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A Real-time Cycle-slip Detection Method for CDGPS

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ABSTRACT

The CDGPS technique is frequently applied because of it can determine accurate position in cm-level by using the carrier phase measurement. But, in order to apply the CDGPS technique for the ground transportation environment, several critical problems have to solve. The multipath and cycle-slip are still challenging task. In the presence of cycle-slip effect, the quality of pseudo-range is degraded then the navigation performance is also degraded. Especially, the receivers that navigation graded are affect by cycle-slip effect than the receivers that surveying graded. Therefore, exceptional routine in CDGPS is required to performance degrade by cycle-slip effect. The first step of exceptional routine is the detection of cycle-slip, then furthermore, correction of cycle-slip on the carrier measurement. In this paper, we introduce the cycle-slip detection method using Doppler frequency. And analyse the detection performance by using measurement collected at the signal blockage environment.

KEYWORDS: CDGPS, Cycle-slip, Cycle-slip Detection

1. INTRODUCTION

Recently, GNSS (Global Navigation Satellite System) has been widely used in the ITS

(Intelligent Transportation System), AVLS (Automatic vehicle location system), PDM (Physical Distribution Management), train operation control system as the ground transportation environment. In these applications, the CDGPS (Carrier phase Differential GPS) technique is frequently applied because of it can determine accurate position in cm-level by using the carrier phase measurement. But, in order to apply the CDGPS technique for the ground transportation environment, several critical problems have to solve. These problems include the multipath mitigation and the correction of other abnormal effects on the carrier phase measurement and code phase measurement. And, there are many studies about the multipath mitigation technique. Also in our priori study, the impact of multipath is effectively mitigated by applying the adaptive filtering technique in (Cho, S. L. et al, 2012) and (Cho, S. L. et al, 2013).). However, other abnormal effect issues are still unsolved. In the presence of abnormal effects, measurement quality of GPS is decreased or measurement is shut out, then the performance of CDGPS is heavily degraded. And the performance of our adaptive filtering technique degraded too. Especially, the receivers that navigation graded are affect by cycle-slip effect than the receivers that surveying graded. Because, almost of navigation grade receivers are use the carrier-smoothing of code measurement. Therefore, exceptional routine in CDGPS is required to performance degrade by cycle-slip effect. For exceptional routine for cycle-slip, the cycle-slip detection method is have to consider. Therefore, in order to apply our adaptive filtering technique to ground transportation environment, we introduce some techniques to detect the abnormal effects (cycle slip, jump). If the abnormal effect is occurred, impaired measurements are have not to use in solve the navigation solution or have to correct the characteristics of measurement.

2. CDGPS METHOD

CDGPS estimates the relative position of the use from the known reference position. The common error in measurements is removed by the DD (Double Difference) operation(Teunissen, P.J.G, 1993). First, least-squares estimation is generally applied in order to find the float solutions. In the second step, the real valued float solutions of the ambiguities are adjusted as to take the integer constraints into account. Finally, the float solution of the remaining parameters is corrected by virtue of their correlation with the ambiguities(Paul de Jone and Christian Tiberius, 1996).
To set up the model of the double difference measurement observation equation, a simple mathematical model for a short baseline is adopted. And the linearized double difference observation is given as (Paul de Jone and Christian Tiberius, 1996)

$$y_{L1} = Bb + Aa_{L1} + e_{L1}, \quad y_{L2} = Bb + Aa_{L2} + e_{L2} \tag{1}$$

with

$$y = \begin{bmatrix} \rho & l \end{bmatrix}^T, \quad B = \begin{bmatrix} H & H \end{bmatrix}^T, \quad A = \begin{bmatrix} 0 & \lambda I \end{bmatrix}^T, \quad e = \begin{bmatrix} v & w \end{bmatrix}^T \tag{2}$$

Where y denotes the difference between the measured and the computed L1/L2 code and carrier phase double differences for the initial position estimate, H is the observation matrix characterizing the double difference user reference station-satellite geometry, λ is the wavelength of the L1/L2 carrier(λ_{L1} , λ_{L2}), I is an identity matrix, b is the vector of baseline, a is the vector of double difference L1/L2 ambiguities(a_{L1} , a_{L2}), e is baseline vector of the L1/L2 code(v_{L1}, v_{L2}) and the carrier phase(w_{L1}, w_{L2}) measurement noise. The code and the carrier phase measurement noise are modelled an AWGN (Additive White Gaussian Noise). The noise characteristic, however, is likely to change in the presence of multipath. Theoretically, the L1/L2 code measurement error would be 75/7.5 meter at maximum, and the L1/L2 carrier phase measurement error would be 4.75/6 cm at maximum in the presence of multipath(David Wells, 1987).

3. CYCLE-SLIP DETECTION

The causing sources of cycle-slip are signal obstructions. In the almost of GNSS application field, there are the signal obstructions like that buildings, mountains, street tree and etc. The LOS (Line of Sight) between satellite and receiver is blocked by these obstructions. It also causes the multipath, and low signal-to-noise ratio. Finally, it is possible that the measurements blockage or the measurement quality is degraded. The measurement blockage arouse by instantaneously lock loss in the signal tracking loop, and it affect to the both of carrier measurement and code measurements (pseudo-range). It just means that number of visible satellites is reduced. The positioning performance will be slightly degraded. But, the cycle-slip is affect to only carrier measurement, not to code measurement. When the cycle-slip is occurred, the carrier measurement look like have an offset from any epoch. Therefore, the positioning performance of CDGPS is degraded by cycle-slip. And especially, receivers that using carrier-smoothing of code measurement are highly affected by it.

The basic technique to detect the cycle-slip is to compare the carrier measurement with the code measurement. It could express as following equation(3) by subtracting carrier measurement and code measurement(Malek Karaim et al. 2014).

$$\rho(t)-\phi(t)=-\lambda N+2I(t) \tag{3}$$

The common errors in both measurements are removed, then the ambiguity and the ionosphere delay are remained. The ionosphere delay variation between adjacent epochs would be very small. And the ambiguity is changed only when the cycle-slip occurred. Therefore, left-side of equation(3) could be used for cycle-slip detection parameter. It is the simplest technique for cycle-slip detection. But sometimes, the noise of code measurement is much higher than the quantity of cycle-slip. Therefore, equation(3) could be used for only big cycle-slip. Therefore, we adopt the Doppler frequency instead of code measurement. The time differencing of carrier measurement has same meaning as Doppler frequency. Hence, the quantity that obtained by subtracting time differencing carrier measurement and Doppler frequency is available to detect the cycle-slip. Because of the time differencing carrier measurement has same physical meaning as the Doppler frequency, that quantity gets higher value when the cycle-slip occurred.

4. EXPERIMENTAL RESULTS

4.1 Experiment Environment

In this paper, in order to induce the abnormal effect in the measurements, the user receiver is located near the barrier. We use the 3.25 m height barrier. It will be incur the multipath effect, and the other abnormal effect like as cycle-slip and measurement missing. The Figure 1 and Table 1 are shows our experimental configurations. The NovAtel Propak-V3 (surveying grade receiver) and NovAtel GPS-703-GGG antenna adopted to the reference receiver, in order to reduce the abnormal effect. In other hand, we apply the u-blox EVK-6T (navigation grade) and ANN-MS-0-005 antenna to user receiver.

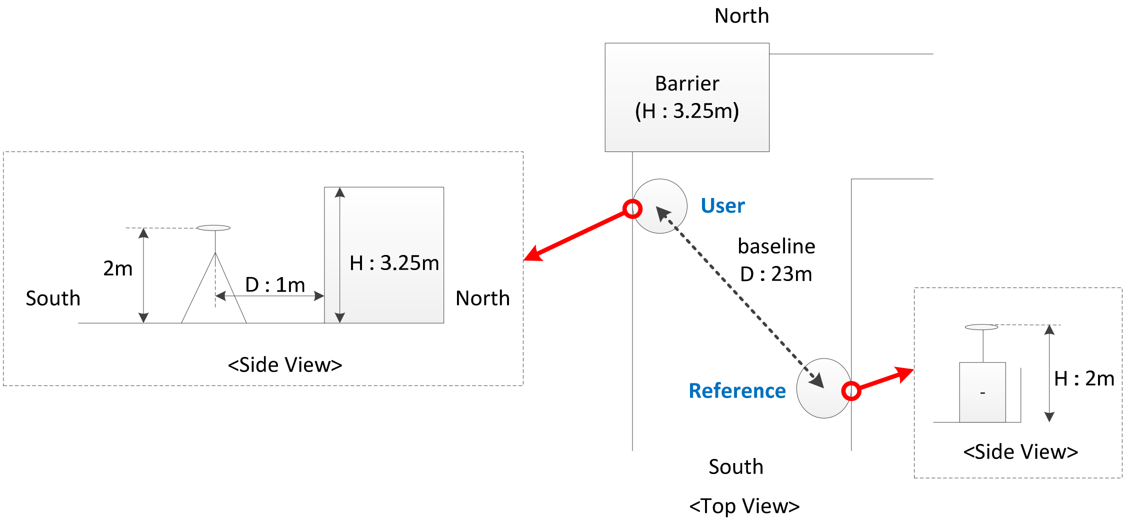


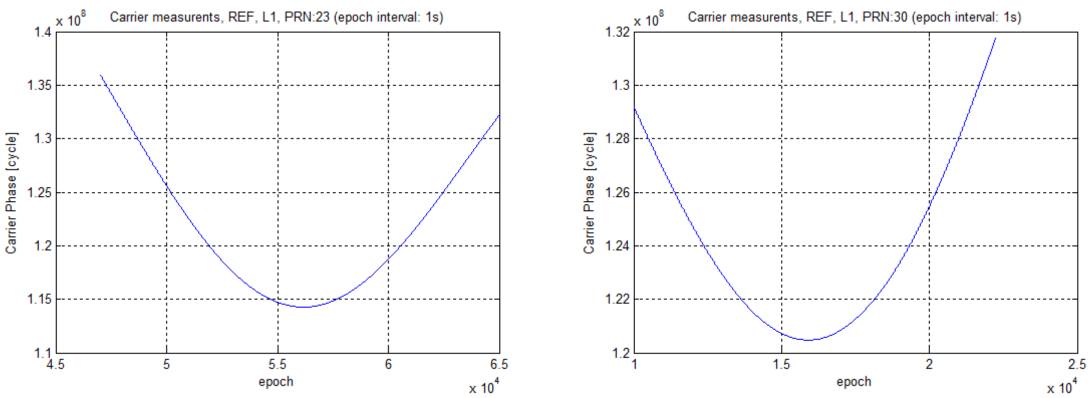
Figure 1. The experimental environment

Reference	Receiver	NovAtel Propak-V3
	Antenna	NovAtel GPS-703-GGG
User	Receiver	u-blox EVK-6T
	Antenna	ANN-MS-0-005
Receiving Time		about 24 hr
Baseline		23 m

Table 1. The summary of experimental configurations

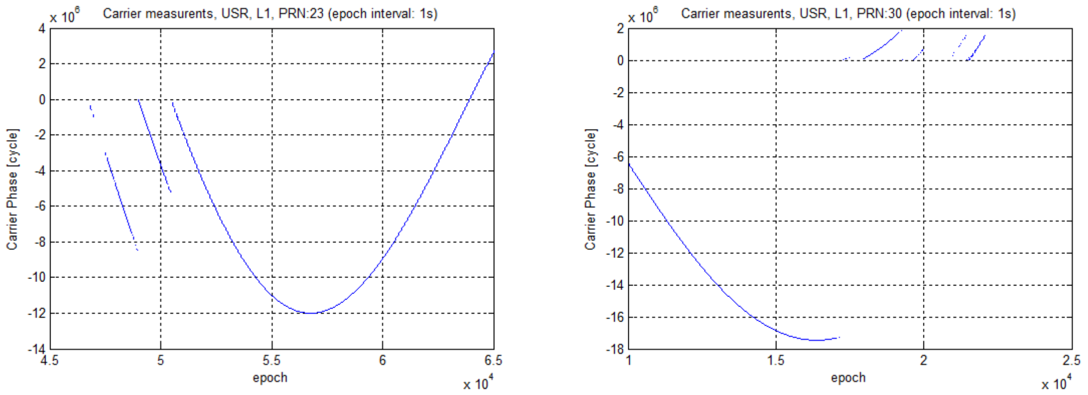
4.2 Cycle-slip Detection and Analysis

The carrier measurements of reference receiver and user receiver from experimental result are shown in Figure 2 and Figure 3. In the Figure 3, there are measurement blockage. The cycle-slip is not detected yet. The time differencing of carrier measurements of reference receiver and user receiver are shown in Figure 4 and Figure 5. In these figures, the shape of time differencing of carrier measurement is similar to Doppler frequency. From this similarity, cycle-slip detection is possible as shown in Figure 6 and Figure 7. In case of reference receiver, the cycle-slip is not detected. While, in case of user receiver, the cycle-clip is detected.



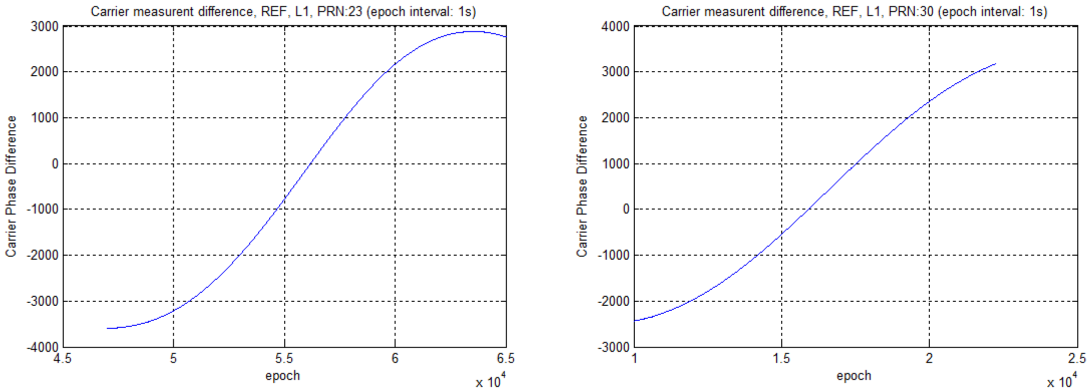
(a) (b)

Figure 2. Carrier measurements of Survey grade receiver (a) PRN 23, (b) PRN 30



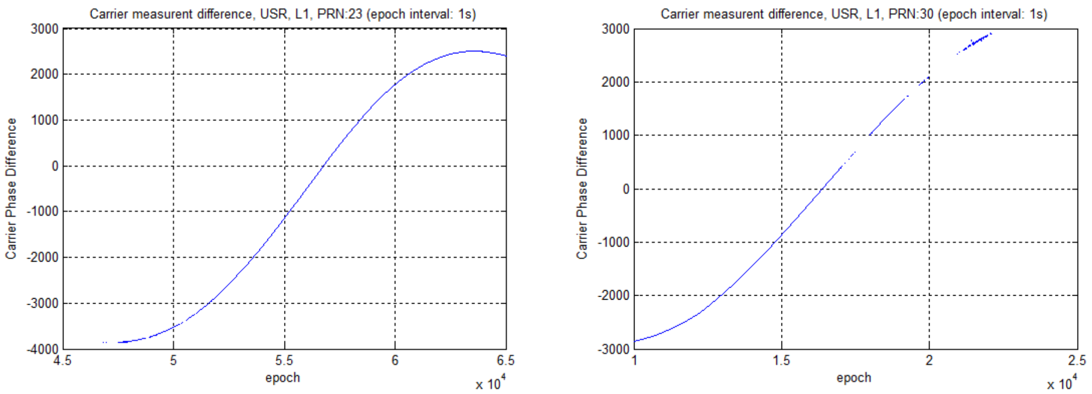
(a) (b)

Figure 3. Carrier measurement of Navigation grade receiver (a) PRN 23, (b) PRN 30



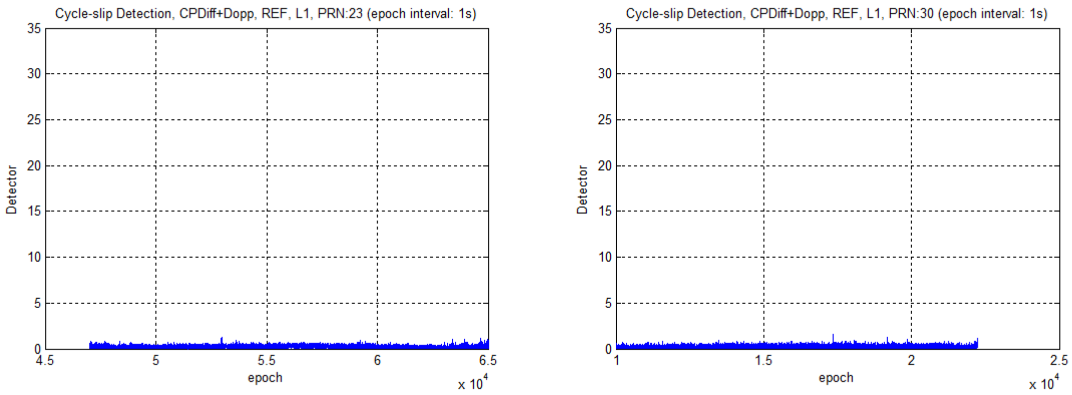
(a) (b)

Figure 4. Carrier measurements difference of Survey grade receiver (a) PRN 23, (b) PRN 30



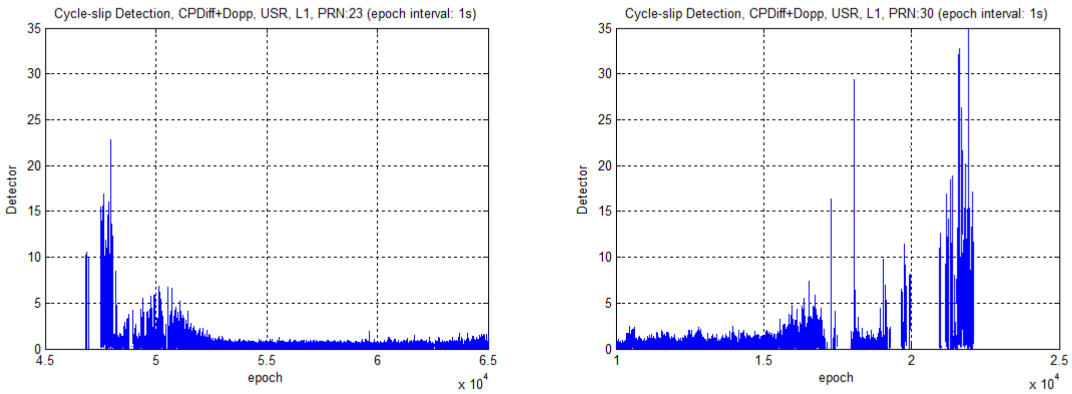
(a) (b)

Figure 5. Carrier measurements difference of Navigation grade receiver (a) PRN 23, (b) PRN 30



(a) (b)

Figure 6. Cycle-slip Detection of Survey grade receiver (a) PRN 23, (b) PRN 30



(a) (b)

Figure 7. Cycle-slip Detection of Navigation grade receiver (a) PRN 23, (b) PRN 30

4. CONCLUSIONS

In this paper, we introduce the cycle-slip detection method using similarity between time differencing carrier measurement and Doppler frequency. And, measurement collecting experiment is performed with signal obstruction for arise the cycle-slip. The introduced method is applied to collected measurement, then detect the cycle-slip

ACKNOWLEDGEMENTS

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