Brief Report

Estimation of Multipath Range Error for Detection of Erroneous Satellites

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1. Introduction

The obstruction and reflection of satellite signals in urban canyons causes pseudorange errors and degradation of global navigation satellite system (GNSS) positioning performance. If direct signals are blocked by buildings and only indirect signals reach the GNSS receiver, the pseudorange errors become so large that the positioning accuracy of the GNSS decreases. It is thus important to identify multipath satellite signals that cause pseudorange errors.

Receiver autonomous integrity monitoring (RAIM) has previously been used to identify GNSS satellite signals that give erroneous positioning data by using statistical reliability tests.(1-4) RAIM is considered to be a robust estimation method, and is well suited to the detection of errors, i.e., outliers, based on calculations of least squares residuals. However, if the percentage of outliers among the observed signals increases, then the estimated receiver position gravitates toward those outliers and away from the true position. This reduction in the residuals of outliers increases the residuals of the correct observations and results in the failure of reliability tests. Such situations frequently arise in urban environments where the high density of tall buildings can obstruct satellite signals. To resolve these problems, an alternative to traditional RAIM that is capable of distinguishing between observed satellite signals is considered necessary.

To improve satellite-based positioning accuracy in urban environments, we developed a new approach for identifying and excluding erroneous satellite signals. Unlike RAIM, which employs least squares residuals, the proposed method directly estimates the size of the multipath error in the observed signal based on partial reference data on vehicle position.

2. Multipath Estimation Using an Altitude Map

Since the altitude of vehicles essentially depends on the topography of the surrounding area, the reference altitudes of vehicles in urban environments, which typically have relatively gentle slopes, are relatively easy to obtain. The pseudorange errors are estimated by using an error equation, which specifies the relationship between positioning errors and pseudorange errors (**Fig. 1**). If we select all n (≥ 5) satellites and remove one of the satellites one by one, there will be $n+1$ combinations. For each combination, the altitude element of the error equation is obtained, which yields $n+1$ simultaneous equations. The matrix form of the equations is thus:

$$\boldsymbol{e}_h = B\mathbf{e}$$

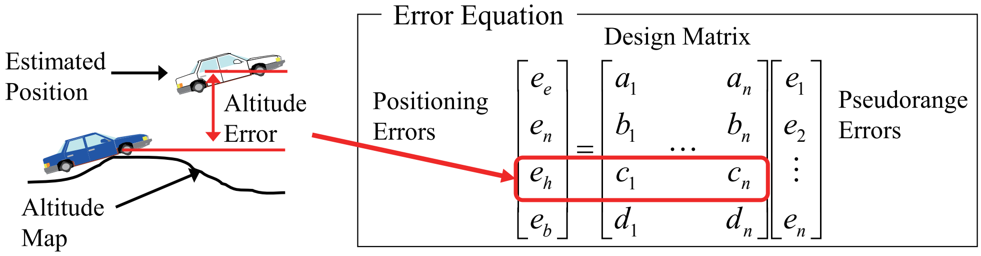

Fig. 1 Equation describing the relation between positioning errors and pseudorange errors.

where, $\boldsymbol{e}_h \in R^{n+1}$ is an altitude error vector and $\boldsymbol{e} \in R^n$ is a pseudorange error vector. The pseudorange errors can be estimated by solving the matrix equation. However, since the rank of the matrix B is $n - 3$, the equation is ill-posed because it uses only altitude information. Three additional constraints are therefore needed to solve the equation. We compensated for the lack of constraints by selecting three reference satellites with small pseudorange errors. As the elevation of satellites increases, the likelihood of obstruction by buildings decreases and satellite signal power increases. We therefore selected three reference satellites based on their elevations and signal-to-noise ratios. The matrix equation can be solved using the least squares method and the pseudorange errors can be estimated after adding the constraint that the three elements in the error vector $\mathbf{e}$ that correspond to the reference satellites are zero. The positioning accuracy can be improved by weighting the satellite signals according to their estimated pseudorange errors. The validity of using the three reference satellites is then examined by evaluating the magnitude of the altitude error associated with weighted positioning.

3. Experiment and Results

An experiment was conducted in an urban area to evaluate the accuracy of pseudorange error estimation. The estimated pseudorange errors were compared with reference pseudorange errors that were calculated based on the actual three-dimensional position of the reference vehicle as opposed to the altitude reference. **Figure 2** shows an example of the estimated pseudorange errors. The root mean squared value of the estimated pseudorange errors was 27.5 m for the duration of the experiment, which is sufficient for detecting satellites with pseudorange errors exceeding several tens of meters. **Figure 3** shows a comparison

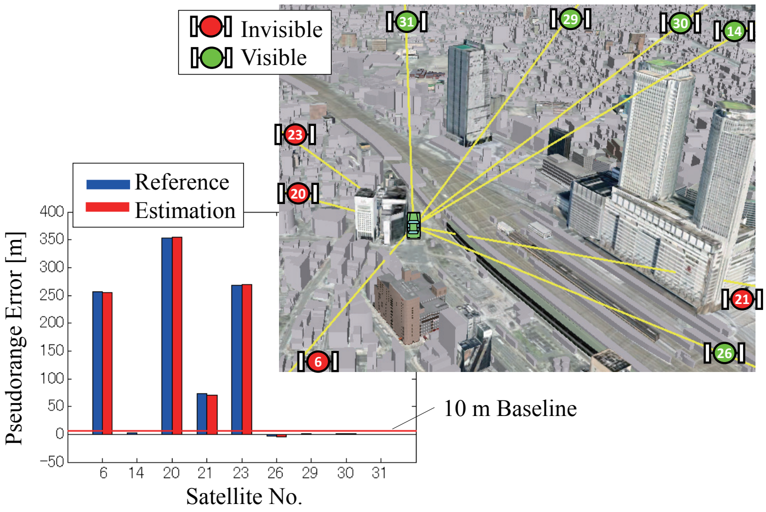

Fig. 2 Estimation of pseudorange errors.

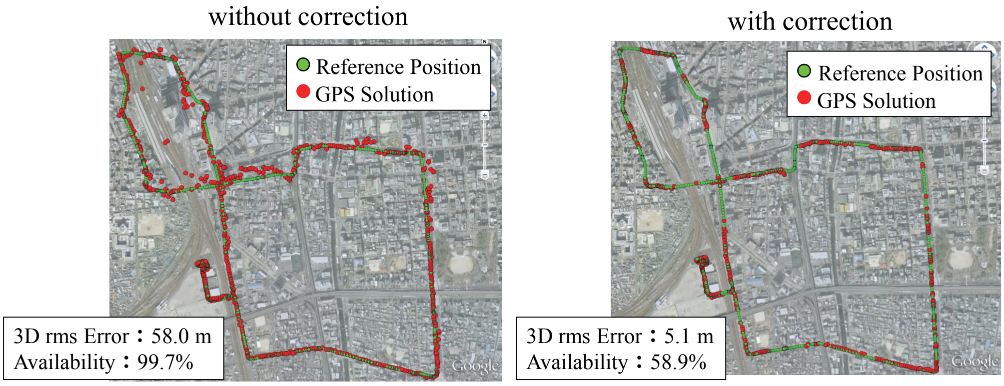

Fig. 3 Improvement of positioning accuracy.

between positioning data with and without correction using the estimated error information. The positioning error associated with the proposed method is 5.1 m, which is approximately ten times less than the 58.0 m error associated with the conventional method. This improvement in positioning accuracy means that the proposed method can estimate the pseudorange error accurately enough to detect and exclude erroneous multipath satellite signals correctly.

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Fig. 3
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