Enhanced SBAS Integration Method Using Combination of Multiple SBAS Corrections

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Abstract

In this paper, we propose a new way of improving DGNSS service using combination of multiple SBAS information. Because SBAS uses Geostationary Earth Orbit (GEO) satellites, it has very large coverage but it can be unavailable in urban canyon because of visibility problem. R. Chen solved this problem by creating Virtual Reference Stations (VRS) using the SBAS signal [1]. VRS converts SBAS signal to RTCM signals corresponding its location, and broadcast the converted RTCM signals over the wireless internet. This method can solve the visibility problem cost effectively. Furthermore it can solve DGNSS coverage problem by creating just a transmitter instead of a reference station. Developing above method, this paper proposes the methods that integrate two or more SBAS signals into one RTCM signal and broadcast it. In Korea, MSAS signal is available even though it is not officially certified for Korean users. As a Korean own SBAS-like system, there is the internet-based KWTB (Korean WADGPS Test Bed) which we developed and released at ION GNSS 2006. As a result, virtually two different SBAS corrections are available in Korea. In this paper, we propose the integration methods for these two independent SBAS corrections and present the test results using the actual measurements from the two systems. We present the detailed algorithm for these two methods and analyze the features and performances of them.

To verify the proposed methods, we conduct the experiment using the logged SBAS corrections from the two systems and the RINEX data logged at Dokdo monitoring station in Korea. The preliminary test results showed the improved performance compared to the results from two independent systems, which shows the potential of our proposed methods.

In the future, the newly developed SBASs will be available and the places which can access the multiple SBAS signals will increase. At that time, the integration or combination methods of two or more SBASs will become more important. Our proposed methods can be one of the useful solutions for that.

As an additional research, we need to extend this research to the system level integration such as the concept of the decentralized WADGPS.

Key Word : SBAS Integration, Interoperability, Multiple Correction Combination

Introduction

As various Global Navigation Satellite Systems (GNSSs) i.e. GPS, GLONASS, Galileo, etc will be available in near future, it will be able to access multiple navigation signals in one spot. Also Satellite Based Augmentation System (SBAS) services such as WAAS, EGNOS, MSAS, etc will

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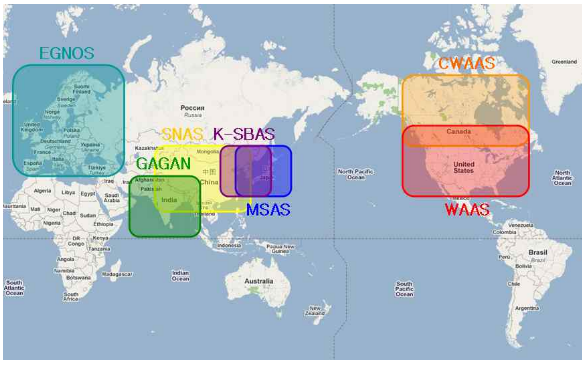

Fig. 1. SBAS coverage in near future

be available as Fig. 1 shows. And its coverage is being extended. And in many regions, two or more SBAS correction will be available. Therefore many researches about transmitting and receiving multiple navigation signals and correction signals are being studied. To step with these changes, the existing DGNSS services are in need of re-engineering.

In this situation, International Association of Marine Aides to Navigation and Lighthouse Authorities (IALA) has proposed several DGNSS re-engineering options in IALA recommendation R-135 on the future of DGNSS] [2]. Developing SBAS integration method, this paper proposes the methods that integrate two or more SBAS signals into one RTCM signal and broadcast it. By multiple SBAS combination, it is highly probable to get improved performance such as accuracy and service availability.

SBAS Integration

Fig. 2 shows a concept of SBAS integration. SBAS integration method means converting SBAS signals to RTCM signals corresponding its location. This method can be achieved by the use of SBAS receivers on each VRS, or by direct data links to the SBAS control center. Therefore SBAS GEO satellite visibility problem could be solved cost effectively by SBAS integration. Furthermore also DGNSS coverage problem can be solved by creating just a transmitter instead of creating a reference station. Another advantage of SBAS integration is that it takes shorter time to initiate the positioning process. In order to initiate the positioning process, SBAS users have to wait until all required messages are broadcasted. It takes fairly long time because SBAS messages are broadcasted by its own schedule because data is transferred in row data rate, 250 bps. Therefore several message such as PRN mask assignments (message type 1), ionospheric grid point masks (message type 18), and long term satellite error corrections (message type 25) are broadcasted in long interval. And

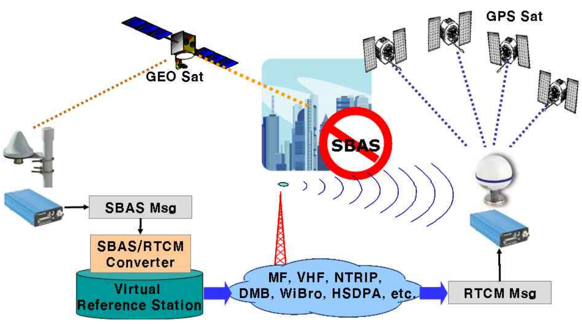

Fig. 2. Concept of SBAS integration

ionosperic delay correction (message type 26) can be transmitted only information of 15 grid points at a time. So it could take a long time to get the grid point information which user needs. In SBAS integration method, corrections are broadcasted as PseudoRange Correction (PRC), therefore user can calculate the position immediately with this information. By SBAS integration, also old DGPS receiver user can access to the SBAS service without update of firmware. It is another advantage of SBAS integration.

Multiple SBAS Combination

As mentioned above, in many regions two or more SBAS GEO satellite will be visible in near future. In this regard, we can use multiple SBAS corrections when conducting a SBAS integration. This method is called multiple SBAS combination. By emerging multiple SBAS information, we can make 1 PRC. And it is expected to have a better performance compared to using only one SBAS information.

Multiple SBAS information can be combined in various levels. It can be combined raw data level, position level, and correction level. In raw data level, service provider generates the combined PRC using raw data from each SBAS reference stations [3]. It is expected to make the best performance. However it needs much information. Therefore it needs very high data rate. Moreover it may causes security and responsibility problems. In position level, user calculates the position using each SBAS information independently, and combines each position using weighted sum scheme. It is the easiest way to combine multiple SBAS information. However it makes the user calculate the position several times and combine it. And service provider must transmit multiple SBAS information in VRS. Thus it is not appropriate to both user and service provider. Therefore in this paper, this method is conducted just for verify the feasibility of improving a performance using multiple SBAS combination. In correction level, it can be combined in SBAS message level, and PRC level. In SBAS message level, service provider combines the each raw SBAS messages like Ionospheric Grid Point Vertical Delay Errors (IGP VDE), satellite position and clock errors, and so on, and transmit combined SBAS message to the user. However different correction generation algorithm can cause a problem. Thus more research about this problem should be performed before. In PRC level, service provider converts each SBAS messages to multiple PRCs, and combines the each PRCs. This method is easy to implement and appropriate to SBAS integration. This method also has some problems. The first problem is different reference station Inter Frequency Bias (IFB) and different system reference time. It causes a bias between each corrections and it must be eliminated. The other problem is different variance levels of each correction. However these problems can be solved simply. So we are suggesting this algorithm.

Brief view of two SBAS systems used in experiment

To verify the feasibility of the SBAS integration using multiple SBAS combination, we have experimented using two SBAS. One is Korean WADGPS Test Bed which is called KWTB, the other is Japanese SBAS, MTSAT Satellite based Augmentation System (MSAS). Ministry of Land, Transport and Maritime Affairs (MLTMA) in Korea decided to develop the KWTB in 2002. The objectives of KWTB are to develop the related essential technology, to evaluate the expected performance, and to examine the feasibility of the Korean SBAS. The WADGPS research group in Seoul National University GNSS Lab. has developed Korean WADGPS test bed for three years under the contract with the MLTMA and development of KWTB phase-1 has been completed. MSAS has launched at Feb. 2005, and two MSAS GEO satellites (PRN 129, 137) are providing a SBAS service. Bothe two satellite signals can be received even though it is not officially certified for Korean users.

In Fig. 3, small red circles indicate the KWTB reference stations and small blue circles indicate the MSAS reference stations. Dark red circle and dark blue circles are master stations of each systems. And red star in the middle of Korea and Japan is Korean territory Dokdo which has been used as a VRS for our experiment. KWTB is a test bed, so it has only four reference stations and its network size is very small. If K-SBAS project begins on, it can overcome this limitation.

Fig. 3. Reference stations and master stations of KWTB and MSAS

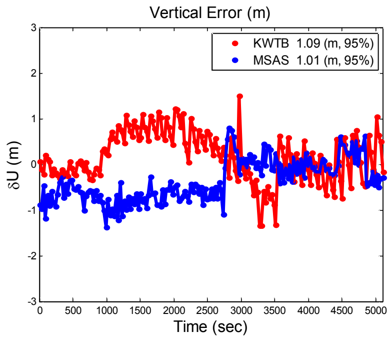

Fig. 4. Vertical position errors using independent SBAS information

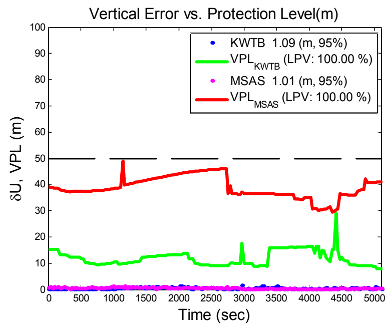

Fig. 5. Vertical protection level using independent SBAS information

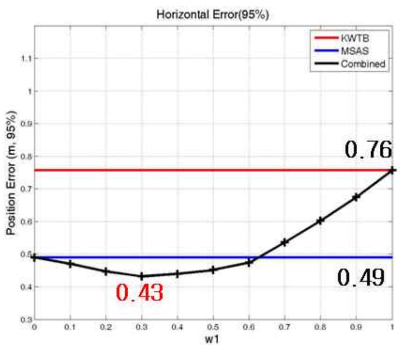

Fig. 6. Horizontal position error when combined in position level

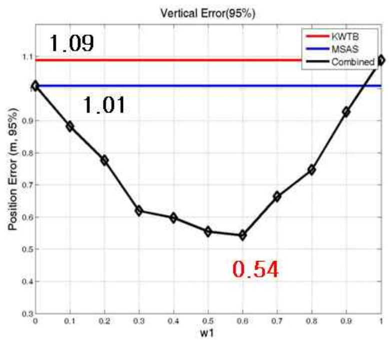

Fig. 7. Vertical position error when combined in position level

Fig. 4 and 5 show vertical position errors (VPE) and vertical protection levels (VPL) of each system. When calculating VPE and VPL using independent SBAS, MSAS has a better positioning performance and KWTB has a better availability performance in this case. As Fig. 4 shows each position errors have a opposite aspect. Therefore we can expect the synergy when two SBAS information are combined.

In Fig. 6 and 7, red line is KWTB position error, blue line is MSAS position error, and black line is combined position error when weight of KWTB position is varied form 0 to 1. Combined position is simply calculated by weighted summing of each position using each SBAS independently.

$$Pos_{combined} = w_{KWTB} \cdot Pos_{KWTB} + w_{MSAS} \cdot Pos_{MSAS} \quad (1)$$

Horizontal position error (HPE) has decreased from 0.49 to 0.43 and vertical position error has decreased from 1.01 to 0.54. This result can verify the feasibility of improving a performance using multiple SBAS information.

Multiple SBAS combination - PRC level

Before combining the multiple SBAS information, some problems which are mentioned above should be solved.

Fig. 8 shows difference between each PRCs. Each difference has similar tendency and its value is about -1. We assumed the average of each difference is equal to bias of each system due to different reference station IFB and system reference time. By this assumption bias between each correction can be simply eliminated using Eq. (1) and (2).

$$PRC_{KWTB}{}^{j} = PRC_{KWTB}{}^{j} \quad (2)$$

$$PRC_{MSAS}{}^{j} = PRC_{MSAS}{}^{j} + \sum_{j=1}^{n_{sat}} \Delta PRC^{j} \Big/ n_{sat} \quad (3)$$

where j is satellite index, n_{sat} is number of common visible satellites.

Fig. 9 shows PRC's variance of each system. Variance level is quite different, so does its aspect changing with elevation angle. It is because of different correction generation algorithm of each system. Therefore it cannot be combined directly. Variance levels have to be normalized, and we should use relative value of it. As Eq. (3), by dividing each variance by its average, it can be normalized easily.

$$\left(\bar{\sigma}_i^{\,j}\right)^2 = \frac{\left(\sigma_i^{\,j}\right)^2}{\sum_{j=1}^{n_{SBAS}} \left(\sigma_i^{\,j}\right)^2 \Big/ n} \quad (4)$$

$$\gamma_i^{\,j} = \frac{1}{\left(\bar{\sigma}_i^{\,j}\right)^2} \quad (5)$$

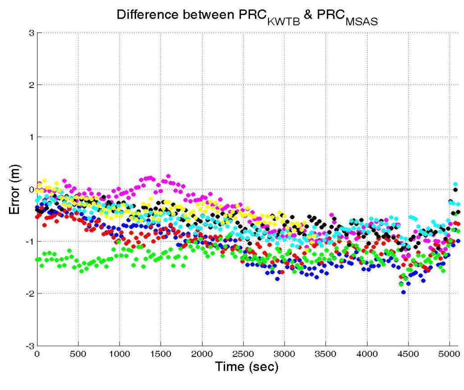

Fig. 8. Differences between PRCs of KWTB and MSAS

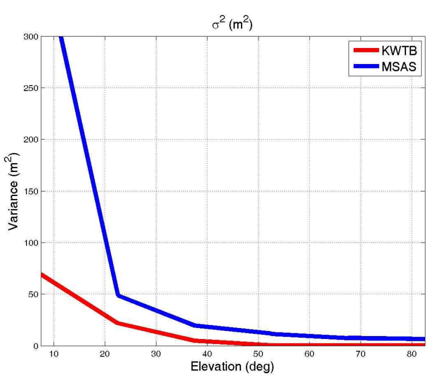

Fig. 9. Differences between PRC's variances of KWTB and MSAS

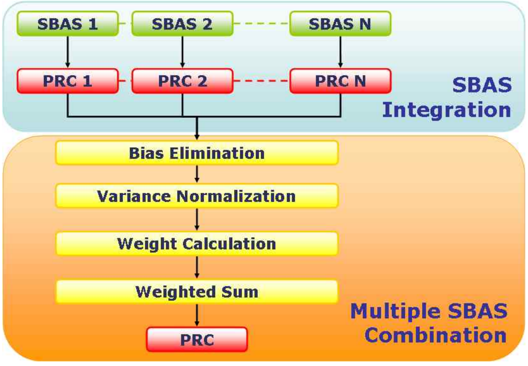

Fig. 10. Multiple SBAS integration flow

where $\bar{\sigma}_i^j$ is the j-th satellite PRC's normalized variance of the i-th SBAS, n_{SBAS} is number of SBAS, and γ is a weight. In this paper, i = 1 means KWTB, 2 means MSAS, and n_{SBAS} = 2. These normalized variances can be combined and the weight of each satellite is inverse number of its normalized variance as shown in Eq. (4). The weights are used when calculating weighted least square position. And additional SBAS weight is considered. As in Eq. (5), we can get combined PRC by weighted summing of PRCs of each system.

$$PRC_{comb}{}^{j} = \frac{\sum_{i=1}^{n_{SBAS}} w_i PRC_i{}^{j}}{\sum_{i=1}^{n_{SBAS}} w_i} \tag{6}$$

where w_i means additional weight for the i-th SBAS. The whole process of SBAS integration using multiple SBAS combination is shown in Fig.10.

By this method we can get one PRC from multiple SBAS information.

Experiment Setup and Results

In order to verify proposed algorithm, we performed the experiment by post processing. The logged SBAS corrections from the two systems and the RINEX (Receiver INdependent EXchange format) data logged at Dokdo monitoring station in Korea have been used for this experiment. Because the Dokdo station is in the midst of the coverage of the two systems, it is the optimal location for the test user. Table 1 summarize the experiment setup.

Table 1. Experiment Setup

Date	238th day,2008
VRS Site	Dokdo, Korea
Experiment Time	5100 seconds
Experiment Type	Post process
Data Format	RINEX

Experimental Results

At first, position was calculated without additional SBAS weights. That is, PRCs of each SBAS are combined with ratio of 1:1. Fig. 11 is a horizontal position error and Fig. 12 is a vertical position error of each case. As expected both horizontal and vertical position errors have been decreased. Horizontal position error has been decreased about 16% and vertical position error has been decreased about 28%.

When additional SBAS weight is applied, the results are similar. Fig. 13 and 14 are combined position errors with respect to the weight of KWTB. The weight of KWTB has been changed from 0 to 1 in scale of 0.1.

When more weight is applied to KWTB, vertical positioning performance is more improved. In opposite case, vertical positioning performance is more improved.

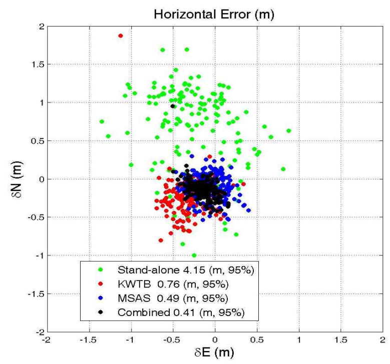

Fig. 11. Horizontal position error without SBAS weight

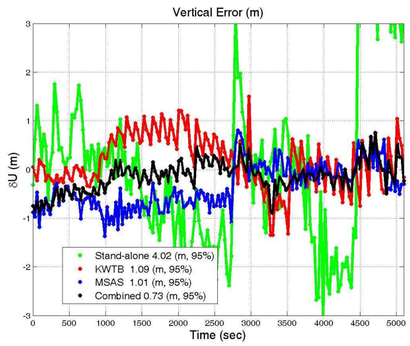

Fig. 12. Vertical position error of without SBAS weight

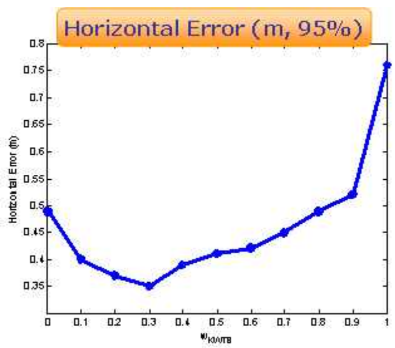

Fig. 13. Combined horizontal position errors with respect to the weight of KWTB

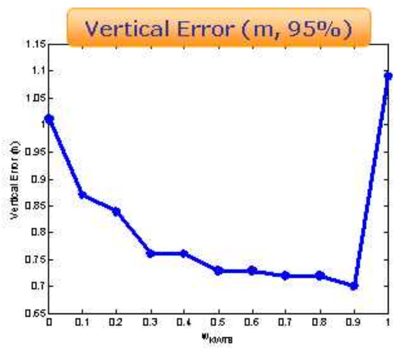

Fig. 14. Combined vertical position errors with respect to the weight of KWTB

Table 2. HPE, VPE and 3D position error of each case

$W_{KWTB}:W_{MSAS}$	HPE (m, 95%)	VPE (m, 95%)	3D Error (m, 95%)
KWTB only	0.76	1.09	1.33
MSAS only	0.49	1.01	1.12
1:9	0.40	0.87	0.95
3:7	0.35	0.76	0.84
5:5	0.41	0.73	0.84
7:3	0.45	0.72	0.85
9:1	0.52	0.71	0.87

Table 2 summarizes this result. In 3D domain, optimal weight is widely distributed nearby 5:5. It is because Dokdo which are used as VRS in this experiment is located in the middle of two systems. For a better result, weight can be set adaptively by consideration of system network size or distance between positioning site and the center of the network. And more experiment with various VRS positions and corresponding SBAS weight is required.

Conclusions

Nowadays the number of SBAS is increasing and its coverage is being extended. To step with these changes, we proposed the enhanced SBAS integration method using multiple SBAS combination as the one of the options of DGNSS re-engineering. After combining two SBAS information in PRC level, horizontal position error has been decreased about 16% and vertical position error has been decreased about 28%. This work verified the feasibility of improvement of performance using SBAS integration with multiple SBAS combination concept. It is required to conduct more research about combining SBAS information in row level such as raw SBAS message level or reference station raw data level. And also more research about optimal SBAS weight determination method is required.

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