


How multipath error influences modernized GNSS ambiguity resolution in urban areas



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Motivation

□ Early studies

Triple-Frequency Combinations in Future GNSS (2006, Andrew Simsky)

Civilian GPS: The Benefits of Three Frequencies (2000, Hatch)

□ New viewpoints in this study

Triple frequency AR in the open sky have been already discussed. However, the effects of multipath (**urban area performance**) are still not discussed.



The relationships between **multipath**, the **decreasing of visible satellites** and **triple frequency AR** are investigated in this study.



Visible satellites and SNR were determined by **raw data collected in Tokyo by car**. Multipath are generated according to **the statistics in urban areas**.

Features of triple frequency ambiguity resolution

- We will make a linear combination of carrier phase for the triple-frequency $\varphi_{i,j,k} = i \cdot \varphi_1 + j \cdot \varphi_2 + k \cdot \varphi_3$

- Effective frequency, wavelength and integer ambiguity combination $f_{i,j,k} = i \cdot f_1 + j \cdot f_2 + k \cdot f_3$ $\lambda_{i,j,k} = c / f_{i,j,k}$

$$N_{i,j,k} = i \cdot N_1 + j \cdot N_2 + k \cdot N_3$$

- Standard deviation M [cycle] of the linear combination

$$M_{i,j,k}[\text{cycle}] = \sqrt{i^2 + j^2 + k^2} \cdot M_0[\text{cycle}]$$

$$M_{i,j,k}[m] = M_{i,j,k}[\text{cycle}] \cdot \lambda_{i,j,k}$$

- Observation equation

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

Ratio value between the ionospheric delays on the combinations and L1 carrier phase measurement → **K**

Some typical carrier phase combination with long wavelength

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

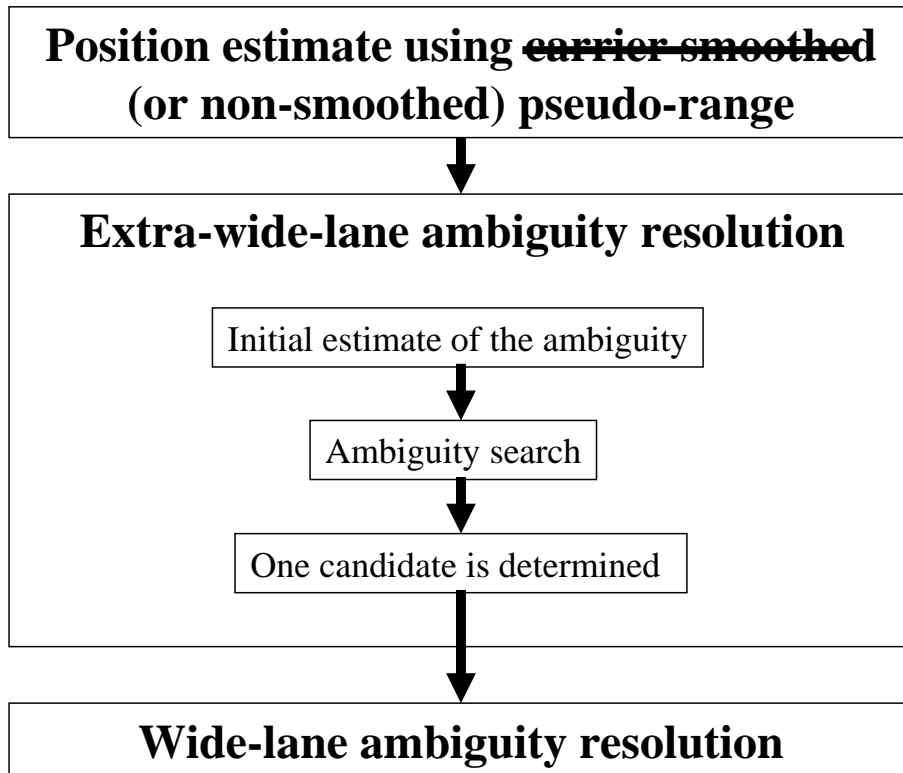
← EWL

← WL

$\Phi(0,1,-1)$ is suitable for the starting point for ambiguity resolution

$\Phi(0,1,-1) \rightarrow \Phi(1,-1,0)$ Cascading AR

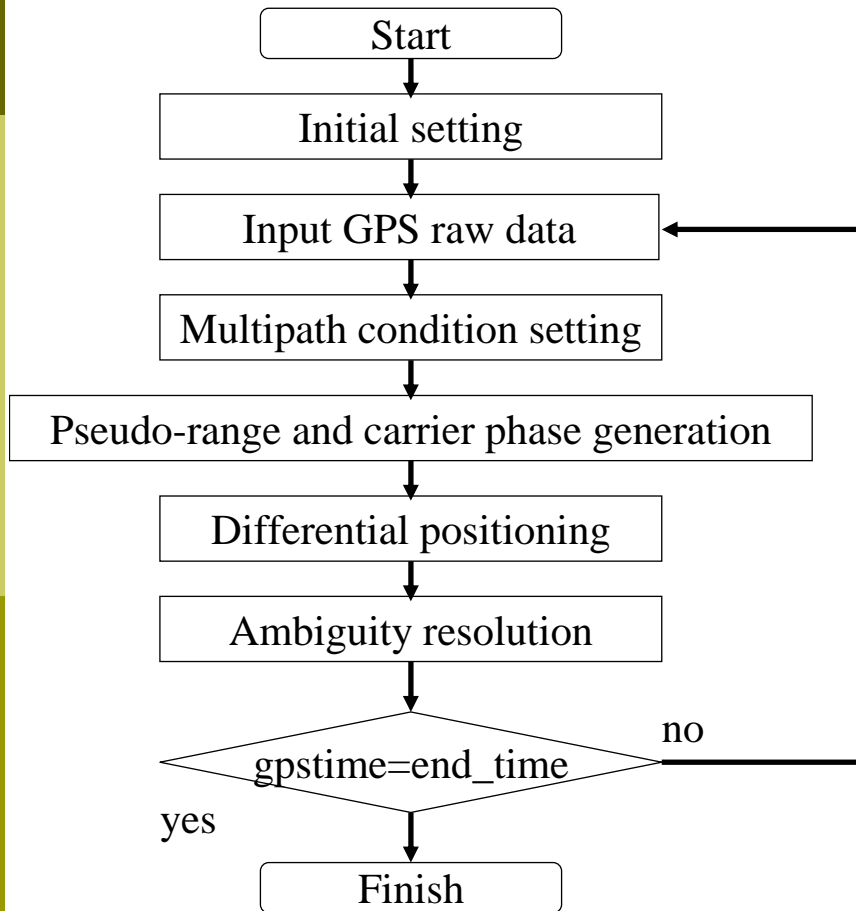
Ambiguity Resolution



Flowchart of RTK algorithm

- ❑ Integer Ambiguity is **resolved every second**.
- ❑ In order to resolve on single epoch, **the candidate of minimum residual** is regarded as fix solution.
- ❑ Single epoch AR has some advantages. It is robust against cycle-slips, loss of locks, changes in the tracked satellite constellation.

GNSS Simulator



Flowchart of this simulation

- This simulator is to analyze RTK performance.
- **Clock, satellite and propagation errors are neglected** because of the usage of double differenced data in the positioning (short baseline).

DLL loop bandwidth	0.05 Hz
PLL loop bandwidth	18 Hz
DLL detector	Early-late power
PLL detector	Sinus
Correlator spacing	0.1 (narrow or strobe)

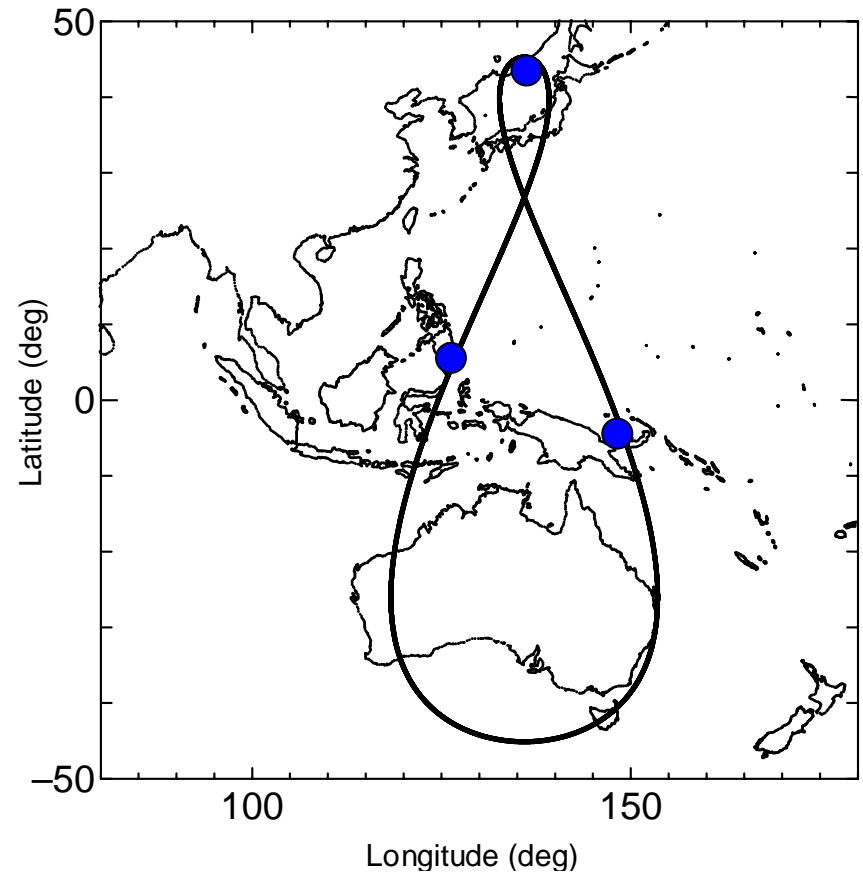
Receiver Parameters

Input GPS raw data

- ❑ In order to simulate the **urban condition performance**, raw GPS data collected in Tokyo **by car** are used.
- ❑ In 2005, the data was repeatedly collected in **downtown Tokyo** using the NovAtel OEM4 receiver.
(over 20 times : 30-60 minutes)
- ❑ 12 hours of raw GPS data are generated by combining several data periods.
- ❑ **The rover satellite configuration and the carrier to noise ratio** on each satellite are based on the raw GPS data.

Constellation (GPS and QZS)

- GPS constellation is based on the raw data.
- QZS constellation
 - Eccentricity : 0.099
 - Inclination : 45 degree
 - Mask : 45 degree
- L1, L2 and L5 signals are used in both GPS and QZS in this simulation. Signal parameters are assumed same.



QZS Constellation

Multipath Generation

- Since it was **impossible to extract the multipath errors from the raw GPS data in the car**, multipath errors were set artificially according to the **statistical data in urban condition**.

1. Multipath errors from the ground

Throughout simulation period in the reference and rover
Antenna height and the electric properties setting

2. Multipath errors from the structures

Throughout simulation period in the rover

One or two satellites were randomly selected

Multipath amplitudes : **0.05-0.5** (elevation dependent)

Multipath delays : **5m-100m**

- ## 3. When the pseudorange or carrier phase was generated, the above multipath errors were added to them.

Generating pseudo-range and carrier phase

- Pseudo-range = true-range + noise + multipath
- Carrier phase = true-range + noise + multipath + N

*Clock, satellite and propagation errors are neglected because of the usage of double differenced data in the positioning.

*N is randomly set.

*Noise is set according to the following equations.

$$\sigma_{tDLL} = \lambda_c \sqrt{\frac{4F_1 d^2 B_w}{c/n_0} \left[2(1-d) + \frac{4F_2 d}{Tc/n_0} \right]} \quad (m) \quad \text{Pseudo-range}$$

$$\sigma_{tPLL} = \frac{\lambda_L}{2\pi} \sqrt{\frac{B_w}{c/n_0} \left[1 + \frac{1}{2Tc/n_0} \right]} \quad (m) \quad \text{Carrier phase}$$

Scenarios

- ❑ **GPS with dual frequencies (L1 and L2)**
- ❑ **GPS with triple frequencies (L1,L2 and L5)**
- ❑ **Combined GPS and QZS with triple frequencies (L1, L2 and L5)**

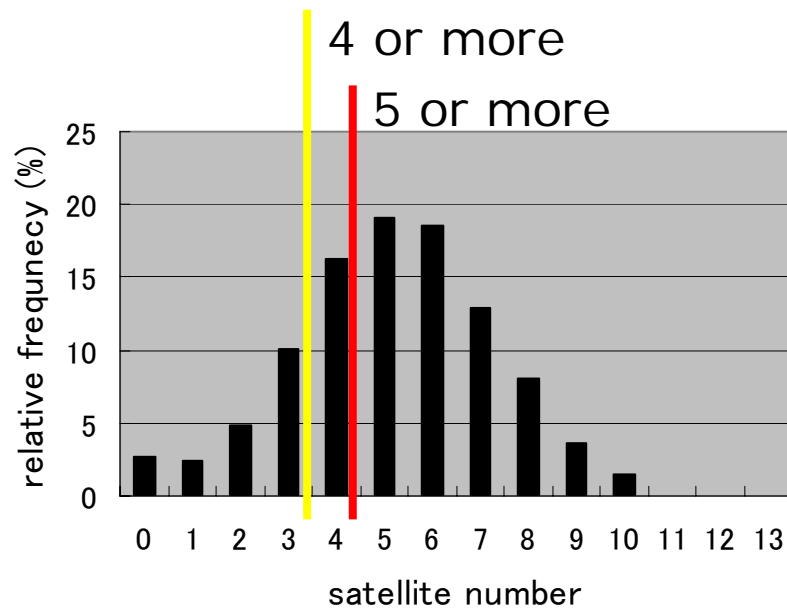
Each scenario has been tested under two types of correlators: **narrow and strobe correlator.*

Criteria of performance

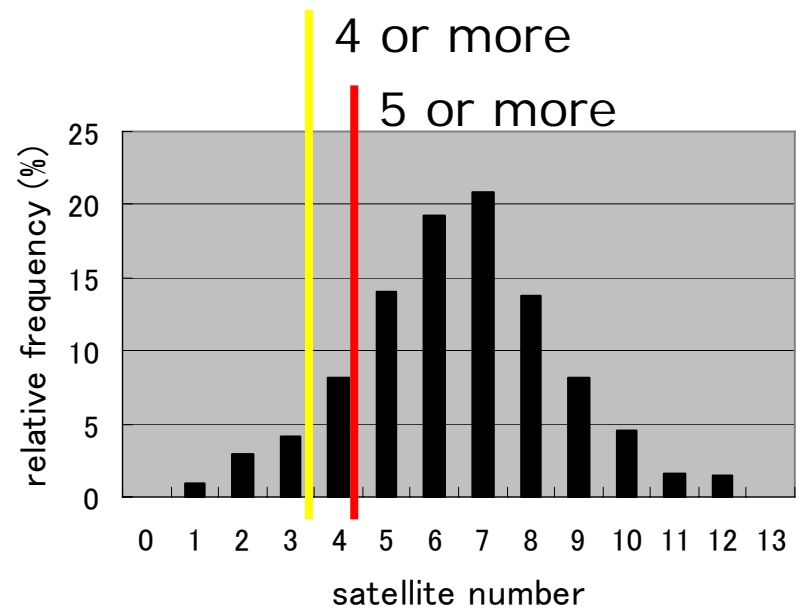
- ❑ The **ambiguity fix percentage** is adopted here as an indicator of the performance.
- ❑ The ambiguity is computed for all **43,200 epochs** (12 hours). The integer ambiguity is **re-initialized every second**.
- ❑ The ambiguity fix percentage can be obtained by calculating the ratio value between the number of correct ambiguity fixes and the number of the total ambiguity fixes.

$$\text{Ambiguity fix percentage} = \frac{\text{Correct Number}}{\text{Total Number}}$$

Visible Satellites



Urban raw data (GPS)



GPS+QZS

Potential availability of DGPS (from 80% to 92%)

Potential availability of RTK (from 63% to 84%)

Even in the case that QZS mask angle is set 45 degrees, the good effects of adding QZS on visible satellites number is obvious.

DGPS horizontal errors

(GPS: 34356epoch) Distribution of the absolute DGPS horizontal errors

Horizontal Errors (m)	0-1	1-2	2-4	4-6	6-10	10-
Strobe (%)	73.8	16.0	6.5	1.3	1.1	1.3
Narrow (%)	33.5	26.7	26.6	6.6	3.5	3.1

(GPS+QZS: 39704epoch) Distribution of the absolute DGPS horizontal errors

Horizontal Errors (m)	0-1	1-2	2-4	4-6	6-10	10-
Strobe (%)	72.2	17.8	6.2	1.4	1.1	1.3
Narrow (%)	39.0	27.0	24.5	4.8	2.6	2.1

Mitigating 30-100m delay multipath is very important in urban conditions.

Ambiguity Fix Statistics

Ambiguity Fix Percentage (GPS with L1 and L2 signals)

	1epoch Fix (%)	Wrong (%)	No-RTK (%)
Strobe correlator	40.0	22.8	37.2
Narrow correlator	24.5	38.4	37.2

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

	1epoch Fix (%)	Wrong (%)	No-RTK (%)
Strobe correlator	60.5/58.3	2.3/4.5	37.2
Narrow correlator	51.6/49.9	11.2/12.9	37.2

EWL / EWL and WL

Ambiguity Fix Percentage (GPS and QZS with L1, L2 and L5 signals)

	1epoch Fix (%)	Wrong (%)	No-RTK (%)
Strobe correlator	80.7/79.8	2.9/3.8	16.4
Narrow correlator	71.6/71.0	12.0/12.6	16.4

EWL / EWL and WL

Summary and future works

- ❑ The GNSS simulator has been developed to simulate the performance of **single epoch ambiguity resolution in urban areas**
- ❑ In order to simulate **more realistically, raw GPS data collected in Tokyo by car were used.**
- ❑ Centimeter-level instantaneous RTK GPS in urban areas can be **feasible** with modernized triple frequencies and the latest multipath mitigation correlator. Fortunately, owing to the advent of L5 frequency, **a special correlator does not have to be used.**
- ❑ The increase of visible satellites was still a key to ambiguity resolution in urban areas. **Galileo in the world / QZS in asia**
- ❑ In urban areas, multipath delay within 10-100m is dominant. Further improvement will be expected in order to reduce **short delay multipath within 30m.**