How multipath error influences on ambiguity resolution

Nobuaki Kubo, Akio Yasuda
Tokyo University of Mercantile Marine

BIOGRAPHY

Nobuaki Kubo received his Master of Engineering (Electrical) in 1998 from the Hokkaido University. After that, he joined NEC and had worked on GBAS and MSAS project especially in the area of GPS software development for several years. Currently he works as a research associate at Tokyo University of Mercantile Marine (TUMM) in the area of some GPS systems.

Akio Yasuda is a professor at TUMM. He received his doctorate in engineering from Nagoya University. He is the president of GPS Society, Japan Institute of Navigation (JIN GPS). His major subjects are satellite communication and positioning system, including GPS application and the development of the instruments for marine researches.

1 ABSTRACT

It is known that both code and carrier-phase multipath is currently one of a few remaining obstacles against high precision real time positioning. It easily leads to incorrect ambiguity resolution and causes cm-order fluctuations of positioning. If the multipath error in pseudorange fluctuates largely, the initial ambiguity for the satellite is biased and its search space can be enlarged. As a result, a longer time is needed to resolve the ambiguity and the probability of successful integer ambiguity estimation decreases. The carrier phase, disturbed by multipath largely, leads to the incorrect ambiguity resolution and the fluctuation of the positions of a few cm even if the integer is estimated correctly.

The more the available satellites, the more the robustness against multipath of the ambiguity resolution. This implies that combined receivers of GPS, Galileo, and QZSS (Quasi-Zenith Satellite System) is more robust against multipath, as they can remove the satellite, which is seriously contaminated by multipath, in the calculation of RTK positioning.

This paper demonstrates the effects of multipath error on ambiguity resolution for short-baseline in both simulation and real data analyses. We have often found that the effects of multipath in both carrier phase and pseudorange measurements make it difficult to fix ambiguities correctly. On the other hand, we have also found that removing satellites of which signal is contaminated by multipath is effective in RTK-positioning. Current RTK system isn't perfect against the biases such as multipath and insufficient satellites. Because of this, the range of RTK data service is limited. We also showed one example of the ambiguity resolution under strong multipath and insufficient satellites conditions.

2 INTRODUCTION

For the last decade or so, it has been a continuing interest to mitigate the effects of multipath in GPS code and carrier phase measurements. From the simplest approach like optimal antenna location selection, to the most complicated receiver technology, a number of multipath mitigation techniques have been proposed by many groups from all over the world. However, multipath is currently seen as one of the few remaining obstacles for high-precision real-time positioning. And it seems that it has not been demonstrated so much about the impact of multipath on ambiguity resolution [1].

Firstly, we show how much biases due to multipath affect the ambiguity resolution through the simulation in section 3. The amount of biases due to both pseudorange and carrier phase multipath are estimated using GPS YUMA almanac, geometrical relationship between an antenna and a virtual obstacle, positioning algorithms and parameters for GPS receiver. The case of short baseline is only considered under some assumptions to specify the effect of multipath.

Secondary, the effect of multipath on ambiguity resolution is introduced using real field observables. Section 4 consists of 2 parts of field test with several one static conditions. They are during the periods with relatively large number of visible satellites and relatively small number. Each test uses 2 remote stations and one reference station. The reference station is on the roof of the 5-story building of our laboratory under the condition of almost free multipath. The two remote stations are on the roof of the same building with the baseline of 29 m under weak multipath condition and with the baseline of 25 m under strong multipath condition. We developed the post-processing software for integer ambiguity resolution [2]. It refers to the real observations. All static baselines are processed in only single epoch mode. We have to say that there are some ambiguity resolution techniques that have good performance (success rate) compared with our software [3,4]. However, the object in this paper is to demonstrate the effects of multipath on the ambiguity resolution but to find the best ambiguity resolution algorithm. From the result of section 4.1, when there are a large number of redundant satellites, we can improve the performance of ambiguity resolution by detecting and removing the satellite contaminated by multipath. It is found that pseudorange carrier phase single differences and the frequency of occurrence of cycle slips is effective criteria to detect outliers and biases such as multipath. From the result of section 4.2, we found that it is considerably difficult for our present post-processing RTK positioning software to obtain the high fix percentage and success rate under insufficient number of satellites and strong multipath. However, in the present contribution, we proved our proposed technique was effective to improve fix percentage and success rate under the severe conditions as mentioned above. The larger the number of satellites available, the more effective improving the performance.

3 AMBIGUITY RESOLUSION UNDER MULTIPATH ENVIRONMENTS

Cycle slips, multipath effects, residual atmospheric biases, orbital errors, and random noise induce errors mainly in the pseudorange and carrier phase observations. They make it quite difficult to obtain the instantaneous ambiguity resolution even with state-of-the-art GPS techniques. In order to see how the multipath affects on the performance of ambiguity resolution, we tried the simulation for ambiguity resolution with short baseline under various multipath conditions.

3.1 SIMULATION METHOD

The simulation, based on the least squares ambiguity search technique, comprises mainly 3 steps. The first step is based on the positioning of DGPS single difference carrier-smoothed pseudorange measurements. Following the first step, wide-lane positioning is performed to improve the solution precision. The operation of double differences is used in this procedure. The third step is to determine the double difference L1 ambiguity vector. The statistical tests to resolve the ambiguities are performed in the the measurement domain and positioning domain. The χ^2 test is performed using the sum of measurement residuals. The candidates satisfying the fixed condition are rejected. In the positioning domain, taking the differences between the horizontal positions computed using smoothed pseudorange and those using each ambiguity candidate, the candidates that satisfy the fixed condition are rejected.

The following items are assumed in this simulation.

1) Residual atmospheric biases and orbital errors are assumed to be negligible.
2) Reference station is only affected by ground reflection multipath.
3) Satellite and receiver clock is perfect.
4) Cycle slip is not considered.

The code standard deviation value refers to a tracking channel with a non-coherent early-power minus late-power discriminator, a discriminator spacing of d (in chips) and a delay lock loop bandwidth of 1Hz. Typical code and carrier phase measurement accuracy values, due respectively to DLL and PLL thermal noise, are used in the simulation. These are computed according to the equations in the literature of Elliott D. Kaplan [5]. Carrier to noise ratio is empirically estimated as a function of elevation. The receiver parameters are shown in table 1.

Table 1. Receiver Parameters

DLL Loop Bandwidth.	1Hz
PLL Loop Bandwidth.	18Hz
DLL Detector	Early-Late Power
PLL Detector	Sinus
Correletor Spacing	0.1
Receiver Clock	Perfect

Generally speaking, the errors due to multipath will be much larger than those due to thermal noise in most cases. To reflect these aspects, realistic values of multipath error are assumed. Single speculum reflection is only considered. Cycle slip is not considered. The reference station is settled in the city of Tokyo, Japan, where the latitude is 35.666260N, longitude 139.792315E and altitude 100m. The remote station is located at 1km from the reference station. The first scenario, a receiver antenna placed statically 1m above the ground under multipath-free environment. The second scenario, the antenna is placed at the position of 10m apart from a wall of 7 m in height. The third scenario, the antenna is placed at the position of 3 m apart from a wall of 3 m in height. These are shown in Figure 1. The wall is made of concrete (ε_r=3 and $\sigma=2\times10^{-5}$) and the ground floor is made of medium dry ground (ε_r=7 and $\sigma=4\times10^{-2}$). The antenna is a general one for precise positioning and can receive multipath signals from the wall and the ground floor. The observations for 24 hours on July 27th 2003 are simulated.

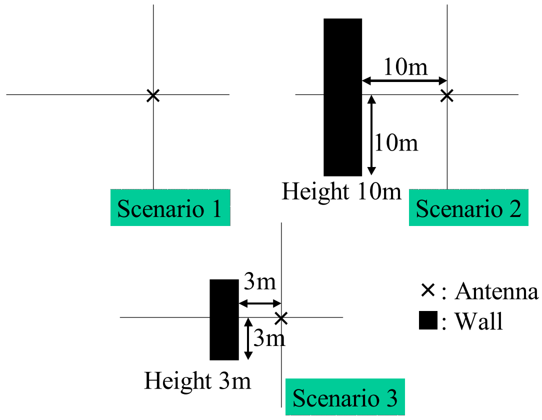


Figure 1. The location of the receiver antenna

3.2 SIMULATION RESULT

Table 2 shows the ambiguity fix statistics in the simulation. The first row gives the number of scenarios. The second row gives total number of ambiguity initializations, which took place when a set of primary satellite changes or reference satellite changes. The third row gives the number of right ambiguity fixes within 300 seconds in which the number of wrong ambiguity fixes is shown in the fifth row, while the fourth row gives the number of cases in which ambiguity can be fixed over 300 seconds among the fixed cases of the third row. The sixth row gives the average number of visible satellites of all observations.

Table 2. Ambiguity fix statistics (86400 epochs)

Scenario	**1**	**2**	**3**
Cases	50	60	58
Fix	50	52	56
Fix (over 300sec)	2	7	9
Wrong Fix	0	8	2
Average Satellite	7.3	6.5	6.5

Figure 2 shows the relationship between the results of horizontal DGPS positioning error and the threshold for positioning domain statistical test in each scenario. A blue line shows the difference between the results of horizontal DGPS positioning and correct wide-lane positioning and a purple line shows the threshold for positioning domain statistical test with a confidence level of 99%. If the difference between the results of horizontal DGPS positioning and each candidate's wide-lane position exceeds the threshold, the candidate is rejected. Figure 2b shows that horizontal DGPS positioning error sometimes reaches up to several meters due to multipath and exceeds the threshold. This means that correct wide-lane ambiguity can be rejected wrongly. To avoid the miss rejections, the threshold has to be set based on not only Gaussian noises but also biased errors such as multipath errors. However in reality, it is very difficult to set the threshold based on the biased errors. It can be also seen the same difficulty in the case of ambiguity range determination.

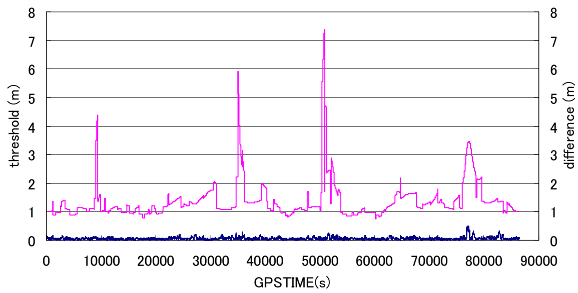


Figure 2a. Relationship between DGPS error and threshold (Scenario 1)

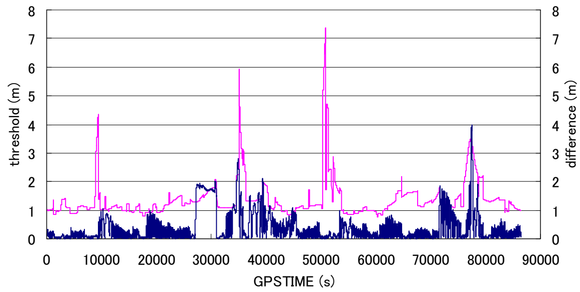


Figure 2b. Relationship between DGPS error and threshold (Scenario 2)

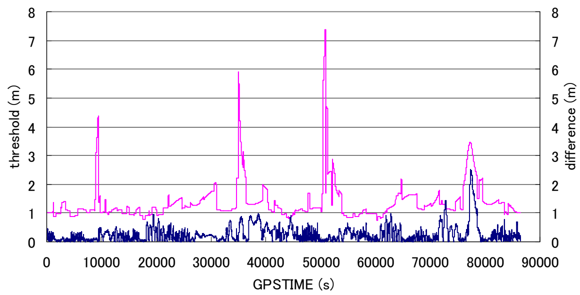


Figure 2c. Relationship between DGPS error and threshold (Scenario 3)

Figure 3 shows the simulated code and carrier multipath for 24 hours in each scenario. 10 satellites (from PRN1 to PRN10) are selected and drawn by different colors. The fluctuations of code multipath error of scenario 2 reach up to 6 m and those of scenario 3 reach up to 4 m. The multipath error increases until the multipath delay reaches up to about a few tens of meters according to the performance of 0.1chip narrow correlator used for the simulation here. On the other hand, there is little difference between carrier multipath of scenario 2 and that of scenario 3. The results of table 2 and figure 3 show the correlation between the results of ambiguity fix statistics and the simulated code multipath errors. Under multipath free condition, the simulated code multpath error is less than 2 m and the ambiguity are fixed correctly in all cases. Compared scenario 2 with scenario 3, the number of wrong fixes in the case of scenario 2 is larger than that in the case of scenario 3. The main reason is that simulated code signal of scenario 2 is more severely contaminated by multipath effect than that of scenario 3.

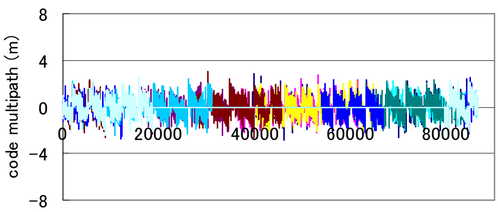


Figure 3a. Simulated code multipath (scenario 1)

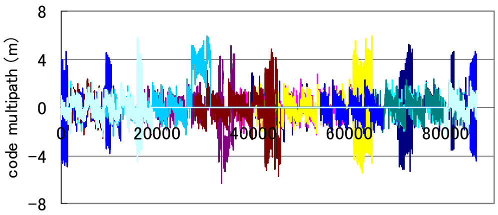


Figure 3b. Simulated code multipath (scenario 2)

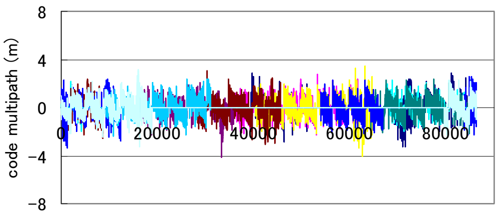


Figure 3c. Simulated code multipath (scenario 3)

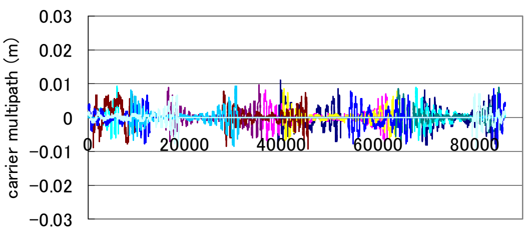


Figure 3d. Simulated carrier multipath (scenario 1)

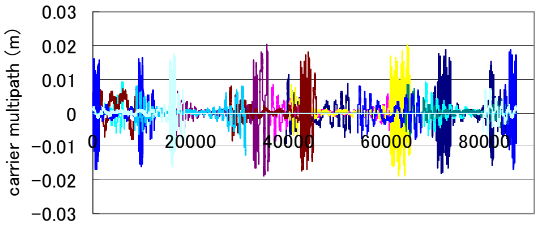


Figure 3e. Simulated carrier multipath (scenario 2)

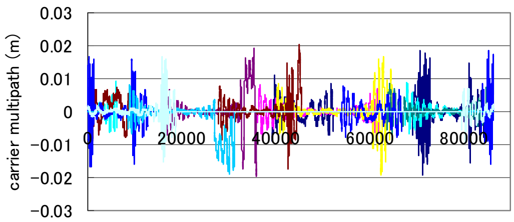


Figure 3f. Simulated carrier multipath (scenario 3)

To demonstrate the relationship between the result of ambiguity fix statistics and the simulated code (or carrier) multipath errors, we need to know how biases due to multipath on the original observations propagate into the ambiguity solution. In the following, we pick up 2 significant examples in the case of scenario 2. One is that integer ambiguity can't be resolved correctly due to code multipath errors. Figure 4 shows wide-lane double-difference measurements using PRN 25 (reference satellite) and PRN 6. The latter is a source of the wrong fix in the case of scenario 2. In this case, correct wide-lane integer ambiguity is 209. However, wide-lane double-difference measurements fluctuate largely due to code multipath in spite of 100 seconds of carrier smoothing. Initialization takes place in 43299 s at GPS TIME and thus search range of wide-lane integer ambiguity is set from 210 to 214 at a confidence level of 99%. Even if we try to search the correct wide-lane integer ambiguity, we will not be able to find it due to the failure of the ambiguity range determination. There is an initial accuracy requirement for the ambiguity search when using only a single epoch of observations. To solve this problem, some methods have already been developed [6].

The other one is that integer ambiguity can't be resolved within 300 seconds due to both carrier multipath errors and insufficient number of satellites. Figure 5 shows the sum of measurement residuals for 400 seconds in each ambiguity candidate. Correct candidate for integer ambiguity resolution is candidate5. The number of available satellites has been 5 for 400 seconds. The candidate that passes both measurement and positioning domain test remains. In the figure 5, the beginning of the plots is 76806 s of initialization time and threshold is for the measurement domain test. It takes over 300 seconds to resolve correct integer ambiguity. The main reason of taking longer time is insufficient number of satellites. One glance was enough to determine which candidate was correct integer ambiguity. However, it is usually difficult for us to resolve it in a single epoch. Furthermore, it is more difficult under multipath condition. One of the effective ways to reduce the time-to-fix without loosing the reliability requirement is to increase the number of satellites. If the more satellites are tracked, some of the observations can be removed if they are suspected to have been contaminated by the biases such as multipath [7]. In the above simulation, cycle slip is not considered. The ambiguity resolution will be more complicated in the real field where the cycle slips take place often.

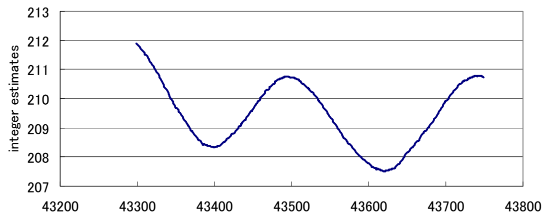


Figure 4. Integer estimates for the wide-lane double-difference (sc. 2)

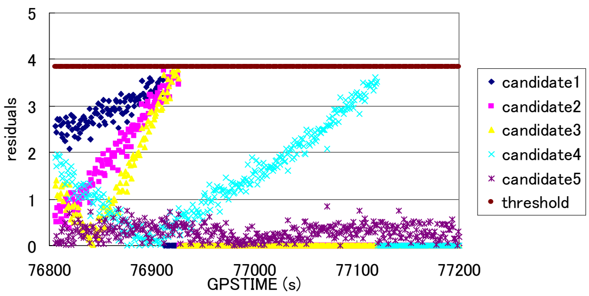


Figure 5. Sum of measurement residuals

4 STATIC TEST IN THE REAL FIELD

In the last section, the effect of multipath on ambiguity resolution was inferred using simulated data. In this section, it is inferred using real field observations acquired at two periods in a day of relatively large and small number of visible satellites. 2 remote stations and one reference station are set up on the roof of the building of our laboratory. The reference station is under multipath free condition. A remote station is at the baseline of 29 m under weak multipath condition (remote station 1). The other is at the baseline of 25 m under strong multipath condition (remote station 2). GPS receiver is NovAtel RT-2 with an antenna for precise positioning. Figure 6 shows the allocation of the antenna of the rooftop. There are some antennas for HF field reception and a lightning conductor besides obstacles. We developed the post-processing software for integer ambiguity resolution. It provides fix solution step by step using real observations. The GPS stochastic model gives a specification of the noise characteristics of GPS observations and the contributions to the final solution of the individual observations through the variance covariance matrix. In this simulation, we simply adopted the stochastic model dependence on satellite elevation. All static baselines are processed in only single epoch mode.

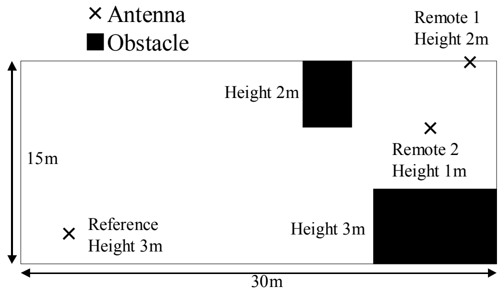


Fig. 6 The outline of the rooftop

4.1 FIELD TEST WITH RELATIVELY LARGE NUMBER OF VISIBLE SATELLITES

Pseudorange and carrier phase observations were obtained from noon to 3 pm (JST) on August 2, 2003. Mask angles for DGPS and RTK positioning are 10 and 15 degrees respectively. Table 3 shows the ambiguity fix statistics in the analysis. The first row is the number of remote station. The second is total number of ambiguity initializations, which take place when a set of primary satellite changes or cycle slips happen. The third is the number of right ambiguity fixes within 300 seconds in which the number of wrong ambiguity fixes is shown in the fifth, while the fourth is the number of ambiguity fixes over 300 seconds among the number of the third. The sixth is the number of unfixes which mean that integer ambiguity can't be resolved by the next initialization. The seventh is the average number of visible satellite over RTK mask angle of 15 degrees during the analysis. The eighth is the number of epochs when the visible satellites are less than 5. The ninth is the correct ambiguity fix percentage, which is the ratio of number of fixes to total epochs with 5 and more visible satellites. For the ambiguity resolution and RTK positioning, the minimum number of satellite needed in the present analysis is 5. Table 3 shows the big differences between the results of station 1 and those of station 2. The major reason is that the multipath condition is depending on the location of antenna. Figure 7 shows the relationships between the results of horizontal DGPS position error and the threshold for positioning domain statistical test. A blue line shows the difference between the horizontal DGPS position and correct wide-lane position and a red line shows the threshold (confidence level of 99%). Figure 7b shows the observations of remote station 2 are obviously contaminated by code multipath. Thus threshold can't bound the horizontal DGPS positioning error induced by the code multipath error. Figure 8 shows the height deduced by L1 integer ambiguity in the remote station 2 in the period when the wrong fixes take place. In addition, figure 9 shows the single differences, of 3 satellites of PRN 10, 15 and 28, between pseudorange and carrier phase for the period. It is known that they are very effective for the detection of multipath affected GPS signals [8]. Table 4 shows the number of cycle slips in each satellite in the period (from 532400 s to 532500 s) in the remote station 2. Figure 9 and table 4 show that the signal of PRN 28 is clearly contaminated by multipath and a lot of cycle slips can be observed. In the present case, PRN 28 should not be used in the ambiguity resolution process. Fortunately, 7 satellites can be used in the ambiguity resolution process without PRN 28. Figure 10 shows the altitude variation by L1 integer ambiguity removing PRN28. Then the post-processing software can get the correct integer ambiguity. Although the temporal variation of altitude shows still the sign of contamination by the multipath, the fix percentage improved from 80.2% to 89.2%. What we have to notice is that 7 satellites can be used in the positioning process even after removing PRN 28. If enough satellites are not tracked, we have to use all visible satellites in the case that satellite number is small even if one of visible satellites is contaminated by multipath. We will face frequently such a situation on the streets in the downtown. This means that even if we develop the excellent outlier detection method, it is not useful. The next section shows static field test under insufficient satellites to investigate the problem.

Table 3. Ambiguity fix statistics (10800 epochs)

Remote station	**1**	**2**
Cases	6	37
Fix	6	27
Fix (over 300sec)	0	0
Wrong Fix	0	4
Unfix	0	6
Average Satellite	7.7	7.1
Under 5 satellite (epochs)	0	0
Fix percentage	99.8	80.2

Table 4. The number of cycle slips (532000-532500)
(the case of remote station 2)

PRN	9,17,18,21,26	10	15	28
Cycle slips	0	49	8	89

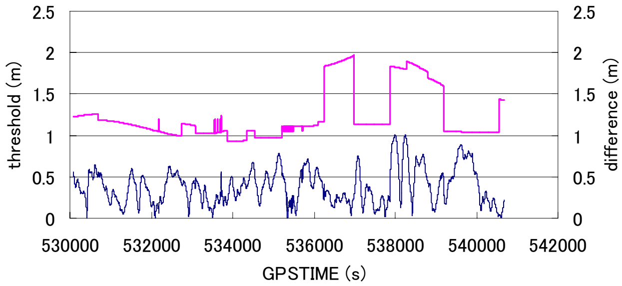


Figure 7a. Relationship between DGPS error and threshold

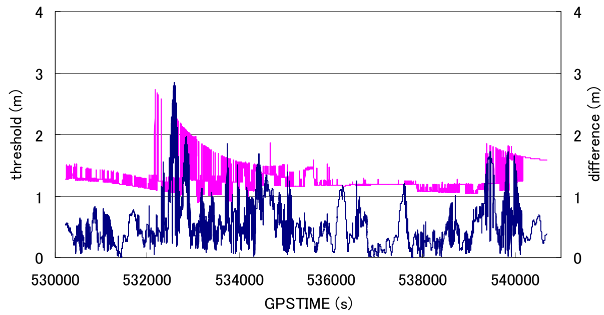


Figure 7b. Relationship between DGPS error and threshold

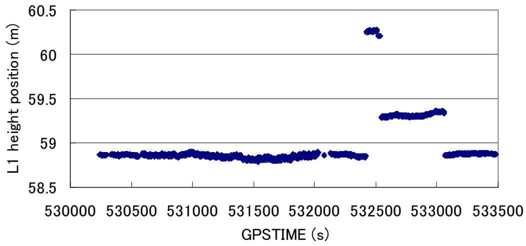


Figure 8. Height position of L1 integer ambiguity

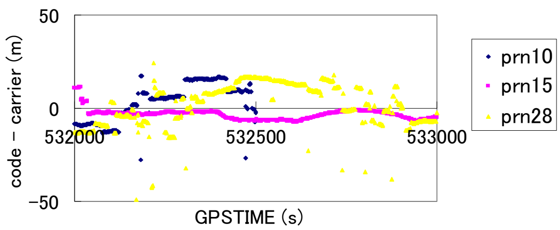


Figure 9. Pseudorange carrier phase single differences

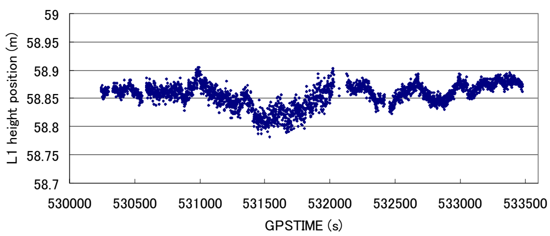


Figure 10. Height position of L1 integer ambiguity

4.2 FIELD TEST WITH FEWER NUMBER OF VISIBLE SATELLITES

Pseudorange and carrier phase observations were acquired from 0:30 AM to 3:30 AM (JST) on August 18, 2003 with the mask angles of 10 and 15 degrees for DGPS and RTK positioning respectively. Table 5 shows the ambiguity fix statistics in this analysis. Each item is same as that of table 3. In the case of remote station 1, wrong fix does not appear although the average number of visible satellites is less than that in the remote station 2 of section 4.1. This is because the observations in the remote station 1 are not so contaminated by multipath. On the contrary, in the remote station 2, ambiguity initializations take place often due to the cycle slips of particular satellites. The ambiguity resolution is greatly affected by the fact. Figure 11 shows the number of satellites over 15 degrees during the period. The number of satellite changes frequently. It is considerably difficult for the RTK positioning software to cope with frequent cycle slips with insufficient satellite. If the more satellites are tracked, some of these observations, which are suspected to have been contaminated by the outliers or biases, can be removed. The ambiguity resolution combining GPS and Galileo is proposed with very high ambiguity success-rate and fix-percentage [9].

To improve fix percentage keeping normal reliability by using only 5 GPS satellites, we improved the method to choose 4 satellites as primary satellites. If one of primary satellites is exposed to cycle slips frequently, ambiguity initializations take place frequently and it results in low fix percentage and low reliability. If we can choose 4 satellites that are not likely to take place cycle slips frequently as primary satellites, it is possible to improve fix percentage at least. In the proposed algorithm by the authors, the validation for integer ambiguity is achieved by using the secondary satellites. If one of secondary satellite is contaminated by multipath, the validation has a chance of failure. In our proposal, we make much of a large fix percentage, although the validation is the top priority. Because we can't move the step of the validation if the primary satellites aren't set and it results in the loss of the chance of correct integer ambiguity resolution.

We usually choose 4 satellites that have the minimum RDOP (Relative Dilution of Precision) as primary satellites. In addition to the usual operation, the frequency of cycle slips and the fluctuation of the SNR (Signal to noise ratio) are considered in the selection of the primary satellites in our proposal. Table 6 shows the improvement of ambiguity fix statistics in our proposal. There are still many ambiguity initializations due to the frequent change of the number of visible satellites to 4 or 5. Fix percentage increases from about 60 % to about 80%. It implies that our proposal method is effective to the ambiguity resolution.

Table 5. Ambiguity fix statistics (10800 epochs)

Remote station	**1**	**2**
Cases	4	108
Fix	4	18
Fix (over 300sec)	0	0
Wrong Fix	0	26
Unfix	0	64
Average Satellite	5.8	5.1
Under 5 satellite (epochs)	0	2196
Fix percentage (%)	97.2	60.3

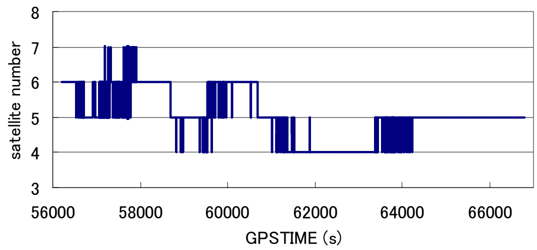


Figure 11. Number of satellite over 15 degrees

Table 6. Ambiguity fix statistics (10800 epochs)

Remote station	**2**
Cases	77
Fix	15
Fix (over 300sec)	0
Wrong Fix	12
Unfix	50
Average Satellite	5.1
Under 5 satellite (epochs)	2196
Fix percentage (%)	78.8

5. KINEMATIC FIELD TEST

In this section, kinematic field test is introduced to investigate the performance and reliability of our new RTK post-processing software. The observations are acquired at two sites in our university. One is for relatively light multipath condition on the ground and the other for heavy multipath condition at the pond. Pseudorange and carrier phase observations were obtained in the evening (JST) on July 29 and on August 1, 2003. The reference station is set at the place with relatively light multipath. The rover station is installed on the small vehicle. GPS receivers are NovAtel RT-2 with antennas for precise positioning.

Table 7 shows the ambiguity fix statistics in two sites. Each item is the same as that of table 3. The Figure 12 shows the temporal variation of horizontal position and altitude of L1 ambiguity on the ground. The vehicle to collect the observations is going around the dirt track 5 times. The figure 13 shows the temporal variation of the number of satellites over 15 degrees at the pond. The figure 14 shows the temporal variation of horizontal positions and altitude of L1 ambiguity there. The vehicle to collect the observations data is going around the pond. The figure 12 and table 7 proves the ambiguity resolution is almost perfect on the ground. However, the ambiguity resolution on the pond is not so good in spite of relatively large number of visible satellites. The pond is surrounded by walls and thus the rover antenna is always contaminated by short range multipath. As can be seen from the figure 13, cycle slips also take place often due to the nearby obstacles for this period. From the result of this test, we found that it is difficult for us to find correct integer ambiguity even in the case of many visible satellites.

Table 5. Ambiguity fix statistics (2000epochs, 620epochs)

Rover station	**1**	**2**
Cases	2	23
Fix	2	11
Fix (over 300sec)	0	0
Wrong Fix	0	3
Unfix	0	9
Average Satellite	6.0	6.7
Under 5 satellite (epochs)	0	13
Fix percentage (%)	97.7	88.7

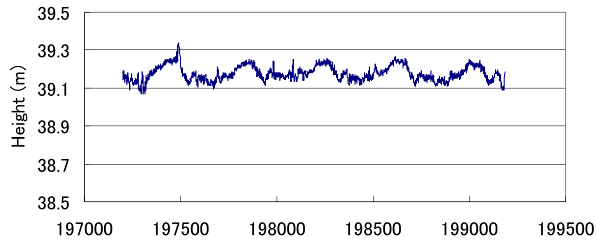


Figure 12a. Height position of L1 ambiguity (Ground)

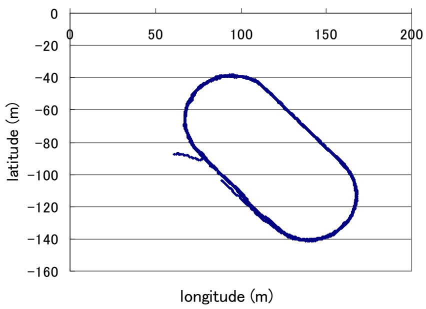
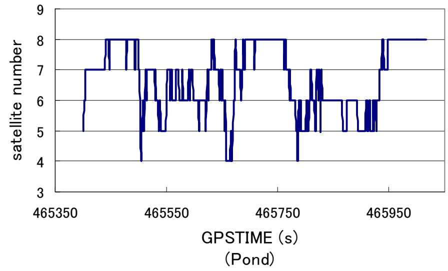


Figure 12b. Horizontal position of L1 ambiguity (Ground)



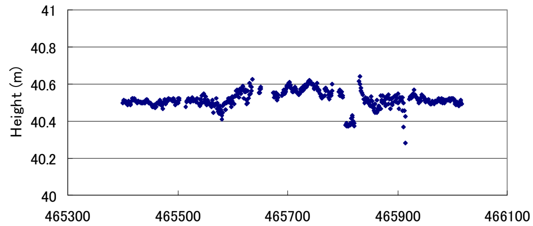


Figure 14a. Height position of L1 ambiguity (Pond)

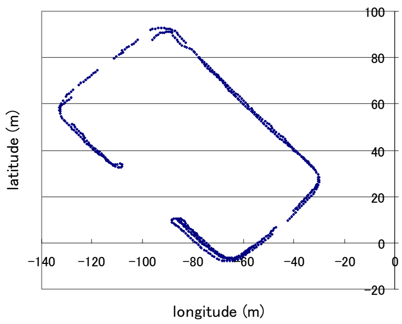


Figure 14b. Horizontal position of L1 ambiguity (Pond)

6. CONCLUSIONS

In this contribution we have shown how the multipath fails the integer ambiguity resolution. The more the satellite number, the robuster the ambiguity resolution against multipath. The ambiguity can be resolved even after removing some of the satellites which are contaminated by multipath. This implies that in the future it might improve the conditions to develop and use the combined GPS, Galileo and/or QZSS receiver.

As a criterion to detect multipath, it is shown that single differences between pseudorange and carrier phase and the frequency of cycle slips are effective. However, when more satellites are not available, ambiguity resolution is rather vulnerable to multipath. From the result of kinematic field test, we found that it is difficult for us to find correct integer ambiguity even in the case of many visible satellites. The frequent changes of satellite number due to cycle slips and multipath make it difficult.

Further research is necessary for ambiguity resolution under severe conditions. Even if combined GPS, Galileo and/or QZSS system can be available, particularly in the kinematic application on the street in the downtown, it will not give enough availability even by the proposed algorithm. These are important problems to be solved for current GPS, as well as for the future GNSS system.

REFERENCES

1. Joosten, P., T. Pany and J. Winkel, "The impact of unmodelled multipath on ambiguity resolution," ION GPS 2002, pp 953-961.
2. Tsujii, T., M. Murata, M. Harigae, T. Ono and T. Inagaki "Development of Kinematic GPS Software, KINGS, and Flight Test Evaluation," TECHNICAL REPORT OF NATIONAL AEROSPACE LABORATOTRY, Octorber 1998.
3. Han, S. and R. Johnson, "Survey Quality Real-Time GPS: Solving the Time to Fix vs. Reliability Paradox" ION2001, pp 1550-1557.
4. Kim, D. and Langley, R.B., "GPS Ambiguity Resolution and Validation: Methodologies, Trends and Issues," 7th GNSS workshop, Seoul,Korea,November,2000.
5. Elliott D. Kaplan, "Uuderstanding GPS Princlples and Applications," Artech House Publishers, pp 157-172.
6. Cunha, T., P. Tome, S. Cunha and L. Bastos, "Reliability Analysis of a Quasi-Instantaneous Ambiguity Fixing Method" ION2001, pp1540-1549.
7. Dai, L., S. Han and C. Rizos, "A Multiple Outlier Detection Algorithm for Instantaneous Ambiguity Resolution For Carrier Phase-Based GNSS Positioning" Proceedings of the International Symposium on Degital Earth," Science Press, 1999.
8. Hoper, M, T. Boelow, and H. Hoffmann, "Detection of Multipath Influence at DGPS Reference Stations" ION2001, pp581-590.
9. Tiberius, C., T. Pany, B. Eissfeller, Kees. j, P. Joosten, and S. Verhagen, "Integral GPS-Galileo ambiguity resolution," GNSS2002, Copenhagen, Denmark, May 27-30.