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Nobuaki Kubo

Ryosuke Shibasaki

Akio Yasuda

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The Possibility of Precise Positioning in the Urban Area

Nobuaki Kubo
Tokyo University of Marine Science and Technology
(2-1-6 etchujima Koto-ku Tokyo Japan, +81-3-5245-7376,
nkubo@e.kaiyodai.ac.jp)

Ryosuke Shibasaki
University of Tokyo
(4-6-1, Komaba, Meguro-ku, Tokyo 153-8505, Japan, +81-3-5452-6412,
shiba@skl.iis.u-tokyo.ac.jp)

Akio Yasuda
Tokyo University of Marine Science and Technology
(2-1-6 etchujima Koto-ku Tokyo Japan, +81-3-5245-7365,
yasuda@e.kaiyodai.ac.jp)

ABSTRACT

A third civil frequency at 1176.45MHz will be added to the GPS system. QZSS (Quasi Zenith Satellite System) proposed by Japan will also have the new signal. This new frequency and the advent of QZSS will greatly enhance the accuracy, reliability and robustness of civilian GPS receivers. One of these enhancements is that it is possible to determine the GPS phase ambiguities more or less instantaneously. This performance will have a tremendous impact on navigation. In this paper, the possibility of precise positioning in the urban area is examined from a point of instantaneous ambiguity resolution.

A typical QZSS constellation, a third civil frequency and ambiguity_estimation for triple-frequency data is discussed. The simulator for precise positioning includes multipath effect which has been developed is also discussed. To reflect multipath effect, the following points are considered: Building reflection, building diffraction, ground reflection, antenna pattern, and correlator selection. It is confirmed that a third civil frequency could make it much easier to resolve ambiguities more quickly and the advent of QZSS helps to increase visible satellites in the urban area (Asian area). Although next generation satellite positioning system doesn't provide perfect navigation, improved performance could be realized.

KEYWORDS: Third civil frequency, QZSS, Instantaneous ambiguity resolution, Multipath

1. INTRODUCTION

Precise GPS positioning requires the use of carrier phase measurements, the data processing of which suffers from having to deal with the integer ambiguities. Ambiguity resolution is the mathematical process of converting ambiguous ranges to unambiguous range data with millimetre precision. Many ambiguity resolution techniques using single-frequency or dual-frequency measurements have been developed over the last two decades. For kinematic positioning, especially in the urban area, the integer ambiguities cannot be reliably determined, or the process suffers from many constraints. However, the precise kinematic positioning is highly valued for many aviation, agriculture, automotive, space systems, and other applications. Driven by these applications, The United States Vice President Al Gore announced that the third civil signal, which is to be located at 1176.45MHz, will be implemented beginning with future satellite launches. When combined with the current L1 and L2 signals, the new signal will significantly improve the robustness and reliability of GPS for civilian users, and consequently will support many new applications.

The main benefits for precise GPS positioning is that triple-frequency measurements will significantly help resolving the ambiguity, and hence increase the reliability of precise GPS positioning rather than positioning accuracy. Strategies for making use of the triple frequency measurements have been studied by Hatch *et al* (1996) and Han and Rizos (1999). Integral GPS-Galileo ambiguity resolution has been studied by Tiberius *et al* (2002). Also integral GPS and QZSS ambiguity resolution has been studied by Kubo *et al* (2004). These papers demonstrated particularly that augmenting the number of satellites turns out to have beneficial consequences on the capability of correctly resolving the ambiguities.

In this paper, the possibility of GPS-QZSS precise positioning in the urban area has been investigated from a point of instantaneous ambiguity resolution. First the features of three frequencies and the integer ambiguity resolution search method used in this paper will be explained. In section 3, the simulator used to generate data for precise positioning will be introduced. This simulator can produce the pseudo-range and carrier-phase which include the effects of noise, multipath and so on. It has already been confirmed that simulation results meet experimental results well under same conditions (using only L1, L2)._In section 4, the performance of combined GPS-QZSS three frequency precise positioning under some conditions will be simulated, specifically, under conditions of open-sky rooftop condition, small town and blockage by high-rise buildings.

2. Integer Ambiguity Resolution

2.1 Multi-Frequencies Integer Ambiguity Resolution

The ambiguities can be determined using pseudo-range and carrier phase data directly. Unfortunately the accuracy of the C/A or P-code pseudo-range is not good enough to determine the integer ambiguities because the wavelength of the carrier phase observable is only 19.03cm for L1, 24.42cm for L2 and 25.48cm for L3. It is very difficult, even if not impossible, to determine integer ambiguity for one-way data because they suffer from the L1, L2 and L3 clock divergence in the satellite and receiver. Therefore, the double-differenced carrier phase ambiguities should be formed and resolved to their integer values.

The fundamental measurements from GPS system will be three pseudo-range and three carrier phase measurements. The observation equations can be written as:

$$R_1 = \rho + \frac{I}{f_1^2} + \varepsilon_{R_1}, \quad R_2 = \rho + \frac{f_1^2}{f_2^2}\frac{I}{f_1^2} + \varepsilon_{R_2}, \quad R_3 = \rho + \frac{f_1^2}{f_3^2}\frac{I}{f_1^2} + \varepsilon_{R_3} \qquad (1)$$

$$\varphi_1 = \rho - \frac{1}{\lambda_1}\frac{I}{f_1^2} + N_1 + \varepsilon_{\varphi_1}, \quad \varphi_2 = \rho - \frac{f_1^2}{f_2^2\lambda_1}\frac{I}{f_2^2} + N_2 + \varepsilon_{\varphi_2}, \quad \varphi_3 = \rho - \frac{f_1^2}{f_3^2\lambda_3}\frac{I}{f_1^2} + N_3 + \varepsilon_{\varphi_3} \qquad (2)$$

The linear combination of carrier phase measurements for the triple-frequency case can be defined as (Han and Rizos, 1999):

$$\varphi_{i,j,k} = i \cdot \varphi_1 + j \cdot \varphi_2 + k \cdot \varphi_3 \qquad (3)$$

and the observation equation can be derived:

$$\varphi_{i,j,k} = \frac{\rho}{\lambda_{i,j,k}} - \frac{i + 77j/60 + 154k/115}{i + 60j/77 + 115k/154}\frac{1}{\lambda_{i,j,k}}\frac{1}{f_1^2} + N_{i,j,k} + \varepsilon_{\varphi_{i,j,k}} \qquad (4)$$

The effective frequency, wavelength and integer ambiguity combination can be formed:

$$f_{i,j,k} = i \cdot f_1 + j \cdot f_2 + k \cdot f_3 \qquad (5)$$

$$\lambda_{i,j,k} = c / f_{i,j,k} \qquad (6)$$

$$N_{i,j,k} = i \cdot N_1 + j \cdot N_2 + k \cdot N_3 \qquad (7)$$

If it is assumed that the standard deviations of the random errors on the three frequencies are equal to M_0 [cycle], expressed in units of cycles of the corresponding wavelength, the standard deviation M [cycle] of the linear combination is:

$$M_{i,j,k}[cycle] = \sqrt{i^2 + j^2 + k^2} \cdot M_0[cycle] \qquad (8)$$

$$M_{i,j,k}[m] = M_{i,j,k}[cycle] \cdot \lambda_{i,j,k} \qquad (9)$$

These formulae clearly show that the random error, expressed in cycles of the effective wavelength, is always greater than the noise on either L1, L2 or L3 carrier phase measurements. However, the noise level for combinations in units of meters may be smaller than the noise on either L1, L2 or L3 carrier phase measurements.

The ionosphere delay (in meters) on the range $\varphi_{i,j,k} \cdot \lambda_{i,j,k}$ can be represented as:

$$d_{i,j,k}^{ion} = K_{i,j,k} \cdot \frac{1}{f_1^2} \qquad (10)$$

where $K_{i,j,k}$ is the ratio value between the ionospheric delays on the combinations (in units of meter) and the L1 carrier phase measurement, derived as follows:

$$K_{i,j,k} = \frac{i + 77j/60 + 154k/115}{i + 60j/77 + 115k/154} \qquad (11)$$

There are many combinations without ionospheric delay effect. However, they could be derived from the three fundamental ionosphere-free combinations $\varphi_{77,-60,0}$, $\varphi_{154,0,-115}$ and $\varphi_{0,24,-23}$. This means that there are opportunities to find the optimal ionosphere-free combination for different purposes. For positioning purposes, the minimal variance for the ionosphere-free combination is desired, which means that the combinations have $K_{i,j,k}=0$ and small $M_{i,j,k}[m]$.

For ambiguity resolution purposes, the longest wavelength of the ionosphere-free combination is desired, which means that the combinations should have $K_{i,j,k}=0$, $f_{i,j,k}=\min$ and small $M_{i,j,k}[m]=\min$. It can be proven from equation (5) that the minimum frequency among all combinations is 10.23 MHz. Although many different combinations with minimum frequency can be found, Table 1 shows some typical carrier phase combinations with long wavelength. $M_0[cycle]$ is assumed to be small multipath condition and is set 0.05/19.03 (= 5 mm) in the case of L1 signal.

$\varphi_{i,j,k}$	$f_{i,j,k}[MHz]$	$\lambda_{i,j,k}[m]$	$M_{i,j,k}[m]$	$K_{i,j,k}$
$\varphi_{-6,1,7}$	10.23	29.305	13.588	717.22
$\varphi_{-1,8,-7}$	10.23	29.305	15.645	-16.52
$\varphi_{3,0,-4}$	20.46	14.653	3.663	-180.45
$\varphi_{-3,1,3}$	30.69	9.7684	2.129	118.1
$\varphi_{1,-7,6}$	40.92	7.3263	3.397	1.98
$\varphi_{0,1,-1}$	51.15	5.861	0.414	-1.72
$\varphi_{1,-6,5}$	92.07	3.256	1.282	-0.07
$\varphi_{1,-1,0}$	347.82	0.862	0.061	-1.28
$\varphi_{1,0,-1}$	398.97	0.751	0.053	-1.34

Table 1. Some Typical Carrier Phase Combinations with Long Wavelength

An important question is which of the combinations should be used for ambiguity resolution? Han and Rizos (1999) concluded that $\varphi_{0,1,-1}$ is suitable for the starting point for ambiguity resolution. The signal by this combination is sometimes called extra-wide-lane signal. No matter how long the baseline is, $N_{0,1,-1}$ can be fixed using pseudo-range measurements directly, which means that the widelane carrier phase measurements of L2 and L3 are always available without ambiguity. They could be used for positioning with standard deviation of 40 cm (assuming $\sigma_\varphi=5mm$) and ionospheric effect $-1.74\cdot I/f_1^2$ in meters. It is important that the performance of this technique suffers from measurement noise and multipath effects.

In this paper, this extra-wide-lane signal as a starting point for the triple-frequency ambiguity resolution is used. In the case of using only two-frequency signal (L1 and L2), wide-lane ($\varphi_{1,-1,0}$) signal for the ambiguity resolution is used.

2.2 Search and Validation Method

First of all, the flowchart of our ambiguity resolution used in this paper is shown in Fig. 1. The details are briefly described step by step as follows.
(1) The initial estimations of extra-wide-lane ambiguities are determined using the position, which is inferred from the double differences of L1 pseudo-ranges. Non-smoothed pseudo-ranges are used because the target is the instantaneous precise positioning in this simulation. One–sigma of the double differences of L1 pseudo-range is set to be from 0.3 m to 1.0 m. Performing an active search of the correct solution at each epoch is an adequate strategy for the resolution of the ambiguities. This search is carried out over a measurement or a positioning domain centered around an estimate of the solution. Numerous methods have been proposed so far and it has been investigated by Kim and Langley (2000). Our searching method is based on the method described by Hatch *et al* (1991). Primary satellites are chosen on the basis of minimum PDOP from among all of observed satellites. Ambiguities of primary satellites are resolved and the probable positions of the user receiver are

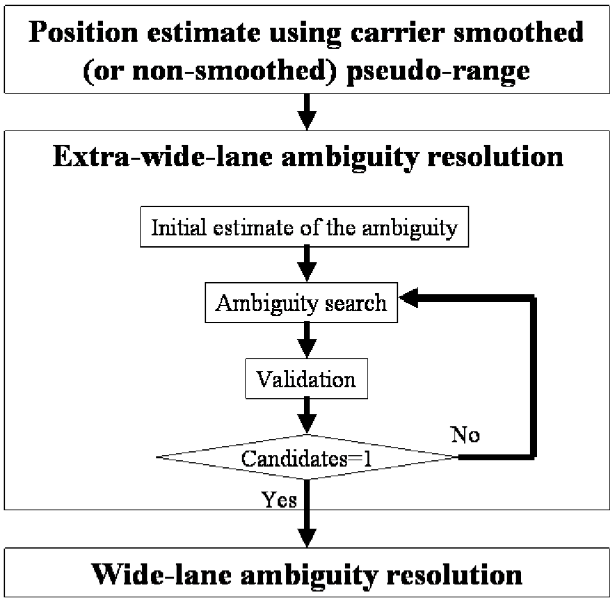


Figure 1. Flowchart of the RTK algorithm

obtained. First, the ambiguities of primary satellites by the least square searching method are resolved, and next, the ambiguities of the secondary satellites are resolved. Since the wavelength of extra-wide-lane is about 5.8m, the solution is in a range of initial value ± 1 cycles with a confidence level of over 99%.
(2) Receiver position is assumed from ambiguity candidates. The statistical tests are performed in both the measurement domain and the positioning domain to identify the most probable position. In the measurement domain, the χ^2 test is applied using the sum of measurements residuals. The candidates satisfying the fixed condition are rejected. In the positioning domain, taking the differences between the horizontal positions deduced by the pseudo-range and from ambiguity candidate, the candidates that fit into the criteria are selected. The confidence level is set at 99% in both statistical tests. In order to reduce the time to fix, the ratio test is also applied to the measurement residuals. The optimal ratio test has been studied by Teunissen and Verhagen (2004). The

critical value of the ratio test is set about 3.
(3) If only one ambiguity candidate set is retained it is considered to be the solution. If more than two candidate sets are retained, the same statistical tests will be applied at the next epoch.
(4) The initial values of wide-lane ambiguity are deduced from the position determined by extra-wide-lane technique.
(5) Procedures same as (2) and (3) are repeated until only one candidate set remains. The procedures of wide-lane ambiguity resolution are almost same as the extra-wide-lane ambiguity resolution, but the search range has to be enlarged.

3. The GNSS simulator

3.1 The outline of the GNSS simulator

A software simulator to analyse the precise positioning performance under some conditions has been developed. In this paper, the main target is to simulate the precise positioning under multipath conditions without distance constraints. In order to simulate the positioning performance, it needs the satellites orbits, signal structure, the receiver's parameters and its position. The simulator can generate the DLL and PLL tracking errors, which are defined respectively as the difference between the true code pseudo-range or carrier phase and the measured one. These are obtained by equations (12) and (13) which model the errors in DLL and PLL tracking loops of the receiver. These equations are written in Kaplan (1996). It can also generate multipath errors by adding some parameters. The clock error is neglected because of making use of double differenced data in the positioning. The propagations and satellites errors are also neglected because of short baseline assumption.

$$\sigma_t DLL = \lambda_c \sqrt{\frac{4F_1 d^2 B_w}{c/n_0}\left[2(1-d)+\frac{4F_2 d}{Tc/n_0}\right]}\ (m) \qquad (12)$$

$$\sigma_t PLL = \frac{\lambda_L}{2\pi}\sqrt{\frac{B_w}{c/n_0}\left[1+\frac{1}{2Tc/n_0}\right]}\ (m) \qquad (13)$$

where λ_c is code chipping rate (293.05m for C/A code). F_1 is the DLL discriminator correlator factor (=1/2). F_2 is DLL discriminator type factor (=1). d is correlator spacing between early and late. B_w is code or carrier loop noise bandwidth (Hz). c/n_0 is carrier to noise power ratio ($C/N_0 = 10^{c/n_0/10}$). T is predetection integration time (sec). λ_L is wavelength for L-band signal (0.1903m for C/A code).

A wide-band (20MHz) GPS receiver tracking C/A code type signal on L1, L2 and L5 separately is simulated. The carrier to noise ratio on each signal is calculated according to the function of the elevation. The satellite configuration is given by the GPS YUMA almanac of GPS week 271. The receiver parameters are shown in Table 2. The flowchart of our precise positioning used in this paper is shown in Fig. 2.

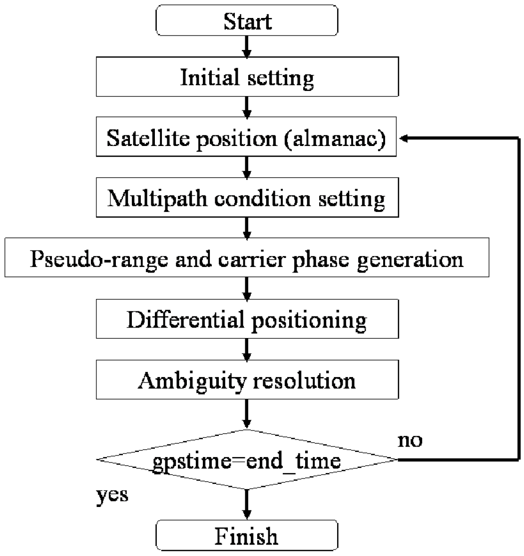


Figure 2. Flowchart of the precise positioning

DLL loop bandwidth	0.8 Hz
PLL loop bandwidth	18 Hz
DLL detector	Early-late power
PLL detector	Sinus
Correlator spacing	0.1 (narrow and strobe)

Table 2. Receiver Parameters

3.2 The simulation for the multipath errors

Multipath refers to the phenomenon of a signal reaching an antenna via two or more paths. Typically, an antenna receives the direct (line-of-sight) signal and one or more of its reflections from structures in the vicinity and from the ground. A reflected signal is a delayed and usually weaker version of the direct signal. The range measurement error due to multipath depends on the strength of the reflected signal and the delay between the direct and reflected signals. Multipath affects both code and carrier measurements, but the magnitudes of the error differ significantly. The effect of multipath can be reduced in antenna design process and it can also be reduced in the signal processing step in a receiver.

To reflect multipath effects in this paper, the following factors are considered: Building reflection, building diffraction, ground reflection, antenna pattern, and correlator selection. It is known that all of these factors affect the multipath parameters except for the types of correlator. This means that if the multipath parameters can be simulated, the multpath errors can be estimated. Multipath parameters consist of amplitude, delay and phase relative to the direct signal. If the signal propagation environment is known, the multipath parameters could be estimated. In this simulation, the two well-known types of correlators used are the narrow correlator and the strobe correlator. As a GPS antenna pattern, the pattern of GPS-700 manufactured by NovAtel corporation (http://www.novatel.ca/Documents/Papers/GPS700.pdf) is used. Fig. 3 shows a plot of the multipath error envelopes for two types of correlator. The error is calculated by our software at the maximum points when the multipath signal is in phase ($0°$) or out of phase ($180°$) with respect to the direct path signal. The 20MHz bandlimited correlation function is used.

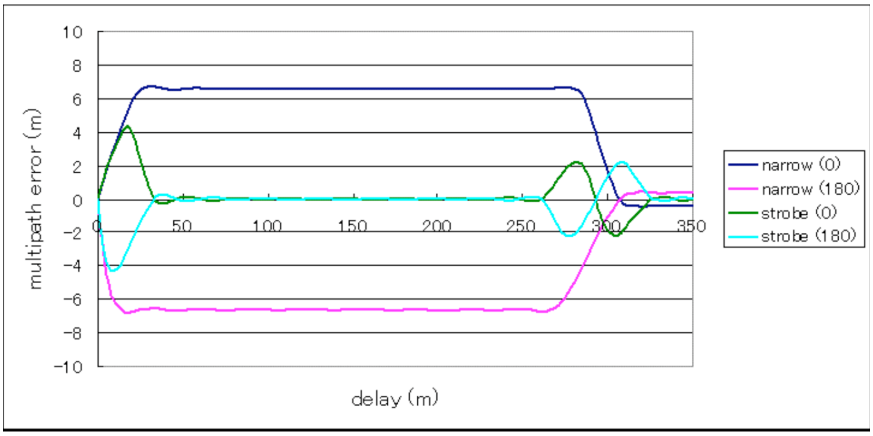


Figure 3. Multipath error envelopes for narrow and strobe correlator techniques

The multipath error generation are briefly described step by step as follows.

(1) Deciding the signal propagation environment (open-sky rooftop condition, small town condition and high-rise building block condition).
(2) Calculating the mask angle in each azimuth according to the environment.
(3) Deciding which satellites are visible will determine multipath types (building reflection, building diffraction, ground reflection) on each visible satellite.
(4) Calculating the amplitude, delay and phase of multipath signal relative to the direct signal from the geometrical and electrical environment.
(5) Estimating the multipath errors from the multipath parameters according to the types of correlator.

3.3 Satellite Constellation and Signal Structure

3.3.1 GPS

The GPS configuration is used of GPS YUMA almanac of GPS week 271, 2004. There are four or more satellites, in circular orbits, in each of the six orbital planes. Key-parameters are an orbital radius of 26,560 km and an inclination of 55 degrees relative to the equatorial plane. With a spare slot ion each plane, the currently deployed constellation can support up to 30 satellites. The present constellation (as of November 7, 2004) consists of 30 satellites.

3.3.2 QZSS

The QZSS constellation parameters have not decided yet, so one case of constellation for the simulation referring to some articles written about the constellation of QZSS is chosen. The inclination for the satellites is 45°. It will contribute to improve satellite communication environment for mobile users in urban and mountainous areas by offering high elevation angles higher than about 70° at all times all over the Japanese islands. If the satellite orbits are appropriately selected, one of them stays over Japanese Islands and the surrounding area with high elevation angle for at least 8 hours. Therefore, three satellites are sufficient with three inclined orbits having the longitude of ascending node of 120° separation for 24-hour operation. The constellation selected is shown in Fig. 4 is with three elliptical orbital planes having one satellite. Key-parameters are an eccentricity of 0.099, the perigee height of 31612 km, the apogee height of 39960 km and the inclination of 45°. L1, L2 and L5 signals are used in both GPS and QZSS in this simulation. Signal parameters are shown in Table 3.

Frequency band:	L1	L2	L5
Carrier frequency [MHz]	1575.42	1227.6	1176.45
Code rate [MHz]	1.023	1.023	10.23
Bandwidth [MHz]	20	20	20
Received signal power [dBm]	-158	-165	-158

Table 3. Signal Parameters, GPS space segment

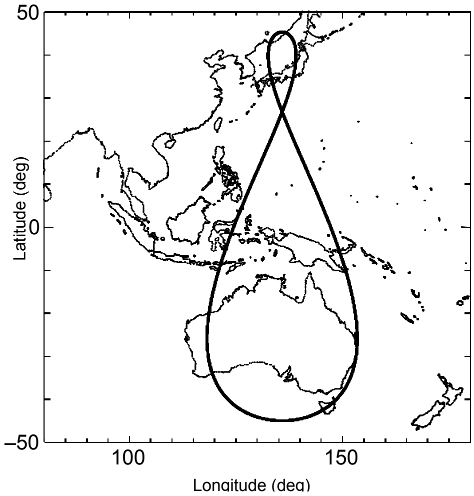
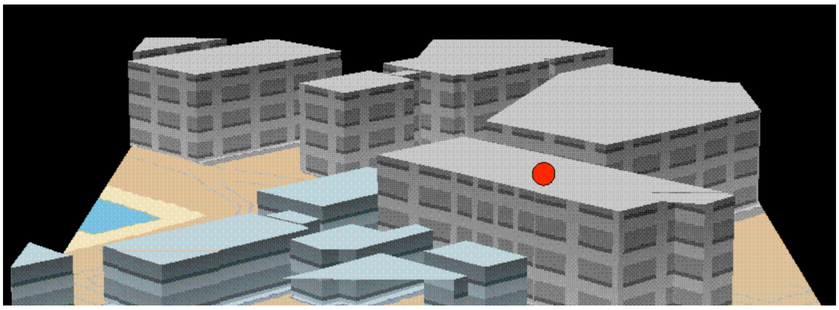


Figure 4. QZSS constellation

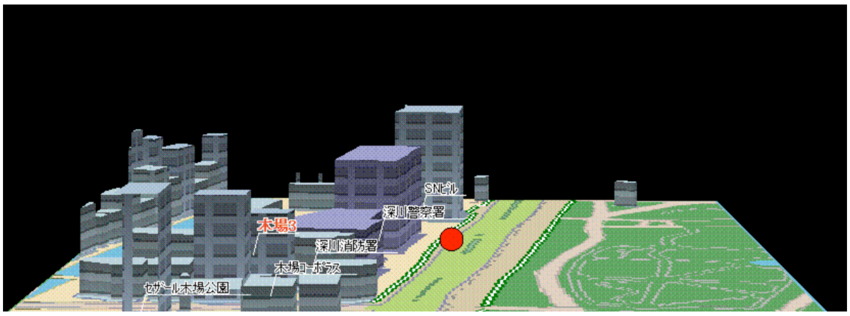
4. The performance of GPS-QZSS three frequency precise positioning

4.1 Scenarios

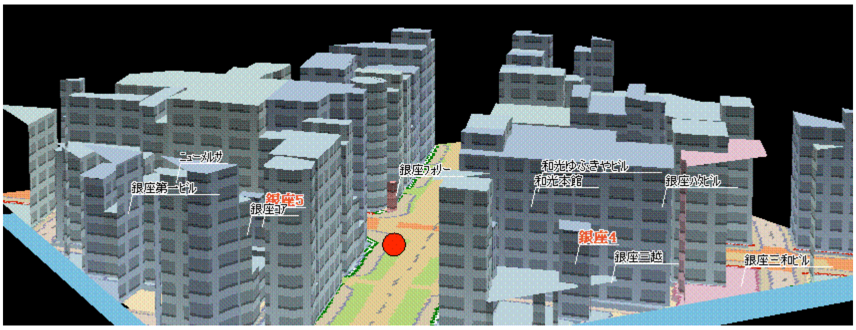
In order to evaluate the performance of the precise positioning, the ambiguity fix percentage by the above simulator for various scenarios are calculated; i.e. GPS with L1 and L2 signals, GPS with L1, L2 and L5 signals, GPS combined QZSS with L1, L2 and L5 signals. Each scenario has been tested under three conditions; i.e. open-sky rooftop, small town, high-rise building blockage. In order to grasp these three conditions, the 3D-maps to display three conditions are shown in Fig. 5. The model parameters and basic assumptions are briefly reviewed as follows.



Condition1: open-sky rooftop



Condition2: small town



Condition3: high-rise building blockage

Figure 5. 3D-maps for signal propagation environments

The short baseline within 1 km is only considered. Differential atmospheric delays are assumed to be completely absent (zero) between reference and user receivers. GPS satellites positions of a full day period during GPS week 271, 2004 was sampled every second. Pseudo-range and carrier phase data are used together. The accuracy of the measurements in the receiver was stated in Section 3. Cycle slip is not considered. The location of the reference is the city of Tokyo, Japan, at latitude of 35.666260 N, longitude of 139.792315 E and height of 100 m. The remote station is located within 1 km distance from the reference location. Satellite elevation cutoff angle is 10 degrees.

The ambiguity fix percentage is adopted here as an indicator of the performance. The ambiguity is computed for all 86,400 epochs over the all day period. The integer ambiguity is re-initialized every 150 seconds. The ambiguity fix percentage can be obtained by calculating the ratio value between the number of correct ambiguity fixes within 150 seconds and the number of the total ambiguity fixes. The total number of ambiguity fixes is 576.

4.2 Results and Analysis

4.2.1 GPS with dual frequencies (L1 and L2)

Table 4 shows the ambiguity fix percentage for GPS with dual frequencies for three conditions; i.e. condition 1 is open-sky rooftop condition, condition 2 is small town condition, condition 3 is high-rise building blockage condition. The second column gives the percentage of ambiguity resolution fixes within 150 seconds, while the third column gives the percentages of times in which ambiguity can not be fixed within 150 seconds. The fourth column gives the wrong ambiguity fix percentage. The fifth column gives the percentage of times in which the number of satellites is less than 5. At least 5 satellites are needed in the ambiguity resolution. Table 5 shows the time to fix statistics. The second column gives the percentage of 1 epoch fix, while the third column gives the percentage of the cases fixed in 2 epochs to 10 epochs. The fourth and fifth columns give the percentage in each case same as the third. In the case of condition 2 and condition 3, there are two types of results. One is the result for narrow correlator (left side), and the other one is the result for strobe correlator (right side).

Fig. 6 shows relative frequency distributions of the number of satellites in three conditions in the case of GPS constellation. Fig. 7 shows relative frequency distributions of the number of satellites in three conditions in the case of combined GPS and QZSS constellations. The visible satellite number under high-rise building blockage is less than 5 during about 68 % of a day in the current GPS constellation. Therefore, the service of precise positioning is not practical, as the ambiguity resolution procedure requires more than 5 satellites. On the contrary, five or more satellites can be found over the sky over a half of a day in the combined GPS and QZSS.

In the condition 1, the ambiguity fix percentage is about 95 % and the time to fix is almost within 10 seconds. However, both in the condition 2 and condition 3, the ambiguity fix percentage is low especially in the condition 3. From the result of condition 2, it is found that the strobe correlator plays an important role to increase the ambiguity fix percentage. This means that the narrow correlator receiver is badly influenced by the long delay multipath (over 20 m) in the case of small town.

	Fix (%)	Unfix (%)	Wrong (%)	No-solution (%)
Condition 1	94.4	0.0	5.6	0.0
Condition 2	49.1/70.8	3.0/0.0	47.9/29.2	0.0/0.0
Condition 3	10.9/13.7	0.0/0.0	21.3/18.5	67.8/67.8

Table 4. Ambiguity Fix Percentage (GPS with L1 and L2 signals)

	1 epoch (%)	2~10 (%)	11~60 (%)	61~150 (%)
Condition 1	65.8	31.8	2.2	0.2
Condition 2	55.5/53.4	40.6/42.2	0.39/0.44	0.0/0.0
Condition 3	28.6/24.1	57.1/63.3	14.3/12.6	0.0

Table 5. Time to fix statistics (GPS with L1 and L2 signals)

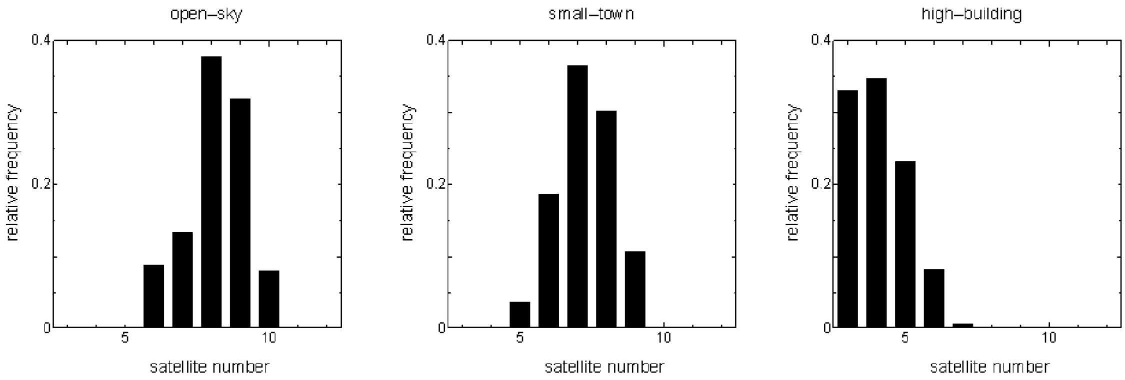


Figure 6. Relative frequency distribution (GPS)

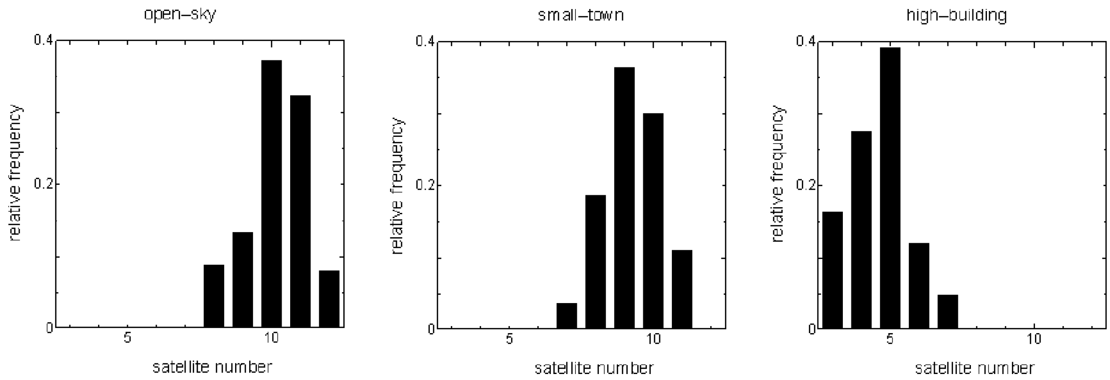


Figure 7. Relative frequency distribution (GPS+QZSS)

4.2.2 GPS with triple frequencies (L1, L2 and L5)

Table 6 shows the ambiguity fix percentage for GPS with triple frequencies for three conditions. Table 7 shows the time to fix statistics. In the condition 1, the ambiguity fix percentage is perfectly 100 % and the time to fix is also perfectly within 10 seconds by adding the third frequency. Also in the condition 2, both the ambiguity fix percentage and the time to fix are promising value for instantaneous precise positioning application. However, in the condition 3, as can also be seen in the case of the above GPS with dual frequency, the ambiguity percentage is fairly low. This is mainly due to the lack of visible satellites. On the other hand, the ambiguity fix percentage over 5 visible satellites is relatively high (28.5/32.2=88.5 %) even in the case of high building condition. This suggests that not only developing the multipath mitigation technique but also the increasing visible satellites under high building condition is important.

	Fix (%)	Unfix (%)	Wrong (%)	No-solution (%)
Condition 1	100.0	0.0	0.0	0.0
Condition 2	98.8/98.8	0.7/0.7	0.5/0.5	0.0/0.0

Condition 3	28.5/28.5	0.7/0.5	3.0/3.2	67.8/67.8

Table 6. Ambiguity Fix Percentage (GPS with L1, L2 and L5 signals)

	1 epoch (%)	2~10 (%)	11~60 (%)	61~150 (%)
Condition 1	84.0	16.0	0.0	0.0
Condition 2	53.2/56.6	46.4/43.2	0.4/0.2	0.0/0.0
Condition 3	12.8/13.4	79.3/78.7	6.1/6.1	1.8/1.8

Table 7. Time to fix statistics (GPS with L1, L2 and L5 signals)

4.2.3 Combined GPS and QZSS with triple frequencies (L1, L2 and L5)

Table 8 shows the ambiguity fix percentage for combined GPS and QZSS with triple frequencies for three conditions. Table 9 shows the time to fix statistics. Both in the condition 1 and condition 2, it can be expected that combined GPS and QZSS with triple frequencies is practical system for instantaneous precise positioning. The percentage of 1 epoch fix in the condition 2 is increased by the adding QZSS. In the condition 3, the ambiguity fix percentage is badly influenced by the lack of visible satellites as can also be seen in the above cases. The ambiguity fix percentage during over 5 visible satellites is not so good compared with the case of GPS with triple frequencies.

	Fix (%)	Unfix (%)	Wrong (%)	No-solution (%)
Condition 1	100.0	0.0	0.0	0.0
Condition 2	99.3/99.8	0.7/0.2	0.0/0.0	0.0/0.0
Condition 3	46.3/46.3	1.4/1.6	8.3/8.1	44.0/44.0

Table 8. Ambiguity Fix Percentage (GPS and QZSS with L1, L2 and L5 signals)

	1 epoch (%)	2~10 (%)	11~60 (%)	61~150 (%)
Condition 1	97.6	2.3	0.1	0.0
Condition 2	80.8/82.8	19.2/17.2	0.0/0.0	0.0/0.0
Condition 3	14.6/15.1	78.6/77.8	6.0/6.0	0.8/1.1

Table 9. Time to fix statistics (GPS with L1, L2 and L5 signals)

5. CONCLUSIONS

It has been demonstrated that the capability of resolving carrier phase ambiguities with triple frequency clearly prevails over the present GPS. Even in the case of small town which is small blockage environment, instantaneous precise positioning service is expected from the results of this simulation. If the QZSS is available for us, the lack of visible satellites can be improved and instantaneous precise positioning service could be more robust and reliable. However, the sufficient ambiguity fix percentage can not be attained under taxing conditions such as busy downtown streets, and therefore continuous precise positioning service is not available. Under busy downtown streets conditions, the ambiguity fix percentage is almost the same between low narrow correlator receivers and strobe correlator receivers. This means raising the ambiguity fix percentage requires to more visible satellites. A few more satellites are needed all the time to accomplish such a service under busy downtown conditions. It will be possible to realize the sufficient ambiguity fix percentage for practical application, if Galileo reinforces the constellation of the combined system of GPS and QZSS.

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