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Coarse-time Positioning without Continuous GPS Signal Tracking

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ABSTRACT

This paper proposes an efficient coarse-time positioning method that can be applied to the environments where continuous GPS signal tracking is not guaranteed due to frequent signal blockages, attenuation, interference or jamming.

If a GPS receiver operates in a normal mode with continuous GPS signal tracking, navigation message acquisition and user position/clock bias estimation, its coarse-time can be aligned with the GPS time accurately. Between the time alignments, the coarse-time usually drifts from the last synchronized GPS time based on the receiver's internal low-cost crystal oscillator.

If GPS signal tracking cannot be performed, the coarse-time largely deviates from the GPS time and varies from a few milliseconds to several tens of seconds since the GPS time information contained in the navigation message cannot be acquired from the signal tracking process. The proposed coarse-time positioning method is purposed to enable positioning in these cases. By an experiment with a software GPS receiver, performance of the proposed method is evaluated.

KEYWORDS: GNSS, GPS, Code Phase, Coarse-time, Coarse-time positioning

1. INTRODUCTION

GPS satellites are placed on about 20,000 km, and transmit GPS signal of about 25 watts to the ground. GPS receiver located on the ground can receive very weak GPS signal with the power level of about -160 dBm. Since GPS satellites are located on very high altitude and their signals are very weak, GPS signal is vulnerable to jamming and interference during the signal transfer to user(Grant *et al*, 2009). Since there are many skyscrapers in metropolitan cities, it is hard for users in urban area to receive sufficient number of signals from different GPS satellites. In addition to the signal visibility, multipath error is also problematic to the GPS users in urban area. Intentional jamming also prohibits the reception of the normal signal. If a jammer transmits very high-powered signal, users distributed on a wide area can be lead to dangerous situations. For the reason explained so far, a positioning algorithm overcoming these severe signal environments is desirable for GPS users.

A GPS receiver has a clock operated by internal oscillator such as XO(Crystal Oscillator) or TCXO(Temperature Compensated Crystal Oscillator). When a GPS receiver tracks the GPS signal successfully, it decodes navigation messages in parallel(Misra and Enge, 2006). During the navigation message decoding process, the internal clock of the receiver can be aligned to GPS time based on the timing information included in the navigation message. However, if continuous GPS signal tracking cannot be guaranteed, the internal clock deviates gradually from the GPS time and the amount of deviations increases as time elapses. The internal operating time of a GPS receiver called as the coarse-time. The coarse-time usually drifts from the last synchronized GPS time. If the receiver's continuous signal tracking is lost, the coarse-time deviates from the GPS time. The deviation ranges, for example, from a few milliseconds to several tens of seconds. As compared, the receiver clock bias, also known as the common bias, is usually limited within one millisecond(Van, 2009). If the coarse-time error becomes large, the non-linear estimation of the user position and the receiver clock bias cannot converge properly since the line-of-sight vectors from the user to the satellites are highly distorted due to the coarse-time error.

In this paper, an efficient coarse-time positioning method is proposed. The proposed method can be applied to severe signal environments where continuous GPS signal tracking cannot be guaranteed. The key point of the proposed method is the rapid positioning with assisted ephemeris data, sub-millisecond pseudoranges, and a priori user position information. To verify the feasibility of the proposed method, a software GPS receiver capable of performing customized GPS signal acquisition modes and providing the reference value of the coarse-time error is utilized. By several experiments, the performance of the proposed method is evaluated.

2. COARSE-TIME POSITIONING

2.1 Coarse-time

During normal operating, a GPS receiver obtains the TOW(Time Of Week) information which contained in the navigation message as a result of its signal tracking process. It synchronizes its internal time to the accurate GPS time utilizing the decoded TOW information. In addition, it samples code phase values and combines them with the TOW information resulting in complete pseudorange measurements. Afterwards, it computes the user position and clock bias based on the pseudorange measurements and the satellite positions.

However, under poor signal environments due to signal obstructions, interference, or jamming, it cannot acquire the TOW information reliably. In addition, its internal time is not synchronized to the GPS time since its clock bias cannot be estimated and compensated under poor signal environments.
The time error in the positioning process consists of two elements; receiver clock bias and coarse-time error. The geometric configurations of the receiver clock bias and the coarse-time error are illustrated in Figure 1 and Figure 2, respectively, for comparison.

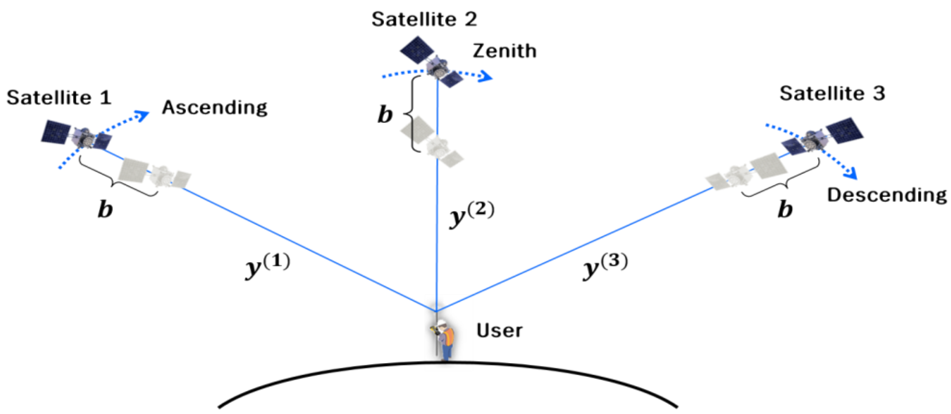

Figure 1. The effect of receiver clock bias(Van, 2009)

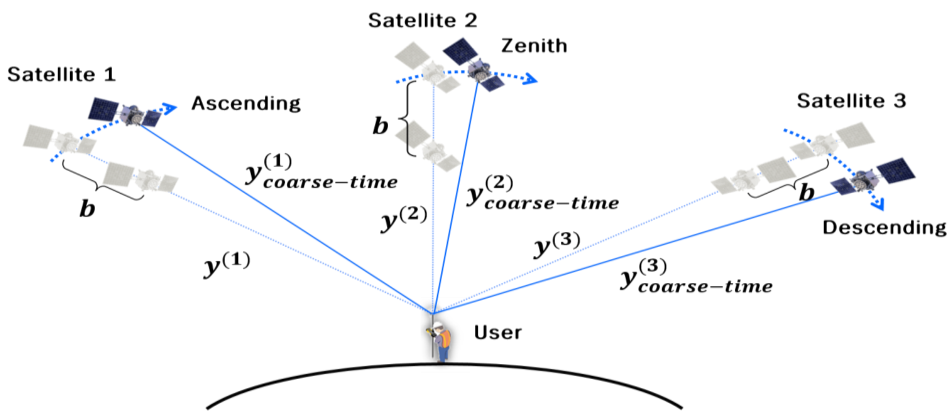

Figure 2. The effect of coarse-time error(Van, 2009)

In Figures 1 and 2, $y^{(N)}$ denotes the pseudorange measurement between the GPS satellite and the user. b denotes the receiver clock bias affecting all the pseudorange measurements by the same amount. $y^{(N)}_{coarse-time}$ denotes the pseudorange measurement affected by the coarse-time error. In the figures, Satellite 1 is in the ascending state, Satellite 2 is on the zenith, and Satellite 3 is in the descending state.

$$\delta y^{(N)} = y^{(N)}_{coarse-time} - y^{(N)} \tag{1}$$

Since moving directions are different among the satellites, $\delta y^{(N)}$ is different among the satellites. Thus, the coarse-time error should be estimated and compensated correctly for accurate positioning.

2.2 Previous research

Studies on coarse-time positioning were initiated during the A-GPS development. Positioning based on one-millisecond ambiguous pseudorange measurements with GPS ephemeris was proposed by Peterson *et al* (1995). Afterwards, Van Digglen (2009) established a basis of coarse-time positioning where GPS ephemeris data can be transferred from the Internet. And, Van Digglen was proposed the basis technique of coarse-time positioning. Extending the Van Digglen's study, Othieno and Gleason (2012) proposed a coarse-time positioning method combining doppler and code-phase measurements. Chen *et al.* (2014) proposed a new method solving dynamic problems. Millisecond integer ambiguity search method using inter-satellite distance was proposed by Jing *et al.* (2015).

2.3 Proposed method

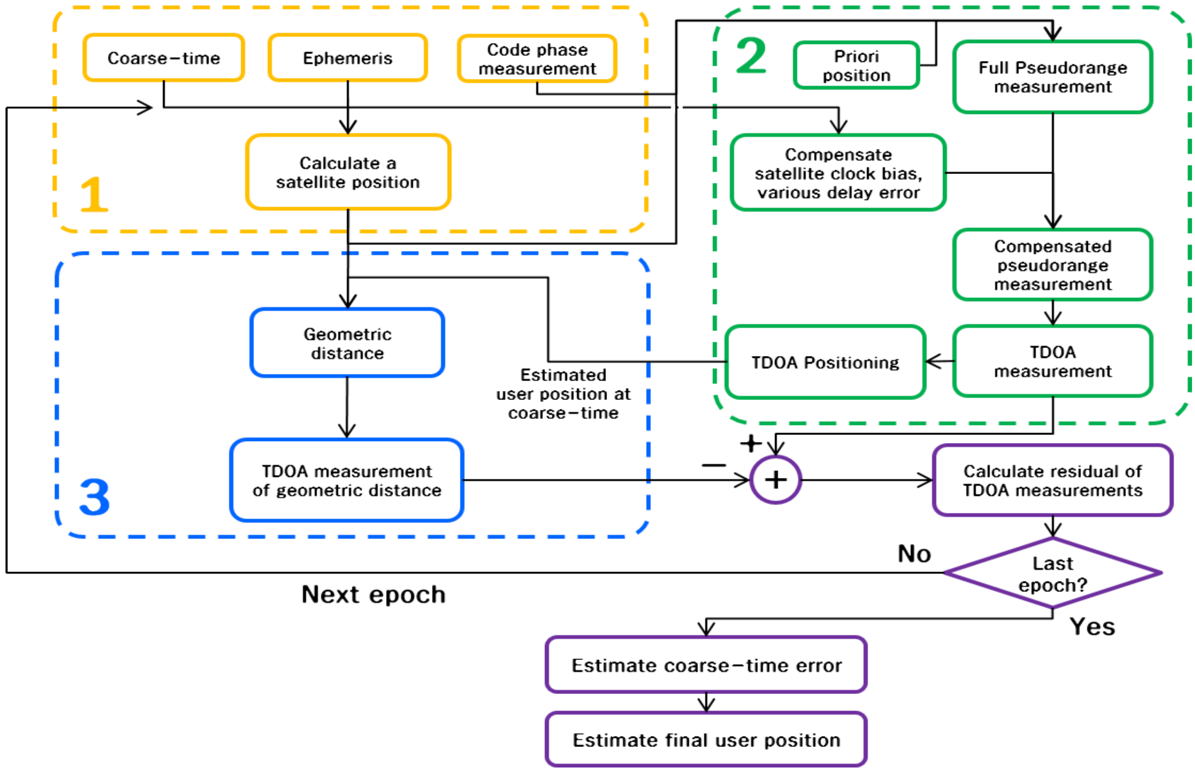

Figure 3. Flowchart of the proposed coarse-time positioning method

Flowchart of the proposed method is illustrated in Figure 3. At first, satellite positions based on the initial coarse-time information are estimated by applying an assume coarse-time to the ephemeris data. Code phase measurements are obtained as one-millisecond ambiguous pseudoranges. Ambiguous pseudoranges can be converted to unambiguous full pseudoranges if the estimates of satellite and user positions are moderately accurate(Yoo, 2016). Satellite clock errors, ionospheric and tropospheric delays are compensated. By forming TDOAs of the full pseudoranges selecting one pseudorange as the reference, the user position can be estimated eliminating the effect of the common clock bias. Residuals are calculated by iterating the process explained so far for each assumed coarse-time error. More small residual sum is more accurate the assumed coarse-time error. Thus, the coarse-time error can be estimated by finding the minimum value of the TDOA residual sum. Finally, based on the estimated coarse-time error, the user position can be estimated.

3. EXPERIMENT

An experiment was performed to evaluate the accuracy of proposed method. To provide reference values of the coarse-time, IFEN SX-3 software GPS receiver was utilized. A Trimble ChokeRing Antenna was installed at the exactly known position in Korea Aerospace University, Goyang City, Republic of Korea and was connected to the software receiver. The GPS ephemeris data was obtained from the PAJU reference station operated by National Geographic Information Institute, Republic of Korea. Though the user receiver was actually located in Goyang City, it was initially assumed to be located at Seoul City Hall. The distance from the user receiver to the PAJU reference station and Seoul City Hall are approximately 20 km and 10 km, respectively. The experiment configuration is illustrated in Figure 4. The experiment consisting of three trials as summarized in Table 1. The resulting errors of the three different trials by the proposed method are summarized in Table 2. As shown in Table 2, the accuracies of three trials similar though satellite visibility conditions are different. The proposed method shows the accuracy better than 100 m though the number of trials is not sufficient.

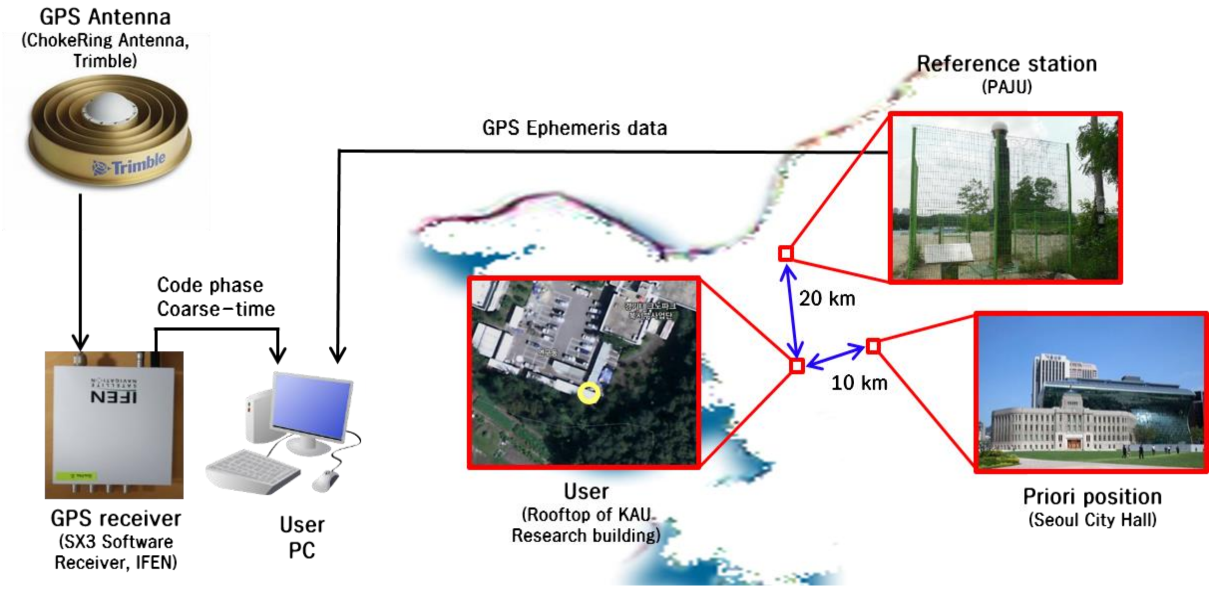

Figure 4. Experiment configuration

An experiment was performed over three times. The experiment overview is expressed as Table 1.

	Period	Evaluation parameters
Trial 1	2015. 9. 10 (22:55~23:05)	✓ CEP
Trial 2	2015. 10. 14 (02:22~02:27)	✓ 1 sigma
Trial 3	2015. 12. 1 (17:30~17:35)	✓ RMSE in NED directions

Table 1. Experiment overview

The performance evaluation of proposed coarse-time positioning method was performed. The positioning errors of three trials are illustrated in Table 2.

		Trial 1	Trial 2	Trial 3
CEP (m)		87.23	57.59	63.74
1 sigma (m)		110.62	71.89	79.19
RMSE of direction (m)	N	47.61	26.24	26.22
	E	46.66	29.89	24.81
	D	93.01	60.42	75.69

Table 2. Positioning errors of three trials

4. CONCLUSIONS

This paper proposed an efficient coarse-time positioning method that can be applied to the environments where continuous GPS signal tracking cannot be performed. To evaluate the proposed method, a software GPS receiver that can provide the reference value of the coarse-time error was utilized. By an experiment with the software GPS receiver, it was demonstrated that the coarse-time positioning without continuous and reliable GPS signal tracking is possible with an acceptable accuracy.

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