoS state in this study, the simulation results with different LoS durations were compared with actual measurements. The percentage of epochs in which data with good signal quality is observed in measurement and exceeded the duration of the LoS state is evaluated in the simulation, and data with poor signal quality in measurement and below the duration of the LoS state in the simulation were counted as matching rates.

Figure 5 shows the results. The horizontal axis in Figure 5 is the number of times the LoS state has continued, and because it was simulated at 1 Hz, it is equal to the number of seconds determined to be LoS. The matching rate is different for each satellite system, but in GPS, GLONASS, and QZS, the maximum matching rate is approximately 3 to 6 s. However, BDS has a different tendency, and the duration of the LoS state is increased to 15 s. The matching rate is gradually increasing. The reason why BDS tends to be different is that C01 and C02 have intermittently poor signal quality even when LoS is present. This is due to the poor reception of BDS geostationary satellite signals in Tokyo in 2016.

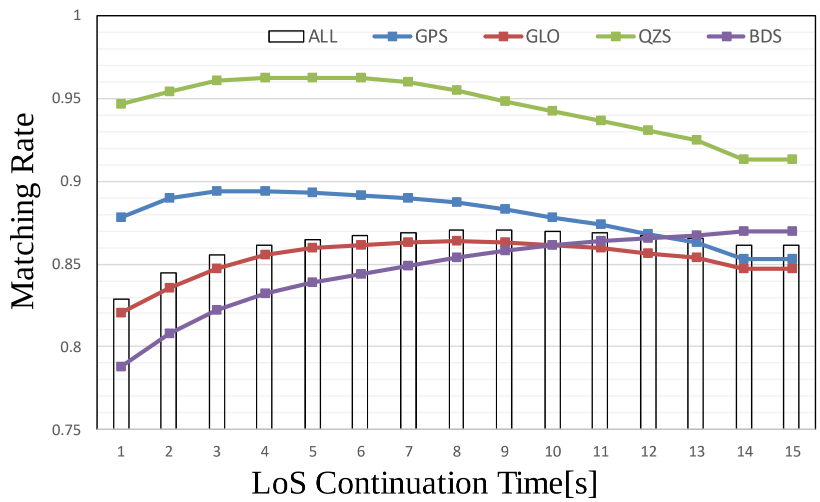

Fig.5 Good Signal Satellite and LoS Continuation time

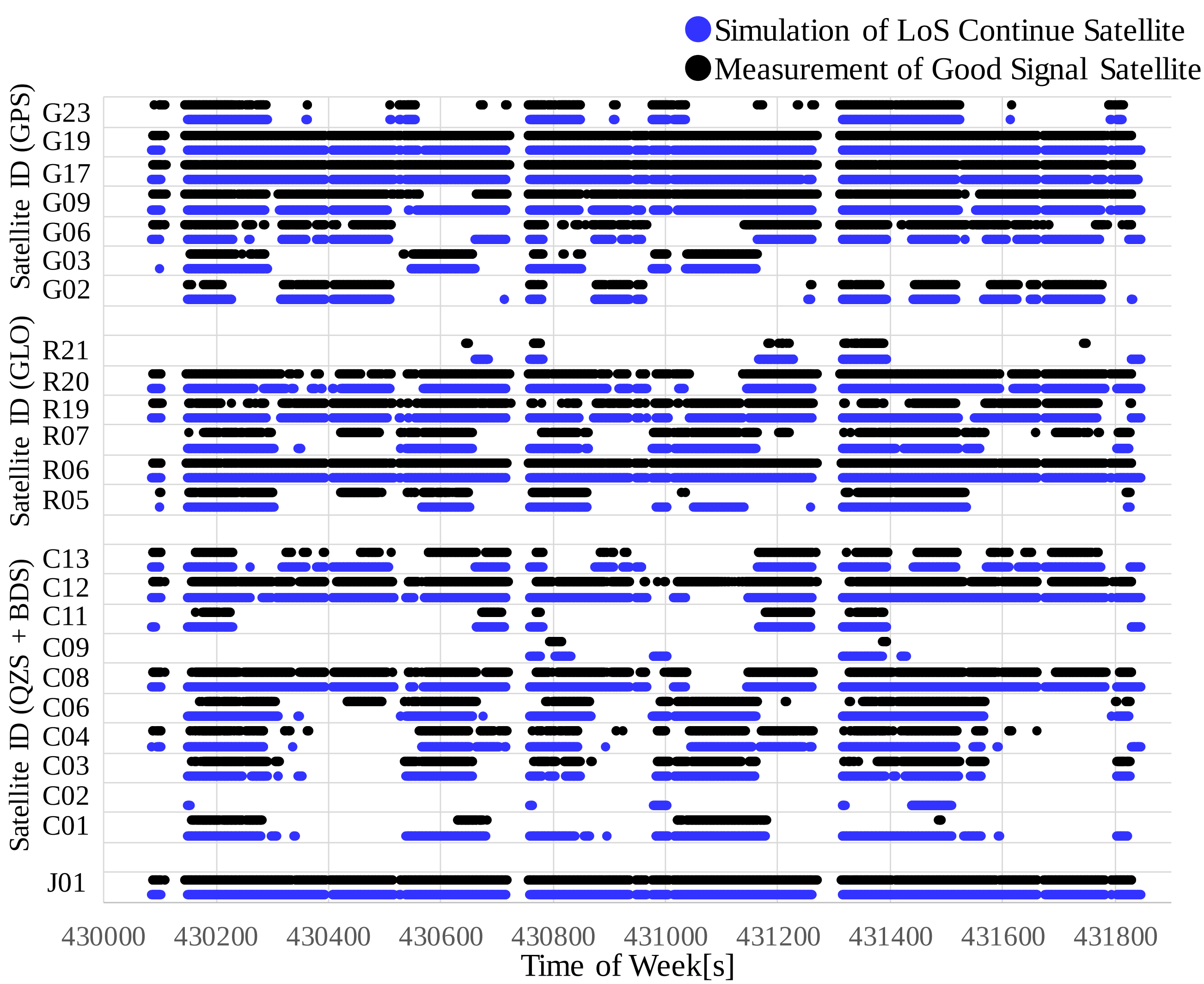

Fig.6 Good Signal Satellites and LoS Continuation Satellites

We let the duration of the LoS state be adjusted for each satellite system, 6 times for GPS, GLONASS, and QZS, and 15 times for BDS. Fig. 6 shows a comparison between satellites in the LoS continuation state that were estimated by simulations of all satellites and satellites that were determined to have a good signal quality from the measured data. The matching rate improved to 87.8%.

3.4 RTK-GNSS FIXING rate prediction

The FIXING status of RTK-GNSS positioning depends on the number of satellites with good quality. The FIXING situation is predicted, assuming that 9 LoS continuation satellites can provide a FIXING solution for RTK-GNSS positioning.

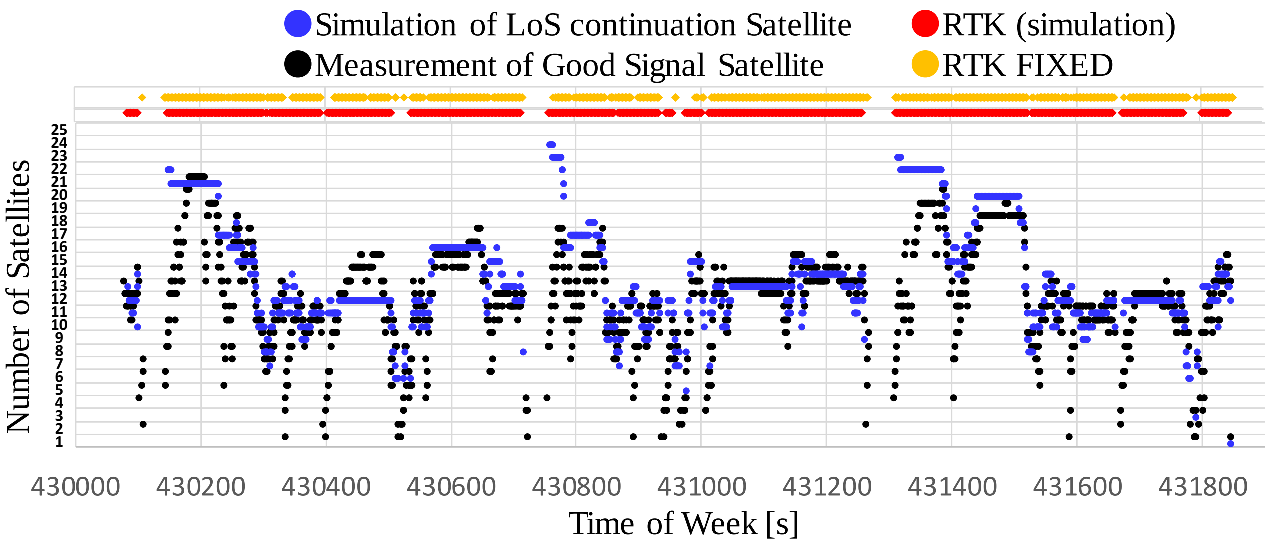

Fig.7 Time Series Comparison of Number of Good Satellites and RTK FIXED

Figure 7 shows the number of satellites with good signal quality and the number of satellites with a continuous LoS state in the actual measurement and the change in time of the time-series when RTK positioning was fixed during the actual measurement.

It can be seen that the locations where RTK positioning is FIXED and where FIX is not fixed are almost the same for both simulation and measurement. In this evaluation, the RTK FIX was predicted with an accuracy of 83.9%.

4. RTK-GNSS FIXING rate improvement using satellite selection

The FIXING rate of RTK-GNSS positioning is degraded by satellites with poor signal quality. Therefore, it is considered that the FIXING rate of RTK-GNSS can be increased via good satellite selection. Figure 8 shows our loscontinuous method for RTK-GNSS improvement. We removed not Continuous LoS Satellites of inputed RINEX observation file using GPS-Studio. The edited RINEX is used for RTKLIB.

We performed an experiment to improve the FIX rate of RTK positioning with the LoS continuation satellite. In the evaluation of the conventional method we used L1 RTK-GNSS with an elevation mask of 10° degrees. The satellite selection method used only the Los continuation satellite, and we also used the same elevation mask of 10°. The satellite selection software we created is currently only available for L1. Therefore, the experiment was performed using only the GNSS L1 signal. The driving data observed with u-blox F9P in Marunouchi, Tokyo was used for this evaluation. The place is different from Otemachi evaluated in Chapter 4, but it is also an area with many tall buildings, and we expected that the same method would be effective. The satellite systems used for the test were GPS, QZSS, GLONASS, GALILEO, and BEIDOU.

In the actual satellite selection, the true position of the receiver is not known. Therefore, the positioning calculation solution is inputted as a temporary position; the satellite selection solution is input again, and gradually approaches the correct solution. Then, using the calculated position, satellite selected positioning is repeatedly performed to converge to a probable solution. This procedure is not implemented in this study, but we mention it for consideration in future studies.

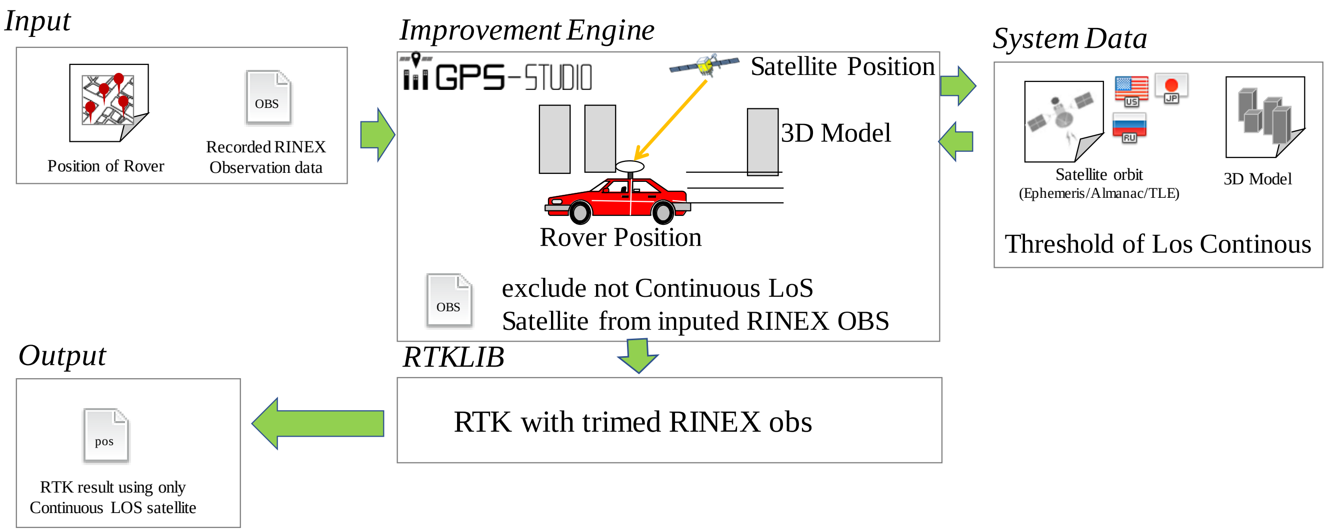

Fig.8 System of continuous LoS for RTK-GNSS improvement

Figure 9 presents the result of the RTK evaluation. It can be seen that the number of RTK solutions is improved by removing satellites with poor signal quality. As a result of the evaluation, the RTK solutions is only 2.5% without the Los continuation method. The Los continuation method increased the RTK solutions to 38.4%. Similarly, the FIXING rate increased by 1.2% to 7.7%. We confirmed some large errors in the floating solution and some missed fix solutions. In this evaluation, since our software could only use L1, the FIXING rate was very low, but an improvement in the FIXING rate was confirmed.

We consider the following as future challenges: Processing for multiple frequencies of observation data. Optimization in combination with other satellite selection methods such as an SNR mask.

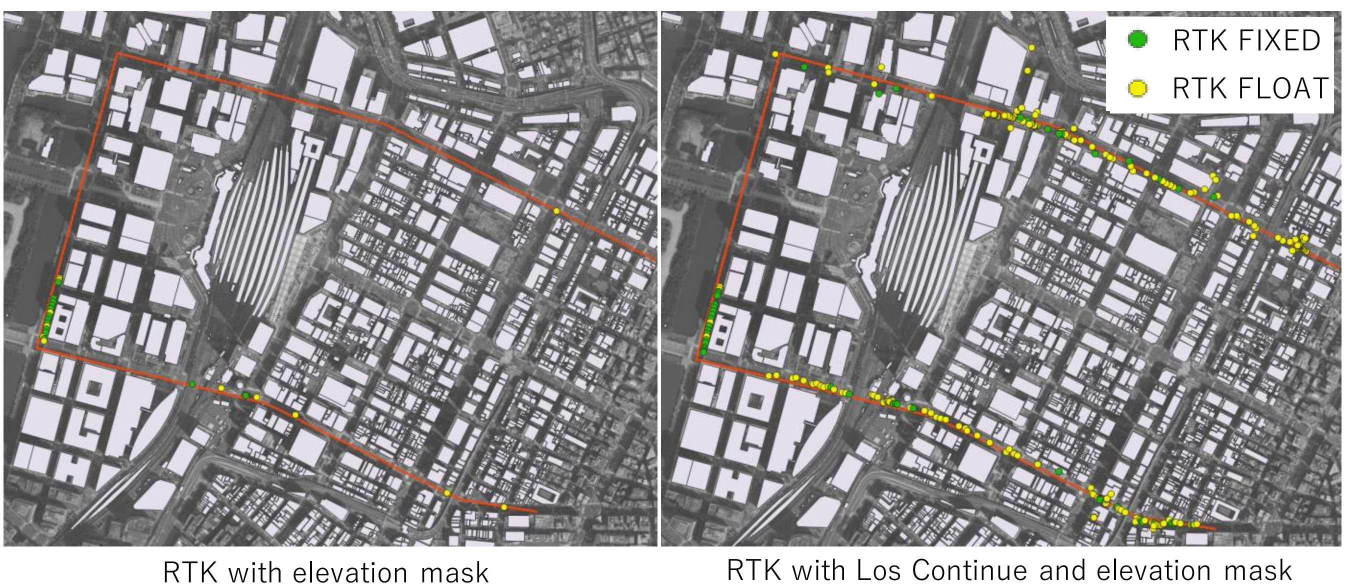

Fig.9 RTK FIXING Rate Comparison Between Conventional and LoS Continuation Satellite Selection

5. Conclusion

In this study, the number of satellites with good signal quality was estimated and compared to the processing results of GNSS observation data obtained by vehicle running and simulation using a 3D buildings model, and it was determined whether or not a FIXING solution can be obtained by RTK-GNSS positioning. Considering the time required to estimate the half-cycle ambiguity, and using a method that considers LoS continuation, a satellite with good signal quality could be estimated with an accuracy of approximately 88%. Moreover, it was estimated whether the FIXING solution could be obtained by RTK-GNSS positioning based on the number of LoS state continuation satellites estimated by simulation with an accuracy of about 84%. In addition, we confirmed that the RTK-GNSS FIXING rate improved from 1.2% to 7.7% by performing RTK positioning using only LoS continuation satellites.

Our future tasks for practical application are the handling of realistic positioning solutions with errors, multi-frequency support, and the combination of other satellite selection methods with LoS continuation.

Acknowledgments

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