


A Real-time Cycle-slip Detection Method for CDGPS

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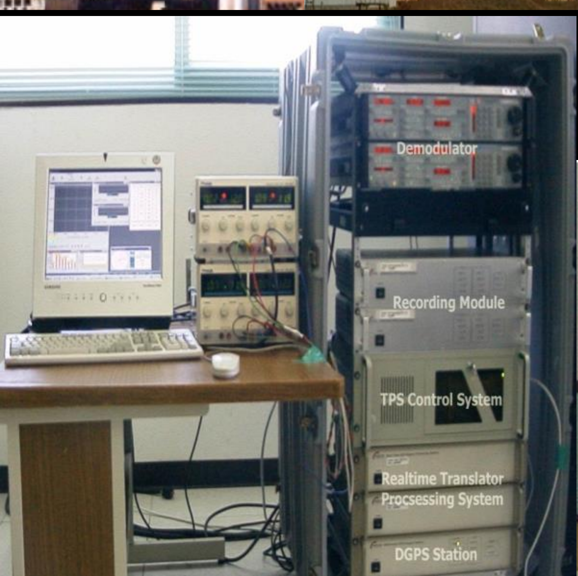


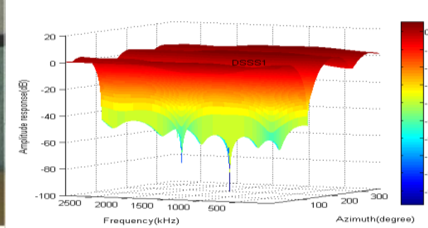


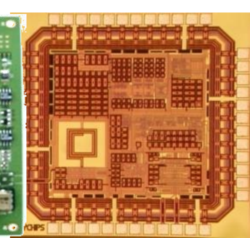

Contents

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Introductions

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■ *Background*

- The GNSS used in diverse and wide application fields
  - ITS (Intelligent Transportation System)
  - AVLS (Automatic Vehicle Location System
  - PDM (Physical Distribution Management)
  - Etc…

- CDGPS technique is frequently applied to those applications

Introductions

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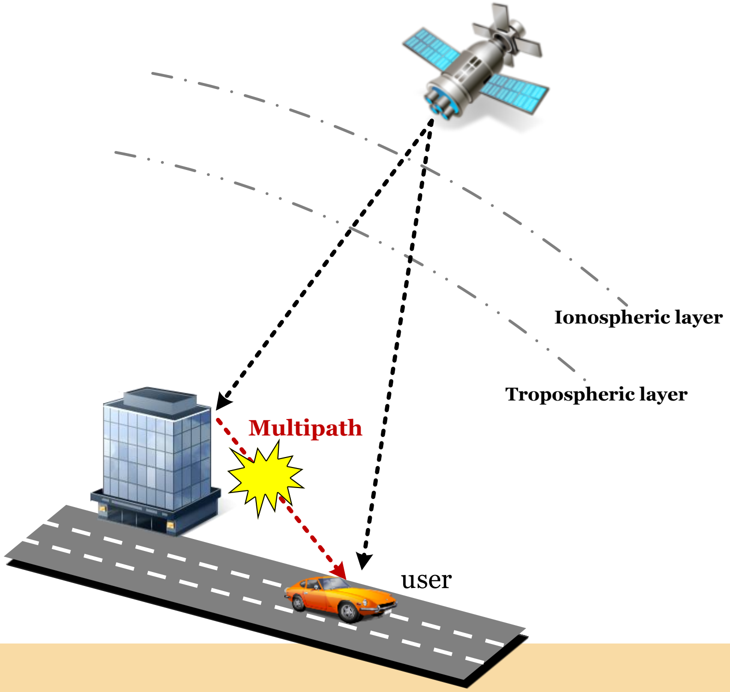
- ***Background***
  - **The multipath error is mostly occurred in the ground transportation environment**
  - **The multipath error is an important performance factor of the float solution**
  - **The accuracy of float solution heavily influences the performance of CDGPS**

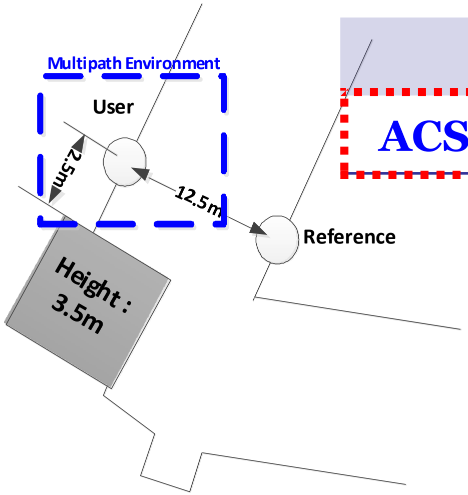


Introductions

■ *Previous Study*

- **Adaptive Filter Design**
  - **Multipath error is effectively mitigated by Adaptive Filtering**

2DRMS [m]	Float solution Position Error		Fixed solution Position Error	
	L1	L1/L2	L1	L1/L2
LS	2.49	1.98	7.31	2.67
CS+LS	1.55	1.13	3.12	1.04
ACS+ASF+KF	**0.93**	**0.77**	**1.57**	**0.73**



Cho, S. L., Choi, Y. S. et al, "Adaptive Filter Design of the float solution in the presence of multipath", ENC 2013.

Introductions

Previous Study

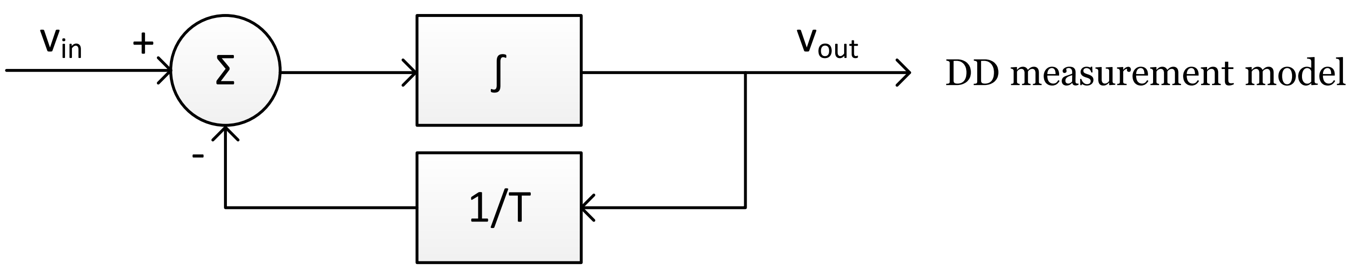
- **Step1: Smoothing filter**
  - **Using the differenced carrier phase measurements**
  - **Simply average measurements over *M* epoch**

$$\rho_k = \frac{1}{M}\rho_k + \frac{(M-1)}{M}\left[\rho_{k-1} + (l_k - l_{k-1})\right] \qquad \rho_1 = \rho(1)$$

ρ : Code measurement

l : Carrier measurement

- **Step2: Shaping filter**
  - **Using the 1st Gauss Markov Process**
  - **Eliminating the bias, drift and periodic error**



Introductions

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- **Previous Study**
  - **Step3: Kalman filter**
    - **System equation**

$$X_k = \Phi_{k/k-1} X_{k-1} + \Gamma_{k/k-1} U_{k-1} \qquad U_k \equiv N\left(0, Q_k\right)$$

    - **Measurement equation**

$$Z_k = H_k X_k + V_k$$

$$Z_k = \begin{bmatrix} \rho_{L1/L2} \\ l_{L1/L2} \end{bmatrix} \quad V_k = \begin{bmatrix} v_{L1/L2} \\ w_{L1/L2} \end{bmatrix} \sim N\left(0, \begin{bmatrix} Q_{D\rho_{L1/L2}} & 0 \\ 0 & Q_{Dl_{L1/L2}} \end{bmatrix}\right) \quad \begin{aligned} Q_{D\rho_{L1/L2}} &= E\left\{\left[v_{L1/L2}\right]\left[v_{L1/L2}\right]^T\right\} = DD \cdot \sigma^2_{\rho_{L1/L2}} \cdot DD^T \\ Q_{Dl_{L1/L2}} &= E\left\{\left[w_{L1/L2}\right]\left[w_{L1/L2}\right]^T\right\} = DD \cdot \sigma^2_{l_{L1/L2}} \cdot DD^T \end{aligned}$$

Introductions

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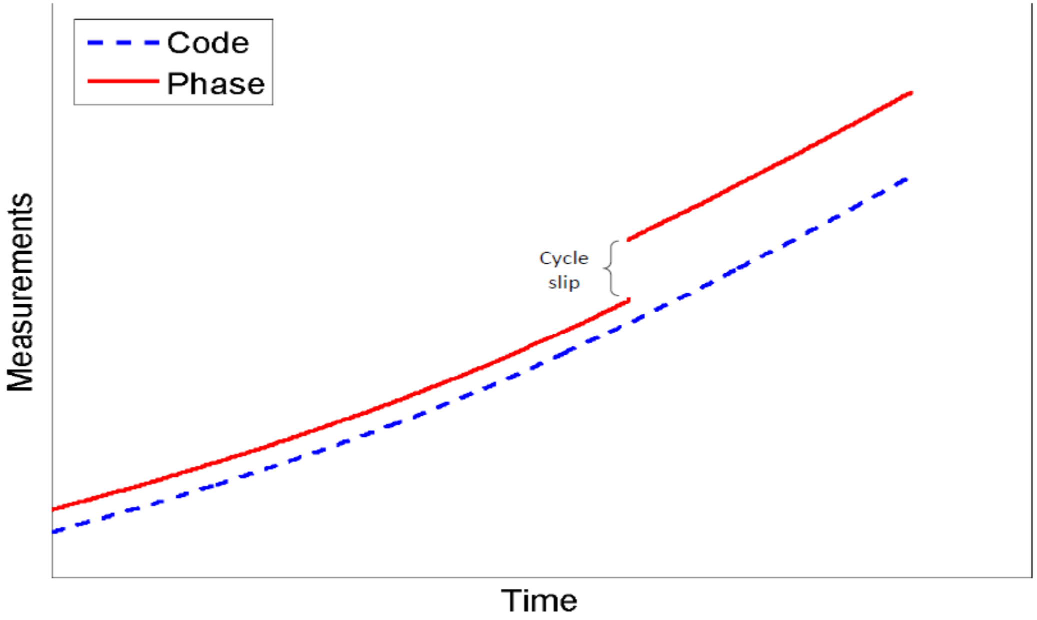
■ ***Problem***



- **When cycle-slip occurred, the margin of measurement error is extended**
- **Because of carrier-smoothing of code measurement**

Malek Karaim et al, "GPS Cycle Slip Detection and Correction at Measurement Level", British Journal of Applied Science & Technology 4(29), 2014

Cycle-slip Detection

Cycle-slip Detection using Doppler frequency

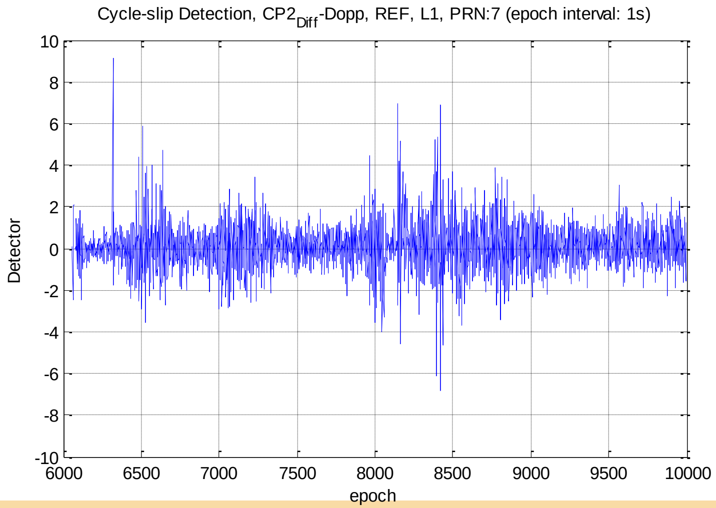
- **Using the Time Differenced Carrier Phase measurement**
- **Using the Doppler frequency**

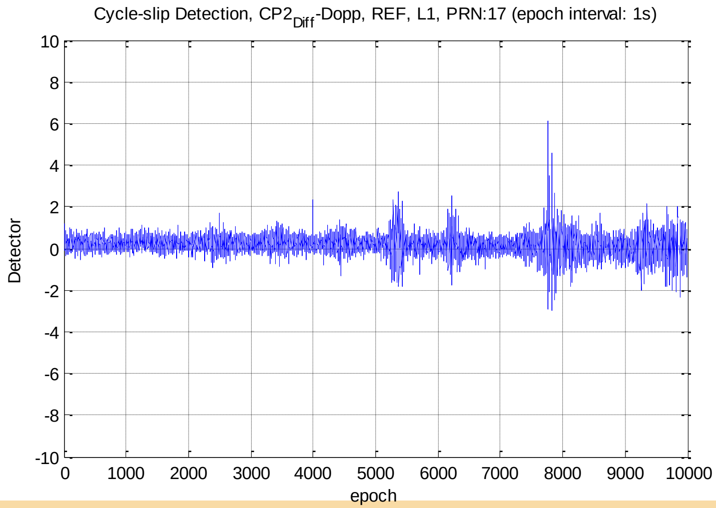
$$\Phi : Carrier\ Phase\ measurment\ [cycle]$$

$$\Phi' = \Phi(k) - \Phi(k-1) : Time\ Differenced\ Carrier\ Phase\ measurement\ [\Delta cycle / epoch]$$

$$\Phi' - f_{dopp} = 0$$

$$= Cycle - slip\ \ Detector$$





Cycle-slip Detection

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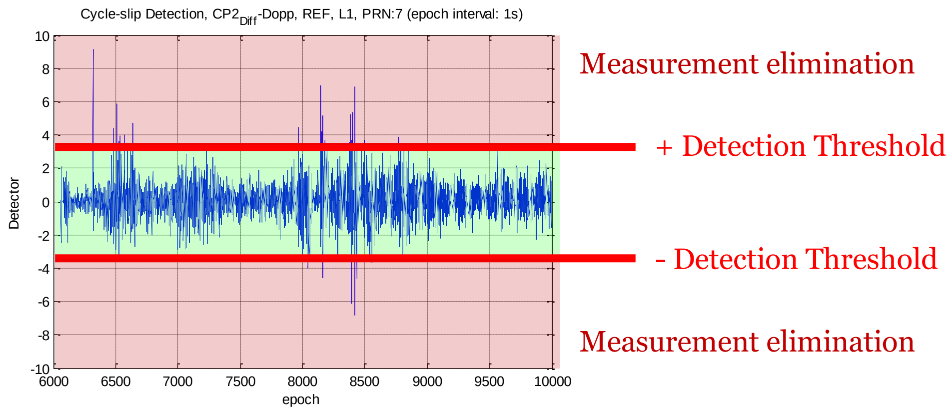
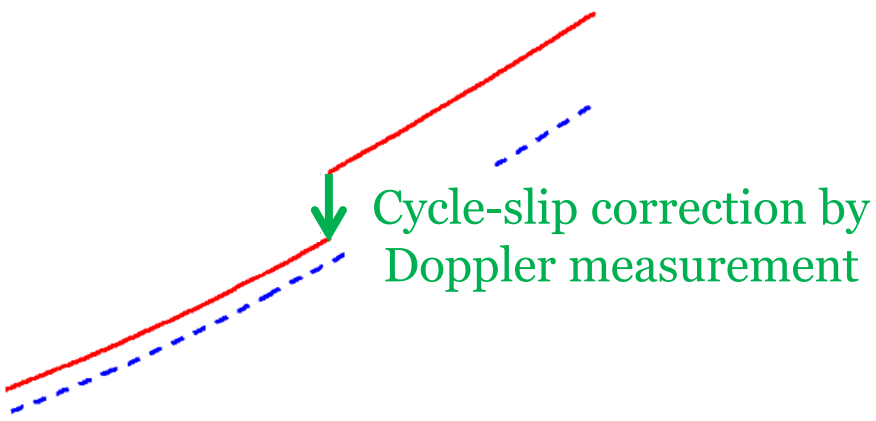
Cycle-slip Detection using Doppler frequency

- **Method 1 – Eliminate the measurement**



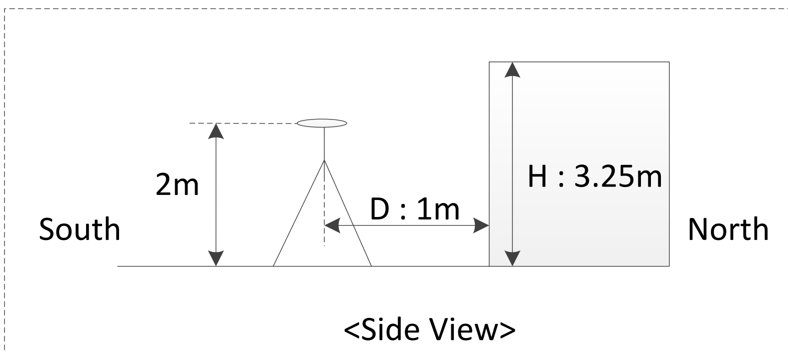
- **Method 2 – Correction by Doppler measurement**

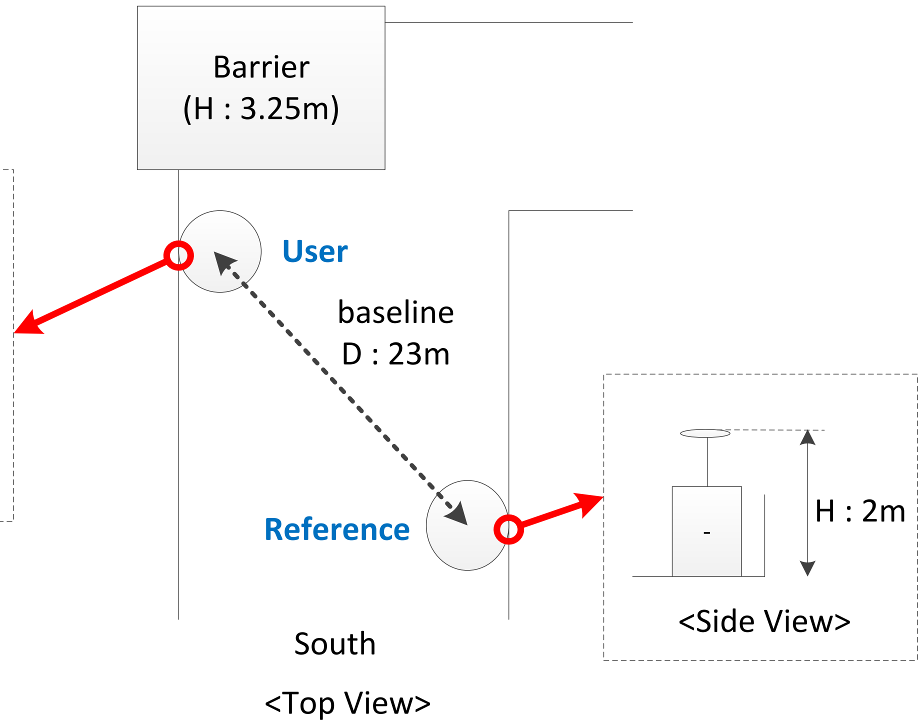


Experimental Results

■ Experiment Setup

- **Shielded by the building height of 3.25m**
- **L1 frequency is considered**





Reference	**Receiver**	NovAtel Propak-V3
	Antenna	NovAtel GPS-703-GGG
User	**Receiver**	u-blox EVK-6T
	Antenna	ANN-MS-0-005
Baseline		23 m

Experimental Results

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Experiment Setup

- **S/W CDGPS algorithm**
- **CDGPS algorithm using LAMBDA method**

‘Float’ Solution	Search Method	‘Fixed’ Solution
Estimate position and Carrier ambiguities	Estimate integer ambiguities	Estimate position (ambiguities fixed)
Least squares	Integer least squares	Least squares

- **Observation Equation**

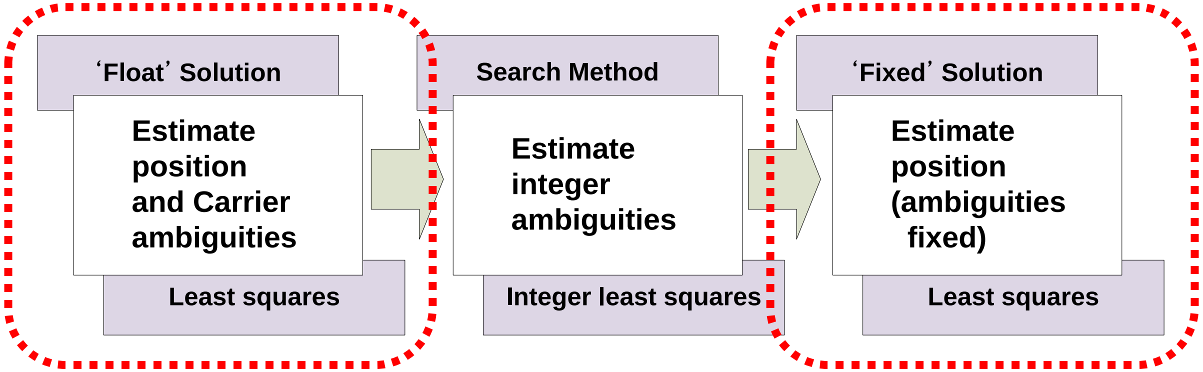
$$y_{L1} = Bb + Aa_{L1} + e_{L1} \qquad y_{L2} = Bb + Aa_{L2} + e_{L2}$$

$$y = \begin{bmatrix} \rho & l \end{bmatrix}^T \qquad B = \begin{bmatrix} H & H \end{bmatrix}^T \qquad A = \begin{bmatrix} 0 & \lambda I \end{bmatrix}^T \qquad e = \begin{bmatrix} v & w \end{bmatrix}^T$$

ρ :code measurement | *v :code measurement noise*
l :carrier measurement | *w :carrier measurement noise*
H :observation metrix | *λ :wave length*

Experimental Results

float & fixed solution



2DRMS [m]	Float solution Position Error	Fixed solution Position Error
None	11.73	11.82
Method 1	10.07	10.18
Method 2	11.56	11.64

Conclusions

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- **Summary & Results**
  - This paper consider about the cycle-slip detection for CDGPS
  - Cycle-slip detection method adopted to the CDGPS using LAMBDA method
  - By using cycle-slip detection method, the navigation performance of CDGPS is slightly improve
  - The quality of Doppler measurement is not enough to correct the cycle-slip

- **Future Study**
  - Find Cycle-slip correction parameters
  - Performance evaluation with Multipath mitigation method (Adaptive Filtering)
  - More study for specific condition studies on various environment
    - Dynamic scenarios

Thank you for your attention