# Performance Analysis of Navigation Algorithm for GNSS Ground Station

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ABSTRACT

Global Navigation Satellite System (GNSS) is been developing in many countries. The satellite navigation system has the importance in economic and military fields. For utilizing satellite navigation system properly, the technology of GNSS Ground Station is needed. GNSS Ground Station monitors the signal of navigation satellite and analyzes navigation solution. This study deals with the navigation software for GNSS Ground Station. This paper will introduce the navigation solution algorithm for GNSS Ground Station. The navigation solution can be calculated by the code-carrier smoothing method, the Kalman-filter method, the least-square method, and the weight least square method. The performance of each navigation algorithm in this paper is presented..

**Key Words** : satellite navigation, ground station, navigation solution

## I. Introduction

Many countries are developing Global Navigation Satellite System (GNSS). GNSS is used in our life variously. Because society requires more convenience, the satellite navigation becomes more important. In transportation, rescue, and defense, GNSS is already used widely and the usage of GNSS technology is expanding in many fields. As GNSS is getting important, many countries construct satellite navigation system as national key industry. Though GPS is used mainly as satellite navigation system these days, other satellite navigation system will be launched in the future gradually. Europe Union is developing Galileo satellite navigation system against GPS system. China, Japan, and India are also developing their own navigation systems. United States, also, establishes a modernization plan of GPS which improves the performance of the GPS system. As the available satellite navigation systems are increased, the satellite navigation infrastructure and technology attract attention. For improving the availability of GNSS, the satellite navigation infrastructure should be established. The GNSS signal should be inspected and the data from GNSS should be collected for analysis. The GNSS Ground Station technology is one of GNSS infrastructures and makes the range of usage expand. [1]

In this paper, the GNSS Ground Station technology will be introduced. The GNSS Ground Station and the Monitoring and Control Subsystem are introduced. The related algorithm of the Monitoring and Control Subsystem for GNSS Ground Station is described. The analysis of algorithm is performed.

## 2. GNSS Ground Station

The GNSS Ground Station which ETRI (Electronics and Telecommunications Research Institute) is developing is comprised of the GNSS Senor Station, the Uplink Station, and the Monitoring and Control Subsystem. The GNSS Sensor Station is composed of the hardware including the GPS/Galileo combined receiver which has high accuracy, antenna, atomic clock, weather observation equipment, and network, and etc. The Uplink Station is composed of the uplink control and monitoring device, modem, and antenna. The Monitoring and Control Subsystem

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which is software system is made of the navigation software, monitoring and control software, and system operation and administration software. The Monitoring and Control Subsystem collects navigation data from GNSS receiver and has data communication interface for providing data to the user who needs the navigation data. Figure 1 shows the configuration of the GNSS Ground Station.

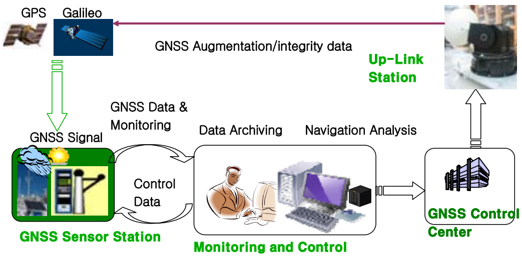


Figure 1: Configuration of the GNSS Ground Station

## 3. Monitoring and Control Subsystem

As hardware configuration, the Monitoring and Control Subsystem consists of a computer and an archiving server. Satellite navigation source data is collected from the GNSS receiver for comprising satellite navigation and weather source data is collected from the weather sensor. The equipment of the GNSS Sensor Station is controlled through the control command and the status of the GNSS Sensor Station is monitored. Figure 2 shows the configuration of the Monitoring and Control Subsystem.

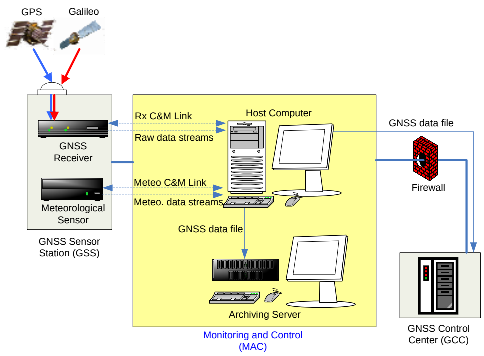


Figure 2: Configuration of the Monitoring and Control Subsystem

The purpose of the Monitoring and Control Subsystem is to monitor and control the equipment of the GNSS sensor station and to provide the availability for GPS and Galileo service and the improved quality of satellite navigation service. The Monitoring and Control Subsystem collects GPS and Galileo navigation signal data and transmit them to the GNSS control center. Figure 3 shows the block diagram of the Monitoring and Control Subsystem.

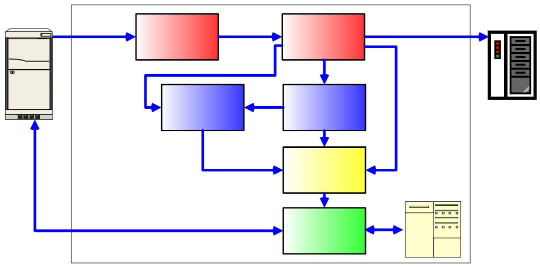

Figure 3: Block Diagram of the Monitoring and Control Subsystem

## 4. Navigation Algorithm

The monitoring and Control Subsystem considers navigation solution algorithm and measurement processing algorithm. Section 4.1, section 4.2, and section 4.3 present navigation solution algorithm. Section 4.4 presents measurement processing algorithm. The measurement processing algorithm is used before navigation solution algorithm for enhancing the measurement property.

### 4.1. Least Square Method

The least square method is basic method for calculating receiver position. Basically, the receiver position can be calculated with four navigation satellites. When more satellites over four are available, to use all the satellites is popular. In the numerical point, the navigation solution step is summarized by the following steps. [2]

A. Choose a nominal position and user clock bias to represent the initial condition.
B. Calculate the pseudorange with satellite position and receiver position.
C. Calculate the difference between the calculated value and the measured value.

D. Calculate the receiver position difference with least square method.
E. In order to find the desired position solution, check the receiver position difference with a certain predetermined threshold. If the value is less than threshold, the iteration will stop.
F. Add the receiver position difference to the receiver position.
G. Repeat the procedure from B to F.

### 4.2. Weight Least Square Method

The weight least square method is the advanced method. The least square method uses the all visible satellites and calculates the position every time with raw data. If there are the wrong signals of satellite, the position accuracy is degraded. In calculate position, if the weighting factor is imposed to the accurate measurement value, the position accuracy will be improved. In this paper, we consider the weighting factor of elevation angle. If the elevation angle of satellite is low, the satellite signal has much noise and error. Thus the weighting value is determined as the satellite elevation angle. [3]

### 4.3. Kalman Filter Method

The Kalman filter is the optimal filter in linear system with white gausian process noise and measurement noise. The Kalman filter is used widely in engineering field. But the Kalman filter is sensitive on system and measurement model and has a weak point that it cannot used in non-linear system directly. [6]

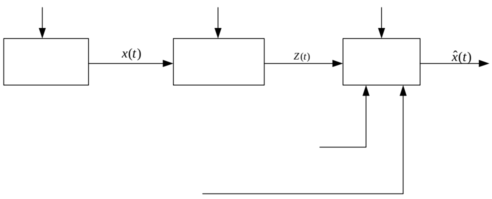


Table 1. Navigation Result of No-Smoothing Method

In the navigation software, the Kalman filter algorithm can be used. The system dynamic model, the measurement model, the system statistics information, the measurement statistics information, and the system initial information are used for the Kalman filter method. Figure 4 shows the Kalman filter process in navigation software.

In navigation, the measurement model uses the pseudorange measurement. The estimated pseudorange and the measured pseudorange from receiver are used for measurement update. The dynamic model uses the properties of ground station. The GNSS ground station is static station. Thus, the system dynamic model considers position, clock, velocity, and clock variation as states. The updated position and the updated clock are influenced by the previous position, the previous clock, velocity, clock variation, and update time.

### 4.4. Code-Carrier Smoothing Method

The code-carrier smoothing method uses the code measurement and carrier measurement simultaneously. Among the measurement values, the code has the chip length of 300m and carrier has the chip length of 0.19m. But the carrier measurement has initial integer ambiguity. [4] Thus the accurate pseudorange cannot be calculated. If code measurement and carrier measurement are used simultaneously, the shortcomings are overcome. In the early measurement, the code measurement can be used. As the measurements are accumulated, the carrier measurement is used more gradually. The code-carrier smoothing method is calculated by the following equations. [5]

$$\hat{\rho}_R^j(k) = \frac{1}{N_{samples}}\rho_R^j(k) + (1-\frac{1}{N_{samples}})\tilde{\rho}_R^j(k) \quad \text{(a)}$$

$$\tilde{\rho}_R^j(k) = \hat{\rho}_R^j(k-1) + [\Phi_R^j(k) - \Phi_R^j(k-1)] \quad \text{(b)}$$

Where $\hat{\rho}_R^j$ is code-carrier smoothing measurement, $N_{samples}$ is the sample number, $\rho_R^j$ is code measurement, $\Phi_R^j$ is carrier measurement, and $k$ is measurement step. The sample number is determined by following.

If $T \times k \le 100\sec$, $N_{samples} = k$

If $T \times k > 100\sec$, $N_{samples} = \frac{100}{T}$

Where $T$ is sampling frequency.

## 5. Performance of Navigation Algorithm

For analyzing performance of navigation algorithm, the data which is received from ETRI reference station is used. ETRI reference station is located at 36° 22′ 56″.858459 north latitude and 127° 21′ 49″.111521 east longitude. The performance is compared by the horizontal root mean square (HRMS) and the vertical root mean square (VRMS) form reference station antenna point. In weight least square method, the standard elevation angle is assumed as 10 degree. If satellite has elevation angle more than 10 degree, its weighting factor is 1. If the satellite has elevation angle below 10 degree, its weighting factor is decreased as the elevation value. Table 1 shows the result which does not use the code-carrier smoothing method. The performance of the Kalman filter method and the least square method are similar and the performance of the weight least square method has good property. Because the weigh least square method excludes the bad elevation angle satellites, the performance is improved.

Table 1: Navigation Result of No-Smoothing Method

| Method | HRMS(m) | VRMS(m) |
|---|---|---|
| Kalman Filter | 2.5520 | 4.3351 |
| Least Square | 2.5399 | 4.2844 |
| Weight Least Square | 2.4461 | 4.1765 |

Figure 5, Figure 6, and figure 7 show the result of each method. The circle represents the 3m boundary from reference point.

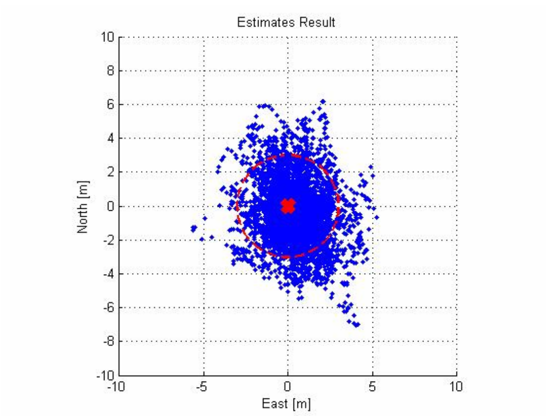


Figure 5: 2D-Position of the Kalman Filter Method

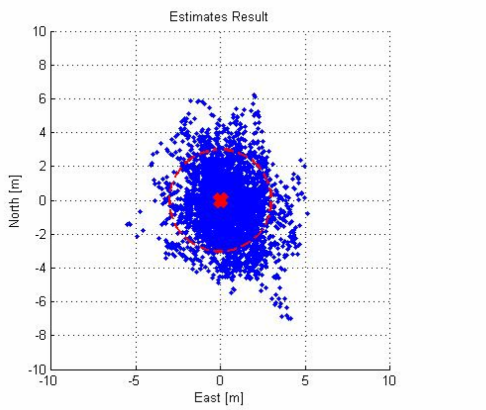


Figure 6: 2D-Position of the Least Square Method

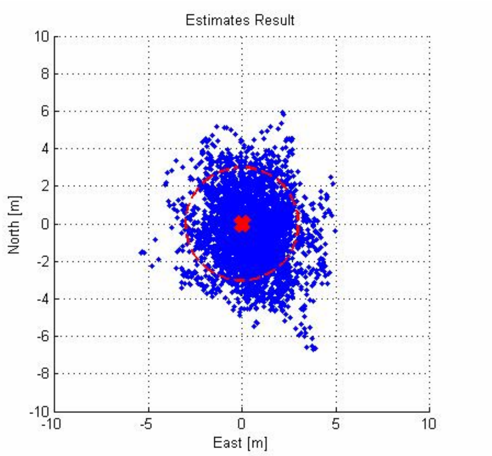


Figure 7: 2D-Position of the Weight Least Square Method

Table 2 and Figure 8 show the smoothing method effect. If smoothing method is used, the performances of all methods are improved. Figure 8 shows the result of the weight least square method and smoothing method.

Table 2: Navigation Result of Smoothing Method

| Method | HRMS(m) | VRMS(m) |
|---|---|---|
| Kalman Filter | 1.1705 | 2.6035 |
| Least Square | 1.1701 | 2.6024 |
| Weight Least Square | 1.1327 | 2.4565 |

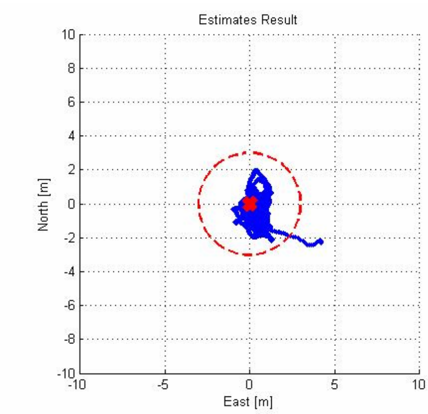


Figure 8: 2D-Position of the Weight Least Square Method with Smoothing Method

The smoothing method effect is shown in comparing figure 7 with figure 8. If the smoothing method is used, the solution is calculated continuously. The carrier measurement has the small variation and resolution. The pseudorange variation is small in each measurement step. The solution is calculated stably and the performance is improved in the smoothing method.

Figure 9 and figure 10 show the comparison between the least square method and the weight least square method. The discontinuous point means the addition of visible satellites. The weight least square method has less error value than least square method because the weight least square method excludes the bad satellite signals which have low elevation angle and are added in navigation solution newly.

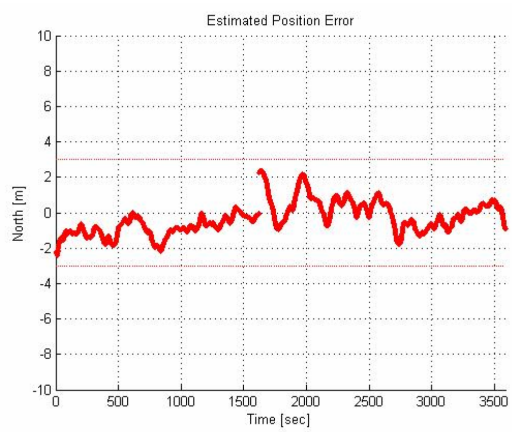


Figure 9: Position Error of the Least Square Method with Smoothing Method

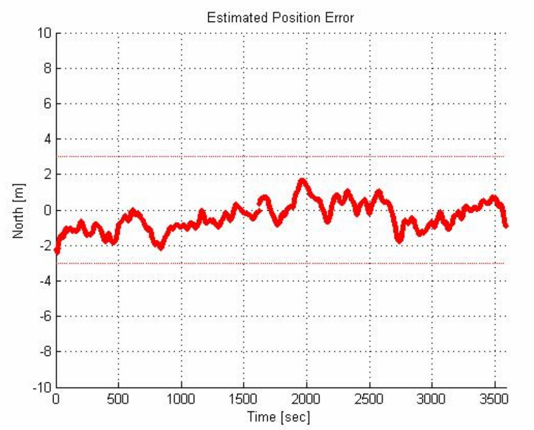


Figure 10: Position Error of the Weight Least Square Method with Smoothing Method

## 6. Conclusions

The Monitoring and Control Subsystem enhances the operation performance of the GNSS Ground Station and contributes in generating reliable data. In this paper, we compare the performance of navigation algorithm for the GNSS Ground Station. The smoothing method enhances the navigation performance and weight method, also, is useful. As the result of this analysis, the method which selects good signal satellite can be studied and the combined algorithm can be suggested in the future.

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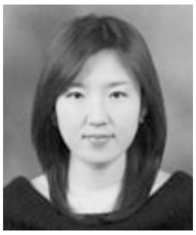

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