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Performance Analysis of WADGPS System for Improving Positioning Accuracy

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ABSTRACT

The Wide Area Differential Global Positioning System (WADGPS) that uses a number of Global Navigation Satellite System (GNSS) reference stations are implemented with various types and provide services as it can service a wide range of areas relatively. This paper discusses a constellation design of reference stations and performance analysis of the WADGPS. It presented performance results of static and dynamic users when wide area correction algorithm was applied using eight reference stations.

Keywords: GNSS, WADGPS, DGPS, SBAS

1. INTRODUCTION

The Wide Area Differential Global Positioning System (WADGPS) is a differential global positioning system (DGPS) that services a relatively large range of user areas using a number of Global Navigation Satellite System (GNSS) observation reference stations. Existing DGPS created GPS error observed by the reference station into a scalar type of correction information thereby having a limitation of degradation of correction performance as a user is farther away from the reference station. In contrast, the WADGPS applies a vector type of satellite-related error correction information and ionosphere grid model from a number of reference stations thereby enabling a service of a uniform performance over a more wide area (Kaplan & Hegarty 2006).

The WADGPS was proposed in 1990s (Kee 1994) and many institutions have studied and implemented the WADGPS in Korea and other nations (Yun et al. 2011) In 2000s, a Satellite Based Augmentation System (SBAS) including integrity information for aviation users has been implemented and serviced as shown in the Wide Area Augmentation System in the U.S. and European Geostationary Navigation Overlay Service in Europe. In South Korea, Korean SBAS implementation project has been under way under the sponsorship of the Ministry of Land, Infrastructure, and Transport.

Along with them, there is a project called Exploitation of DGPS for Guidance Enhancement (EDGE) in the U.S. (Carlo 2015). The EDGE is a WADGPS using reference stations that have a long baseline. It employed four DGPS reference stations and has been known to achieve the performance goal (3 m) of correction accuracy of user receivers. Other than above examples, there are other technical study examples such as Wide Area GPS Enhancement and Talon NAMATH that are broadcasted at the GPS P (Y) code.

This paper discussed the performance analysis results about WADGPS for the purpose of improvements on GPS positioning accuracy. The target system consists of eight reference stations and one master station. Real-time user correction performance was verified.

This paper is organized as follows. In Section 2, configuration of the implemented system is discussed. In Section 3, performance results of post-processing of collected data are presented in order to verify the performance of GPS observation data at the implemented reference station. In Section 4, correction performance of

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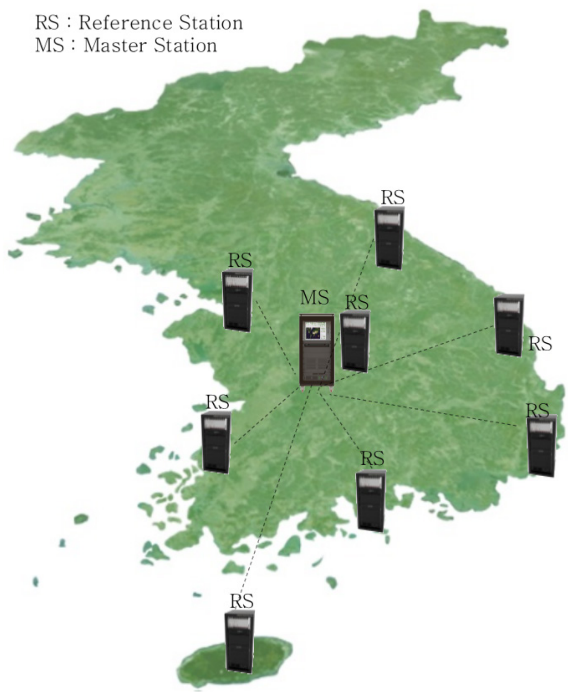

Fig. 1. System architecture of ADD WADGPS testbed.

users in real time using commercial Long Term Evolution (LTE) communication network was verified through static and dynamic experiment results.

2. CONSTRUCTION OF WADGPS TESTBED

2.1 System Architecture

Fig. 1 shows the configuration of reference stations and master station in the WADGPS. The eight reference stations were used and the algorithm of the master station was operated in which observation data from the reference stations were received at Daejeon and correction values were created. Each reference station transmits observation data to the master station in Daejeon using TCP/IP communication. In addition, correction information created at the master station is transmitted to each of the observation reference stations so that WADGPS correction performance can be verified by the reference station independently.

The correction algorithm in the master station was based on the WADGPS post-processing software developed by the satellite navigation research center in Seoul National University (Kee 2014). The developed system can be run in real time and monitoring on operating status and performance visualization function were implemented. The software used in the master station at the current stage was aimed at error correction as a major objective while it did not provide integrity-related functions at the same level provided by the SBAS. For error correction, ionospheric grid model to solve ionospheric delay error and satellite related errors and a method that creates vector satellite error information were used (Chao 1997, Tsai 1999). Transfer message of correction information and scheduling complied with the RTCA DO-229 document that defined the SBAS specification (RTCA 2001).

Table 1. Candidate locations.

No.	Location	No.	Location
1	Daejeon	7	Kimhae
2	Gyeonggi1	8	Gyeongbuk
3	Gyeonggi2	9	Ulleung
4	Gyeonggi3	10	Gangwon1
5	Jeonnam	11	Gangwon2
6	Jeju		

Table 2. Candidate constellation cases.

Case identifier	Number of reference stations	Used locations
1	6	1,4,5,7,10,11
2	6	1,3,5,7,10,11
3	6	1,2,5,7,10,11
4	7	1,4,5,7,8,10,11
5	7	1,4,5,7,9,10,11
6	7	1,4,5,6,7,10,11
7	8	1,4,5,6,7,8,10,11
8	8	1,3,5,6,7,8,10,11
9	8	1,2,5,6,7,8,10,11
10	8	1,4,5,6,7,9,10,11
11	8	1,3,5,6,7,8,10,11
12	8	1,2,5,6,7,9,10,11

2.2 Constellation of Reference Stations

The constellation design of the reference station was conducted using Polaris software, which is a simulation program in the SBAS service region and developed by GMV (GMV 2007, 2014). A candidate list of constellation consisting of 12 cases was selected by combining cases consisting six, seven, and eight reference stations out of 11 candidate places where reference stations can be installed. The 12 cases were applied to the Polaris program and a case that produced the best accuracy performance in the serviceable region was selected.

Table 1 summarizes 11 candidate locations. A number of candidate locations were considered even in the same region in order to verify performance according to the inclusion of island areas. Table 2 summarizes 12 candidate constellation cases selected from 11 candidate locations. The number of used reference stations was in a range of six to eight stations. For the same number of reference stations, a variety of cases were combined according to whether island areas were included or not. The Polaris software simulation was conducted with 12 combinations in Table 2

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and accuracy performance at 3600 user grid points around the Korean Peninsula was compared between the cases as shown in Fig. 2.

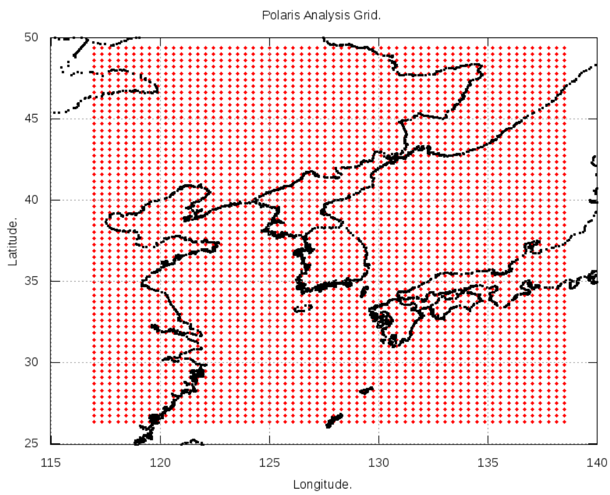

Fig. 2. Grid points of possible ground user for case study.

Fig. 3 shows the result of six reference stations applied and Fig. 4 shows the result of eight reference stations applied including island areas such as Ulleung and Jeju Islands. The left sides of the figs show horizontal position accuracy performance distribution. The right side bar graphs represent a distribution of expected horizontal positioning accuracy for each accuracy interval in percentage. The first columns in the right bar graphs in Figs. 3 and 4 represent a 1m to 1.5m level of horizontal positioning accuracy. The first column of Fig. 3 indicated 37% while that of Fig. 4 indicated 45%, verifying that case #12 had better performance than case #1. This result shows that as reference stations are laid out in a wider distribution uniformly, better accuracy performance can be expected in a wider user region as already known in this field. The simulation result verified that a constellation consisting of eight reference stations in a wider area as much as possible including island areas had the best result but the final selection was a constellation of reference stations consisting of seven inland stations and one station in Jeju Island thereby installing reference

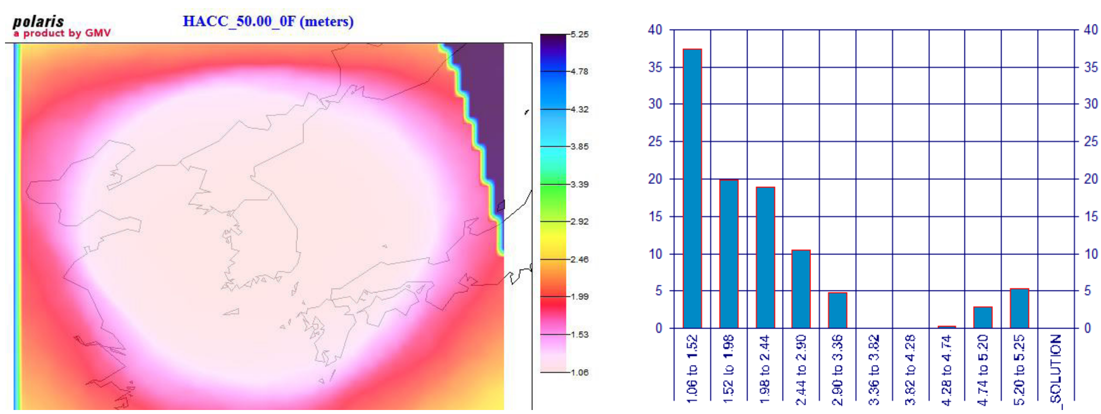

Fig. 3. Simulation result of case #1 (left: horizontal positioning accuracy in CEP, right: distribution of expected horizontal positioning accuracy for each accuracy interval in percentage).

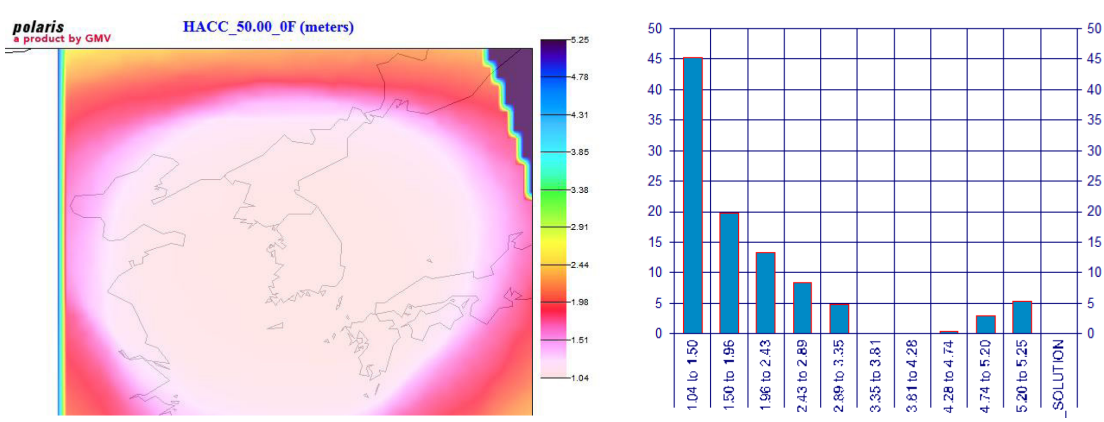

Fig. 4. Simulation result of case #1 (left: horizontal positioning accuracy in CEP, right: distribution of expected horizontal positioning accuracy for each accuracy interval in percentage).

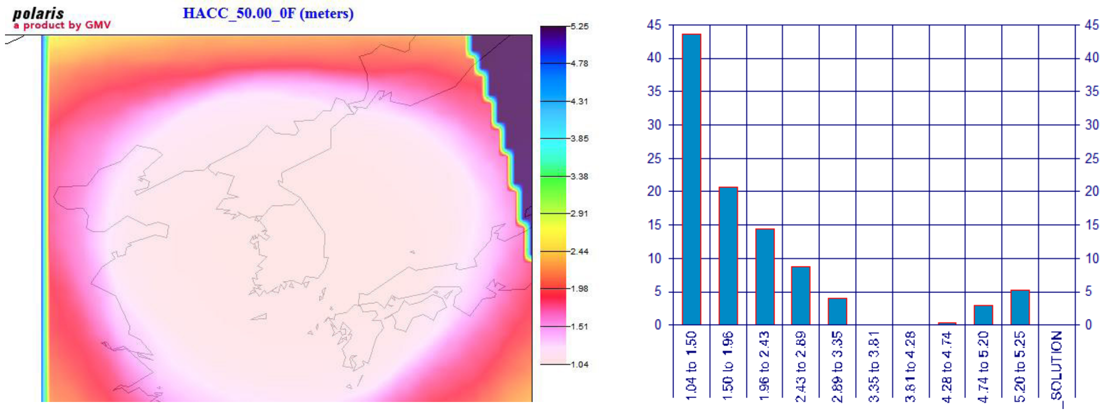

Fig. 5. Simulation result of case #7 (left: horizontal positioning accuracy in CEP, right: distribution of expected horizontal positioning accuracy for each accuracy interval in percentage).

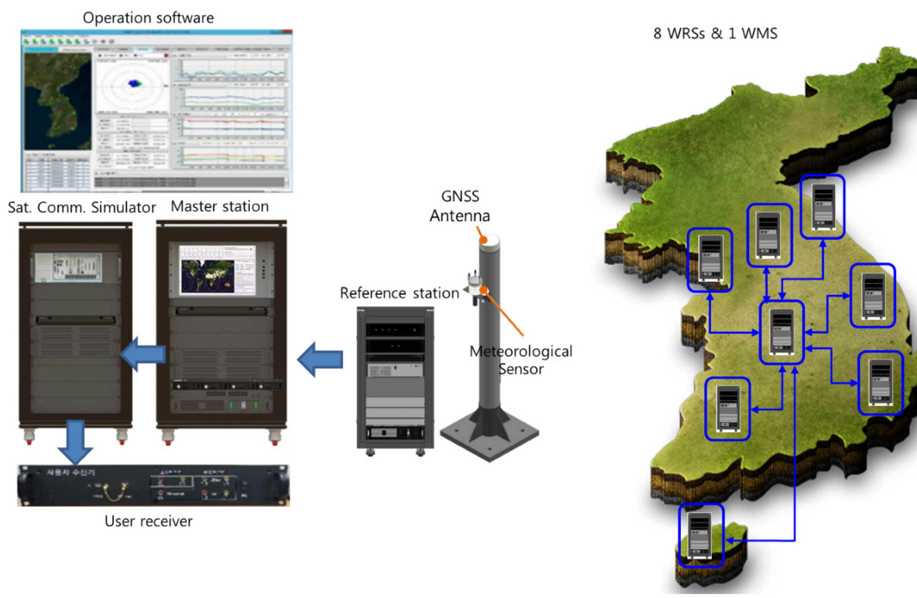

Fig. 6. Conceptual view of real-time operation.

stations. Fig. 5 shows the Polaris simulation result about case #7 constellation candidate.

2.3 Real-time Operation

Fig. 6 shows a conceptual view of real-time WADGPS operation. The reference station transmits observation data at 1 Hz frequency to the master station. The master station is operated in real time and creates correction information and basic integrity information thereby configuring a message. A message is sent to the satellite communication simulation device according to its own transmission protocol. The satellite communication simulation device performs broadcasting of WADGPS correction information into the L1 band. A message created in every sec is coded with reserved GPS PRN C/A code and modulated with L1 frequency. Since additional correction information transmission medium such as geostationary orbit satellite or pseudolite is not considered in this study, radio frequency (RF) signals are created using simulation devices and performance was verified while connecting the signal with user receivers via cable. Additionally, a commercial communication network was used to transfer correction messages in order to verify user performance, which is located remotely.

3. PRELIMINARY PERFORMANCE ANALYSIS

To verify performance of data collected at the installed reference stations, the data were processed using the WADGPS post-processing software. The collected data on July 19, 2015

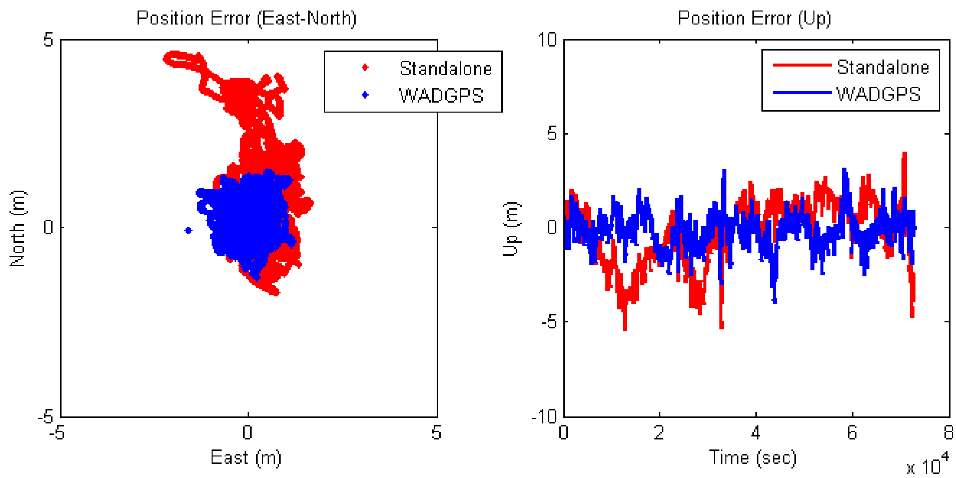

Fig. 7. Comparison of position error between standalone and WADGPS in Daejeon (left: horizontal position error, right: vertical position error).

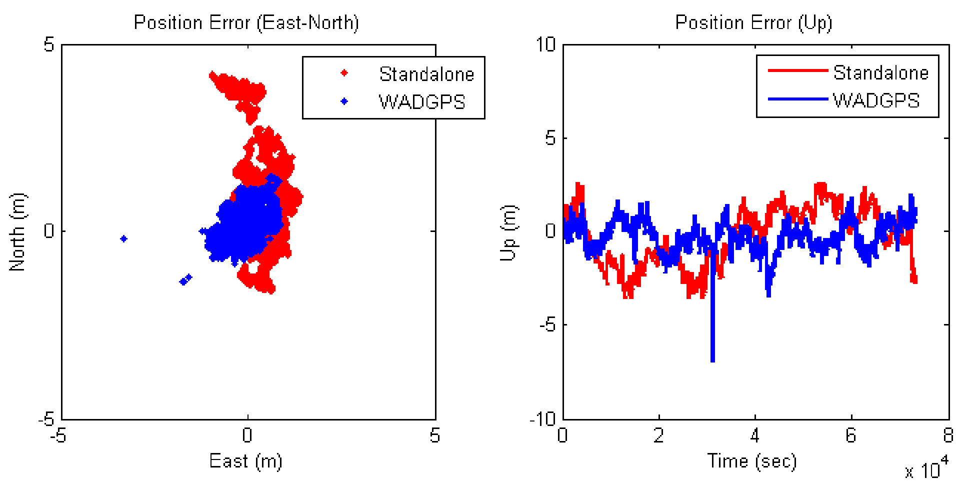

Fig. 8. Comparison of position error between standalone and WADGPS in Jeju (left: horizontal position error, right: vertical position error).

were employed and correction values were created using data from seven reference stations out of eight stations in total and correction accuracy performance was verified using data from Daejeon and Jeju reference stations as a user.

Figs. 7 and 8 compare horizontal and vertical positioning accuracy before and after WADGPS correction information was applied at Daejeon and Jeju. Table 3 summarizes statistical values of accuracy about horizontal and vertical navigation solution. When comparing positioning performance for 20 hours, both of Daejeon and Jeju

Table 3. Post-processing test results of standalone and WADGPS positioning using the reference stations as a user.

	Horizontal position accuracy (95%, m)		Vertical position accuracy (95%, m)	
	Standalone	WADGPS	Standalone	WADGPS
Daejeon	3.43	1.12	3.70	1.90
Jeju	3.81	0.99	2.90	1.66

showed a level of 95% 1 m horizontal positioning accuracy. Considering that a standalone navigation using the Klobuchar model during ionospheric correction is a level of 3 m accuracy, it verified that observation data collection at the reference station was achieved normally.

4. FIELD TEST RESULTS

4.1 Test Set-up

A real-time correction test was conducted with outdoor users using the implemented WADGPS system. Correction messages created at the master station were transmitted via LTE commercial communication network. A message was received by user receiver to which LTE modem was mounted. The correction information was inputted through additional interface. For the experiment, six reference

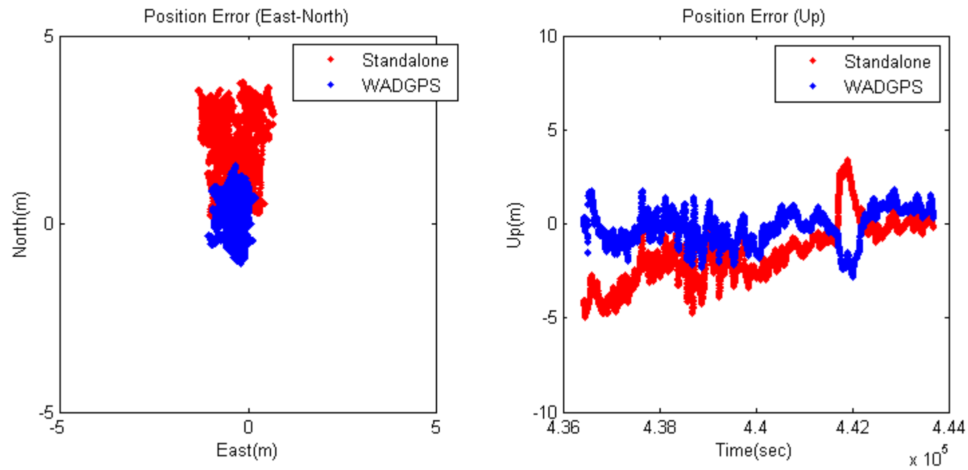

Fig. 9. Real-time positioning accuracy of static user (left: horizontal position error, right: vertical position error).

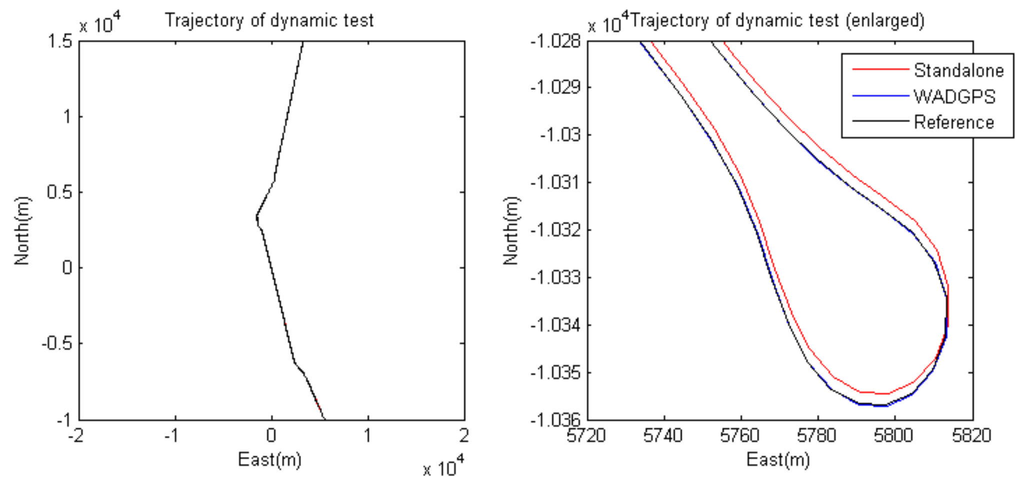

Fig. 10. Full trajectory of dynamic test (left) and the enlarged portion of it (right).

stations were used and static and dynamic tests were conducted. For a reference location for accuracy analysis, post-processing DGPS results of Novatel OEMV GPS receiver were used.

4.2 Test Results

Both of static and dynamic tests were conducted on October 2015. Fig. 9 shows the real-time static positioning results conducted for about two hours from 10 am to 12 pm. It verified the similar accuracy performance with post-processing results in Figs. 7 and 8 with a level of 1.11 m (95%) and 1.88 m (95%) after horizontal and vertical correction.

Fig. 10 shows a trajectory of vehicle test to verify the dynamic positioning performance. The dynamic experiment was conducted for one hour approximately from 3 pm to 4 pm. For true values, DGPS post-processing results of Novatel receiver attached to the same antenna were used. The right side in Fig. 10 is an enlarged trajectory at the location where a vehicle was rotated. The standalone navigation result verified a deviated result from Novatel true value but the WADGPS correction result showed relatively good performance. Fig. 11 shows the user positioning error results calculated based on Novatel true value location at every data acquisition time. The positioning performance showed that horizontal accuracy performance was more degraded than the static experiment result with a level of 1.93 m (95%) and 1.99 m (95%) with regard to horizontal and vertical directions. The reason for this is due to the measurement error of pseudorange caused by visibility block at some sections and multipath due to the geographic features in the driving section. This rationale is based on the experiment result that the standalone navigation horizontal accuracy was 3.43 m (95%) in the static experiment whereas it was increased to 5.45 (95%) in the dynamic experiment. In addition, constellation of satellites according to the

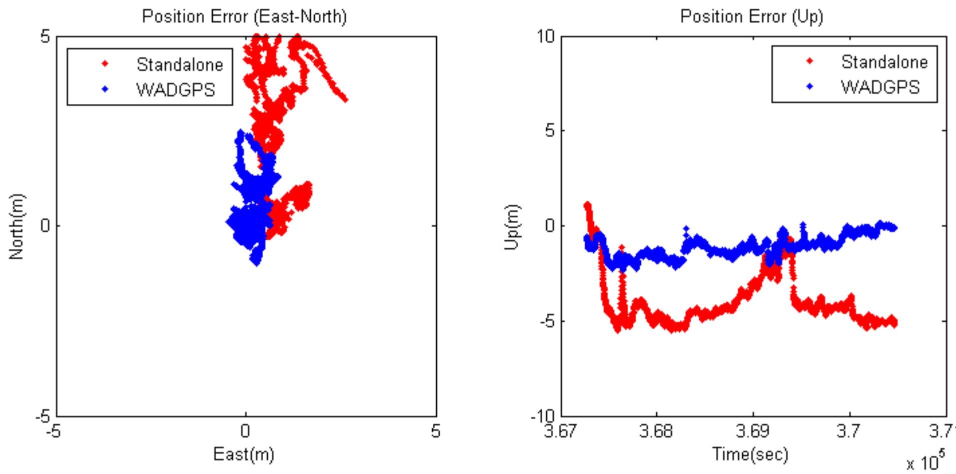

Fig. 11. Real-time positioning accuracy of dynamic user (left: horizontal position error, right: vertical position error).

Table 4. Field test results.

	Horizontal position accuracy (95%, m)		Vertical position accuracy (95%, m)	
	Standalone	WADGPS	Standalone	WADGPS
Static	3.40	1.11	4.13	1.88
Dynamic	5.45	1.93	5.28	1.99

experiment execution time can also affect the result. Table 4 summarizes the above experiment results.

5. CONCLUSIONS

In this paper, configuration of observation reference stations and master station and initial experiment results were presented to verify accuracy correction performance of the WADGPS. The wide area correction algorithm was implemented using eight reference stations and one master station. For the initial performance verification, static and dynamic experiments were conducted. The experiment result showed that the static experiment had a horizontal accuracy performance with a level of 1 m (95%). In the dynamic experiment using a vehicle, performance degradation occurred compared to that of static experiment. The reason for this was due to the measured value error at the user receiver caused by multipath and visibility limitation. In summary, the implementation and performance of the algorithm of early stage were verified. For the future study, user operation characteristics will be considered and additional performance analysis on created correction information will be conducted.

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