

Positioning Simulation Using a 3D Map and Verification of Positional Estimation Accuracy in Urban Areas Using Actual Measurement

Satoru Komatsu and Akira Nagao
Honda R&D Co., Ltd.

Taro Suzuki
Waseda Institute for Advance Study

Nobuaki Kubo
Tokyo University

ABSTRACT

Positional accuracy of GPS measurement has been based on simulation and actual measurement due to the difficulty of conducting 24-hour actual running tests. However, the conventional measurement is only based on brief evaluation; hence variability of positional accuracy which varies depending on measurement time and location had been an issue. Thus, it is significant to show the validity by the estimation of positional accuracy, and actual measurement using of lengthy simulation.

In this study, actual measurement data in an urban area was obtained for long hours, and a simulation using 3D maps was implemented. A high precision positional measurement system was equipped on a vehicle in order to collect actual measurements and positional data at each measurement time. The data obtained by the measurement system was used as the reference coordinate for both the simulation and the actual measurements. Consequently, comparison between the simulation and actual measurement data on positional accuracy was able to be implemented for the first time. A dominant deterioration factor of positional accuracy is multipath error caused by reflection from the likes of buildings. Thus, reception status of incoming waves from GPS at each measurement time and reception point by simulation. Specifically, if a satellite which receives direct waves was exclusively used in simulation, measurement accuracy shall be improved. Thus, improvement of the accuracy was verified by choosing the same satellite used in simulation. Consequently, significant improvement in the measurement accuracy was affirmed, and the validity of satellite measurement simulation using 3D maps was partially verified.

CITATION: Komatsu, S., Nagao, A., Suzuki, T., and Kubo, N., "Positioning Simulation Using a 3D Map and Verification of Positional Estimation Accuracy in Urban Areas Using Actual Measurement," *SAE Int. J. Passeng. Cars – Electron. Electr. Syst.* 9(1):2016, doi:10.4271/2016-01-0083.

INTRODUCTION

When the Global Positioning System (GPS) operated by the United States is integrated with the positioning satellite systems of other countries, the number of satellites that can be referenced increases greatly, and the positioning accuracy of navigation services is therefore increased. On the other hand, positional accuracy is degraded by waves reflected from buildings and other such multipath waves when driving in urban areas. GPS has multiple satellites in circular orbits with a period of approximately 24 hours, so that the configuration of the satellite cluster that can be referenced from a given location differs with the time of positioning. Consequently, the positioning accuracy varies with the time of positioning even at the same location.

In order to bypass the variation in positioning accuracy resulting from multipath error and the time of positioning, it is necessary to carry out simulation over an extended period and indicate that its

positioning accuracy is valid according to actual measurement. In urban areas, however, actual measurement cannot readily be carried out by extended driving over a 24-hour period, and the only reports to date have concerned research on positional accuracy using short periods of simulated driving and actual measurement [1, 2]. Since the signal strength of simulations and actual measurements were compared in these reports, there was an issue with variation of simulation positioning accuracy according to the time of positioning and the measurement location.

In previous work on GPS positioning in urban areas, the authors of the present study reported on simulation using 3D maps with the ray tracing method and work on positional accuracy and the positional ratio using actual measurement [3].

For the present research, actual measurement data for urban areas made over periods of time as long as possible was acquired and applied in simulations using 3D maps, orbital information on GPS satellites and the ray tracing method. For the actual measurement, a high-accuracy position measurement system was mounted in a test vehicle, and the position data that could be acquired at each point in time employing this system was used as reference coordinates for the simulation and for the actual measurement. This made it possible for the first time to compare the estimated results from simulation with the actual measurement results for positional accuracy.

The main causal factor in the reduction of positional accuracy in urban areas is multipath error due to reflection from buildings and other such structures. If the satellites that give rise to multipath signals are detected and eliminated, then positional accuracy can be improved.

First, therefore, simulation was used to analyze the reception state (direct wave, reflected wave, diffracted wave and waves that are combinations of these) of incoming waves from GPS at each point in time and each reception point. Next, the information on incoming wave reception state obtained by simulation was used to select the satellite to be received for actual measurement.

When the satellite received in the simulation was designated to be the satellite received to perform actual measurement, the positional accuracy of the actual measurement matched with the positional accuracy of the simulation. The result was greatly improved positional accuracy, and this verified the validity of satellite positioning simulation using 3D maps.

By the estimation of positional accuracy by means of simulation over an extended period in urban areas together with actual measurement, the validity of such simulation was shown for the first time.

The estimation of position using simulation and the field operational trial were carried out in the Nishi-Shinjuku district, which is a virtual forest of tall buildings.

ESTIMATION AND CALCULATION OF GPS POSITIONAL ACCURACY

Principles of Estimating Positional Accuracy Using GPS

GPS positioning is performed by measuring the distance between the satellite and the receiver. When the distances to three satellites at known positions in outer space are known, the location of the receiver can be identified. The distances are derived from the time taken for the signal from the satellite to arrive at the receiver. The atomic clocks on the satellites provide accurate timing for transmission of the positioning codes. Therefore, if the clock in the receiver and the clocks on all the satellites are on exactly the same time, then the time taken for the positioning code to arrive (the propagation delay) can be determined by measuring the time of arrival. It is, however, impossible to perfectly synchronize these various clocks, so another satellite becomes necessary. In other words, GPS positioning captures four or more satellite signals simultaneously, then use them to solve for four unknown quantities, namely the three 3D coordinates (X_0 , Y_0 , Z_0) of the receiver and one

clock error. In actuality, the clock in the receiver is used to measure the arrival time of the positioning code and calculate the propagation delay time, which is then used to derive the distance.

Figure 1 shows the principle of GPS positioning for derivation of the user's position coordinates.

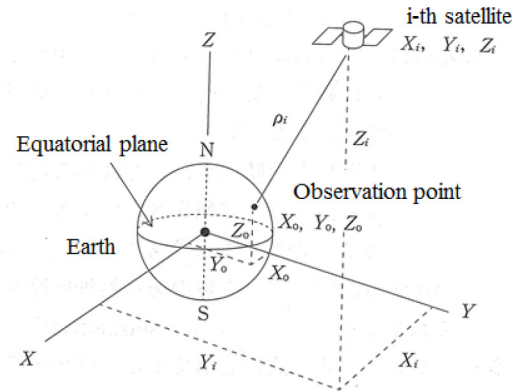


Figure 1. Principle diagram of position estimation using GPS

The satellite's coordinates (X_i , Y_i , Z_i), the geometrical distance ρ_i , the propagation time $\tau + \Delta\tau$ measured by the receiver, the delay error $\Delta\tau$ in the receiver clock and other elements, and the speed of light C_0 are related by the Pythagorean theorem as shown in Equation (1). The right side of Equation (1) shows the algebraic sum that includes the geometrical distance and the delay error of the clock in the receiver ($\rho_i + C_0\Delta\tau$), which is known as the pseudorange.

In order to use GPS to derive the positional accuracy, therefore, it is important to make an accurate measurement of the pseudorange.

$$\sqrt{(X_i - X_0)^2 + (Y_i - Y_0)^2 + (Z_i - Z_0)^2} = C_0(\tau + \Delta\tau) \quad (1)$$

$$= \rho_i + C_0\Delta\tau$$

Derivation of Positional Accuracy Using a GPS Receiver

The correlator shown in Fig. 2 is used in deriving the actual positional accuracy. This correlator uses a replica (early) signal with a slightly advanced phase and a replica (late) signal with its phase slightly delayed to measure the correlation with the received GPS signal. If the reception signal is acquired, the early correlator captures where the correlation function goes high and the late correlator captures where the correlation function goes low. Figure 3 shows the correlation waveform when a direct wave is received.

Figure 4 shows the correlation waveform when a direct wave and a reflected wave are received. The delay error when a Multipath wave is received corresponds to the difference (the pseudorange error) between the correlation peak (vertical axis) generated by the direct wave alone and the center point of the correlator spacing (the spacing between the late correlation waveform and the early correlation waveform). The correlator spacing can be assigned as an arbitrary parameter.

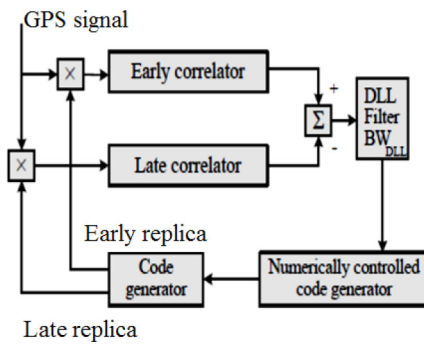


Figure 2. Block diagram of GPS correlator

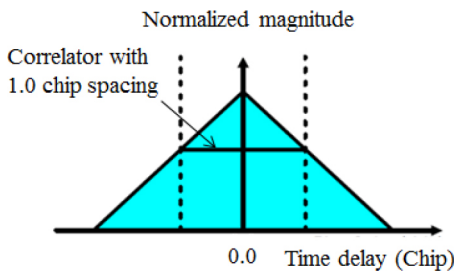


Figure 3. Correlation waveform diagram of direct wave

The correlation waveform (red line) of the multipath wave is distorted by comparison with the waveform of the direct wave (blue triangle).

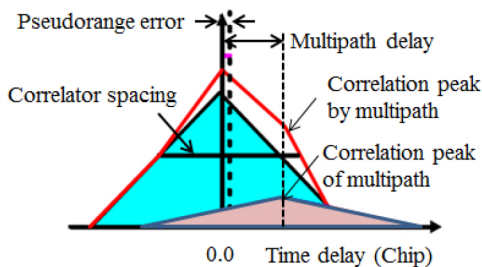


Figure 4. Correlation waveform diagram of multipath wave

GPS Positioning Error

The error factors [4] that determine GPS positioning accuracy are enumerated below.

1. Satellite clock modeling error
2. Error in ephemeris prediction value
3. Error related to ionospheric delay
4. Error related to tropospheric delay
5. General multipath error
6. Error related to receiver noise

The aggregation of these error factors is referred to as user equivalent range error (UERE), which is defined as the square root of the sum of the squares of each error component.

Positioning accuracy is improved using correction information and reliability information from the satellite-based augmentation system (SBAS). Table 1 shows the magnitude of the error factors in the case when SBAS is not used (point positioning) and in the case when it is

used, together with the UERE. The magnitude of error is 1σ (σ is the standard deviation of the positional accuracy). When simulation is used to perform the positioning calculation, the UERE shown in Table 1 is added to the pseudorange obtained by that calculation.

Table 1. Measurement error factor and error magnitude

	Magnitude of error without using SBAS (m)	Magnitude of error using SBAS (m)
1. Satellite clock	2	0
2. Ephemeris prediction value	2	0.1
3. Ionospheric delay	4	0.2
4. Tropospheric delay	0.5	0.2
5. Multipath	0.5	0.5
6. Receiver noise	0.25	0.25
UERE (rss)	5	0.64

Source: [4]

METHOD USED IN THE PRESENT STUDY

The previously reported comparative data for positional accuracy using simulation and actual measurement had issues like the following:

1. Since a high-accuracy positioning system that acquires a reference position for the test vehicle is not used, the reference positions for the vehicle while in movement are not accurate. For this reason, the reference coordinates for the simulation and the actual measurement do not agree.
2. The only condition that can realize agreement between the simulation and the actual measurement is the use of Coordinated Universal Time (UTC). The positioning satellite used in the simulation and the positioning satellite used in the actual measurement will not necessarily agree. In other words, the various positioning differ in their dilution of precision (DOP).

Consequently, the positioning conditions for the simulation and actual measurement do not agree, and the validity of the positional accuracy in simulation could not be verified by actual measurement.

For the present study, the issues were resolved by the method described in the following section.

Method Used in the Present Study

Figure 5 shows the component elements of the present study.

- a. Test vehicle component equipped with high-accuracy position measurement system
- b. Simulation component using ray tracing method
- c. Actual measurement component using high-sensitivity GPS receiver

The respective items of UTC navigation data transmitted by all the satellites and the reference position of the test vehicle while driving are registered in the test vehicle recorder.