Verification of GNSS Multipath and Positioning in Urban Areas Using 3D maps

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Abstract:
The reflections and diffractions of global navigation satellite system (GNSS) signals from buildings may produce large measurement errors. Detecting non-line-of-sight signals using 3D maps is a means to detect and exclude satellites with large measurement errors. However, the true position is typically needed for using 3D maps. In this study, we verify the assumption that an approximate user position can be used when using 3D maps. We found that the correct fixed position of real-time kinematic GNSS (RTK-GNSS) could be achieved when approximate positions for RTK-GNSS assisted by 3D maps were within 5–15 m from the true position.

Keywords: GNSS, 3D map, satellite selection
Classification: Navigation, guidance, and control systems

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1 Introduction

Reducing the multipath errors is one of the biggest challenges in global navigation satellite systems (GNSS), and researchers have proposed many methods to address this challenge. Consequently, other methods have been proposed, such as aiding GNSS by 3D map, fish-eye view, and GNSS/inertial navigation system (GNSS/INS) integration [1, 2]. In this study, we focus on the use of 3D maps to aid real-time kinematic GNSS (RTK-GNSS) at challenging locations. The applicability of RTK-GNSS is expected to increase with the advent of low-cost RTK-capable GNSS receivers. However, the disadvantage of using 3D maps is that the true position of the antenna is typically required to estimate the paths between satellites and the antenna location. Currently, there is a little research available investigating whether the true position is really required for accurately explaining line-of-sight (LOS) or NLOS signals. The most important aspect for a precise method such as RTK-GNSS, is the ability to obtain the correct fixed ambiguities of the carrier-phase measurements, and this is the primary focus of this study.

This study demonstrates the use of 3D maps for high-accuracy positioning through experimental testing. This quality is assessed using 3D maps data and approximate user position with real GNSS observations. As a reference, the accurate residuals of the pseudo-range measurements for each satellite were estimated using the precise antenna positions. Subsequently, we discuss whether the satellites of a large residual matches with the multipath contaminated satellites detected by 3D maps. We convinced that the satellites of a large residual can estimate from 3D maps with the approximate position of receiver and the fix rate of RTK-GNSS had improved.

2 Satellite signal testing using 3D maps and accurate pseudo-range residuals

In urban areas, buildings around the antenna may block, or cause a specular reflection and diffraction of GNSS satellite signals. This causes a ranging error where the propagation path is extended, and accordingly deteriorate the accuracy of positioning. The specular reflection and diffraction of signals from buildings may be approximately estimated using the ray-trace method used to estimate radio wave propagation [3]. As the position of the satellite is determined with respect to time, where the user can be located at a certain location, the propagation path of signal from the satellite to the antenna is estimated and whether it is a LOS or NLOS can be assessed using 3D maps.

In the evaluation whether 3D maps was valid for detecting multipath contaminated satellites, the estimation of accurate residuals are useful. Pseudo-range measurements include errors sources from the receiver clock, satellite clock, ephemeris, ionosphere, troposphere, and multipath + noise. In this study, the predicted pseudo-range is already set as the accurate antenna position and geometrical range are known. All the above mentioned error sources, with the exception of the receiver clock and multipath + noise, can be modeled within a few meters in total. When the receiver clock error is determined within a few meters, each residual can be precisely predicted. These residuals are almost equivalent to multipath errors. In this study, we were able to track a good signal from the Japanese quasi-zenith satellite system (QZSS) even near high-rise buildings in Tokyo, as at least one of the QZSSs remained at a very high elevation angle. Firstly, we pre-processed the receiver clock error by using a reliable QZSS. These estimated receiver clock errors were applied for other satellites. This generated an estimate of the residuals for each satellite within a few meters.

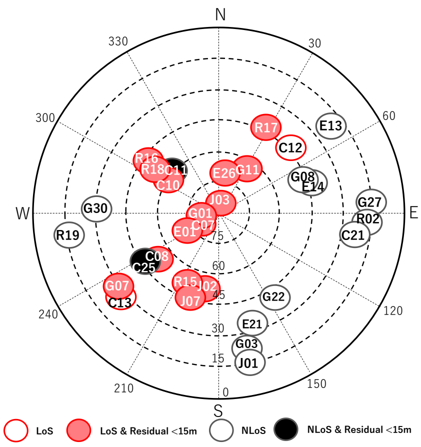
3 Verification of satellite selection using 3D maps

3.1 Evaluation setting

Figure 1 (a) shows the experimental data and an overview of the simulation using the 3D maps. The true position of the receiver was used for validation of the used method. Figure 1 (b) shows the skyplot of observed satellites at 8:25:00 GPST and the condition of the satellites, indicated by the LoS between the satellite and the receiver estimated from the 3D map, and whether the residuals of the pseudo-range observations are within 15 m. Figure 1 (c) shows the measurement location, the surrounding environment, and part of the 3D map data (heights).

Content	Setting
Date	2020/3/4 8:15:00-8:45:00(GPST)
Area	Near Tokyo station
Satellite System	GPS, GLONASS, BDS, QZS, GALILEO
Receiver	U-blox F9P L1&L2 1Hz
3D Map Simulator	GPS-Studio[4]
Raytrace settings	2Reflections, 1Reflection & 1Difraction, 1Reflection, 1Difraction
3D Map Data	NTT GEOSPACE 3D(±1.5m height accuracy at 95%)

(a) Evaluation settings



(b) Satellite position, LoS and Residuals

(c) Measurement location and surrounding environment

Fig. 1. Satellite position, measurement location, and surrounding environment.

3.2 Validation results

To validate the satellite signal quality estimation from radio propagation path using 3D maps, we compared the estimates of the satellite propagation path types (LOS and NLOS), and the post-processed residuals of the satellites. It is generally accepted that the LOS signals have smaller residuals than NLOS signals. Table 1 classifies the relationship between the pseudo-range residuals and the propagation path types. The Table presents the matching rate between the type of the path and the pseudo-range residual within each of given thresholds (<10m, <20m, and > 20m).

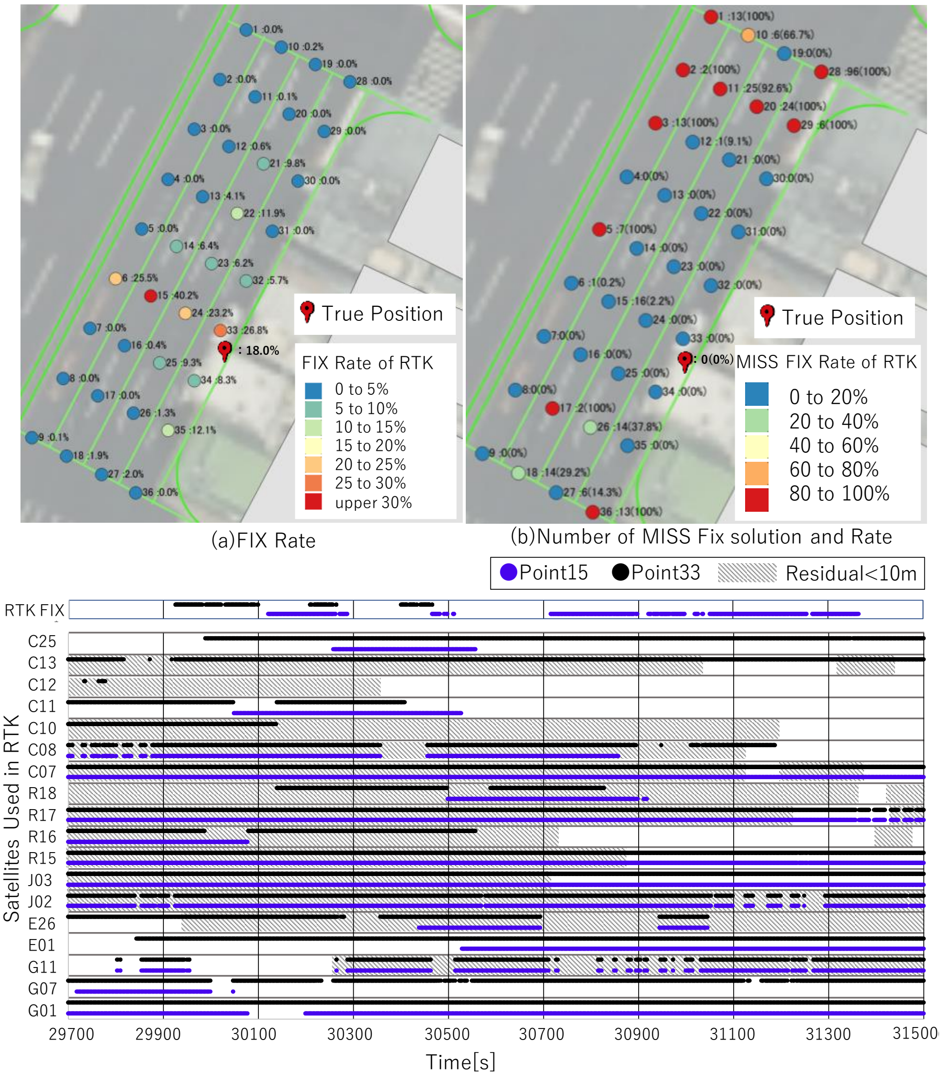
Table 1 Satellite propagation path types and residuals

ID	Path type	Rate	Pseudo-range residuals		
			below 10 m	below 20 m	over 20 m
1	LOS	43.4%	73.9 %	97.2 %	2.8 %
2	LOS + 1 Reflection	2.7%	22.7 %	22.7 %	77.3 %
3	NLOS	16.9%	18.0 %	34.3 %	65.7 %
4	NLOS + 1 Reflection	30.0%	16.0 %	18.0 %	82.0 %
5	NLOS + 2 Reflections	7.0%	1.7 %	3.0 %	97.0 %

For example, for the LOS signals without reflection, 97.2 % of these signals had a residual less than 20 m, whereas 73.9 % of them had a residual less than 10 m. For the NLOS + 1 reflection signals, 82.0 % of these signals had a residual over 20 m. These are reasonable results that are within the bounds of what was expected. Furthermore, in the case of the LOS + 1 reflection, 77.3 % of signals have more than 20 m. This means that large errors could be identified despite receiving a LOS signal. This could be attributed to that the low-cost receiver may use a narrow bandwidth, which make them not immune to LOS signals with strong reflections.

4 RTK positioning using 3D maps and approximate position

Figure 2 presents the test results and evaluation points for a path estimation using a 3D map. The observation data, the surrounding environment, and the 3D map were described in Fig. 1. Evaluation points, with ID 1 to 36, were set at approximately 5 m intervals along the centerline of each lane of the road. For each evaluation point, the type of the received observations, whether LOS, NLOS, or reflected waves between the satellite and each evaluation point were estimated from the geometry using the 3D map. The position of the satellite and the path of radio propagation were calculated every 30 s and used for the satellite selection for observation data at 1 Hz. The ‘continuous’ processing mode in RTKLIB version2.4.3 beta33 was used as the RTK engine. The chi-square test was not used because in this environment the assumption of this test that the observation errors are normally distribution is not valid.
The elevation mask angle was set at 10°. We used the signal-to-noise ratio (SNR) mask depending on the elevation angle to 31 dB at under 10°, 33 dB at 15°, 34 dB at 25°, 37 dB at 35°, 39 dB at 45° and 40 dB over 55°.



(c) RTK FIX, Residuals and Used Satellites Comparison between Point15 and Point33

Fig. 2. Fix rate of RTK for each evaluation point

In the satellite selection process, where satellites whose residuals are likely to be small are assumed in LOS with no reflected waves are selected, and all other satellites were excluded based on the results of the propagation path estimation. Each point in Fig. 2 (a) is considered as an evaluation point, and the shown value at each point is the fix rate of RTK-GNSS using the selected satellites as LOS signals based on the 3D map. Fig. 2 (b) illustrates the number of miss fix solutions and the fix rate for RTK-GNSS. The fix rate is defined as the number of times an integer ambiguity in 1800 epochs is correctly solved. The correct fixed solutions were obtained in five points for over 20 % with satellite selection, and no fixed solutions were observed at any point without satellite selection. The fix rate at the true position was 18.0 % and there were no incorrect fixes. There were also no incorrect fixes at the nearest evaluation point 33, where the fix rate was 26.8 %. Some wrong fixes were observed at evaluation points over10 m away from the true position. Although the true position did not result in the highest fix rate, the area around the true position tended to have a higher fix rate and fewer missed fix solutions.

The fix rate at evaluation point 15 was higher than evaluation point 33. Fig. 2(c) shows a comparison between point 15, which has the highest fix rate and point 33, which is closest to the true value. The upper part of the figure shows the timing of the fix of each point. The lower part of the figure shows the satellites used for RTK-GNSS at each point and the residuals within 10 meters. Point 33 and Point 15 have different timing of fix in most of the periods. The reason for the high fix rate of Point 15 is due to the fix solution after 30700s. After 30700s, when the fix solution is found at Point 15, the difference between the selected satellites is C25 in BDS and G07 in GPS. These satellites have large residuals of pseudo-range in all time periods, which is the reason for the difference in fix rates.

C25 and G07 are shielded by buildings to the west at point 15, but are not excluded at point 33. As shown in the experiments, satellite selection at the true position does not always produce the best fix rate due to the error in the shape of the 3D map and the influence of the surrounding environment during actual measurements. However, the farther away from the true position, the more errors are made in satellite selection by the 3D map cause the satellites selected with lower SNR.

In that case, the SNR filter is effective, the number of satellites is reduced, and the fix solution is difficult to calculate.

As in this evaluation, satellite selection by 3D map at the point around the true position will select the satellite with reasonable candidates and give the desired positioning solution. These results demonstrate that even if the true position is not used, selecting the correct satellite for RTK-GNSS using 3D mapping will suffice.

5 Conclusion

This study proposed aiding positioning using 3D maps. We validated the selection of LOS signals with the help of commercial 3D map data using post-processed pseudo-range residuals relevant to multipath and noise. The data was collected in a dense urban area in Tokyo. For LOS signals without reflection, 97.2 % of these signals had a residual less than 20 m. Additionally, we confirmed that identification of the LOS signals based on 3D map were extremely informative for RTK-GNSS. Generally, 3D maps can be used on condition that the true antenna position is provided. To use the 3D map in practice, we verified that the approximate position can be used. The test results demonstrated that even if the approximate positions for RTK-GNSS assisted by 3D maps are set to 5-15 m from the true antenna position, correct fixed positions of RTK-GNSS can be achieved from the selected candidate satellites.

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