Simulation Analysis for Performance Improvements of GNSS-based Positioning in a Road Environment

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***Abstract*— Global Navigation Satellite Systems (GNSSs), such as the Global Positioning System (GPS) in the USA, the GLObal NAvigation Satellite System (GLONASS) in Russia, and the Galileo in the EU, determine a target position using a satellite signal. They are widely used around the globe at this time. However, there is a critical obstacle when attempting to run a navigation system in a land vehicle. In contrast to aircraft or vessels, which operate in open areas without any obstacles, land vehicles must deal with signal occlusion caused by surrounding buildings, skyscrapers and other objects, especially in urban areas. In order to solve this problem, many researchers have studied many different methods, such as GPS/GLONASS-integrated positioning; pseudolite, which produces a signal similar to that of GPS; and GPS/Vision integrated positioning. These studies have mainly focused on integrated positioning methods. In contrast, this paper focuses on the relationship between the position of a new signal generator and positioning error for high-accuracy positioning in GPS shaded areas using simulation analysis. Through this analysis, we confirmed that horizontal positioning error is the lowest (10m) in the urban canyon when the degrees of geometric stability is the best.**

Keywords- GNSS; Vision; Pseudolite; Simulation.

I. INTRODUCTION

Global Navigation Satellite Systems (GNSSs), such as the Global Positioning System (GPS) in the USA, the GLObal NAvigation Satellite System (GLONASS) in Russia, and the Galileo in the EU, determine a target position using a satellite signal. At present, they are widely used around the globe. Since Selective Availability (SA) was released, the use of such systems has become prevalent in applications ranging from navigation systems for transportation to mobile smart phones. However, there is a critical obstacle when running the navigation system in land vehicles. In contrast to aircraft or vessels, which operate in open areas without any obstacles, a land vehicle must deal with signal occlusion caused by surrounding buildings, skyscrapers and other objects, especially in urban areas. Many researchers have attempted to solve this problem with various methods, such as GPS/GLONASS-integrated positioning [1], pseudolite, which produces a signal similar to that of GPS [2], and GPS/Vision integrated positioning [3]. These studies have mainly focused on integrated positioning methods with a new signal. In contrast, we focus on the relationship between the position of a new signal generator and positioning error for high-accuracy positioning in GPS shaded areas.

For this analysis, we developed a simulator using MATLAB, the configuration of which is described in section 2. The developed simulator generates GPS observation data with a variety of errors, such as ionospheric delays, tropospheric delays and clock errors. Moreover, the simulator filters some signals which are occluded by obstacles such as tall buildings.

Using this simulator, GPS positioning errors were analyzed in diverse road environments, such as housing areas and urban canyons. These results are described in section 3.

The simulator is also able to generate a new signal virtually and then perform integrated positioning using GPS and the new signal data. In section 4, the integrated positioning errors were analyzed according to the new signal generator's position.

Through this simulation analysis, we found that the accuracy of new signals and their degrees of geometric stability should be considered for highly accurate positioning.

This paper starts with the simulator description in section 2, then GPS positioning errors are analyzed in section 3. In section 4, the integrated positioning errors were analyzed. The conclusion of this paper is described in section 5.

II. SIMULATOR

We developed a simulator to perform an error analysis of GPS positioning and integrated positioning with a new signal to enhance the degree of positioning stability.

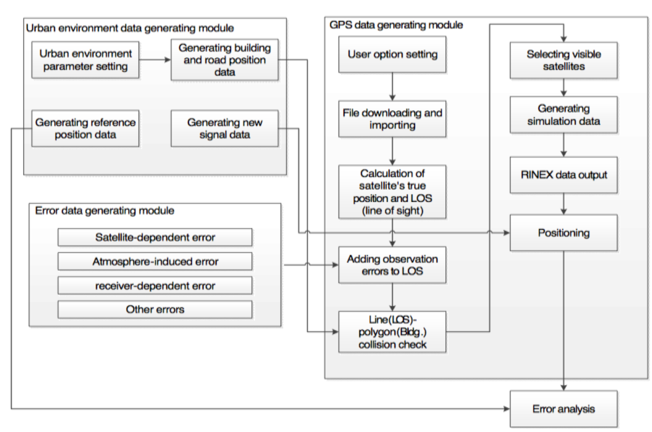

Figure 1. Configuration of the simulator

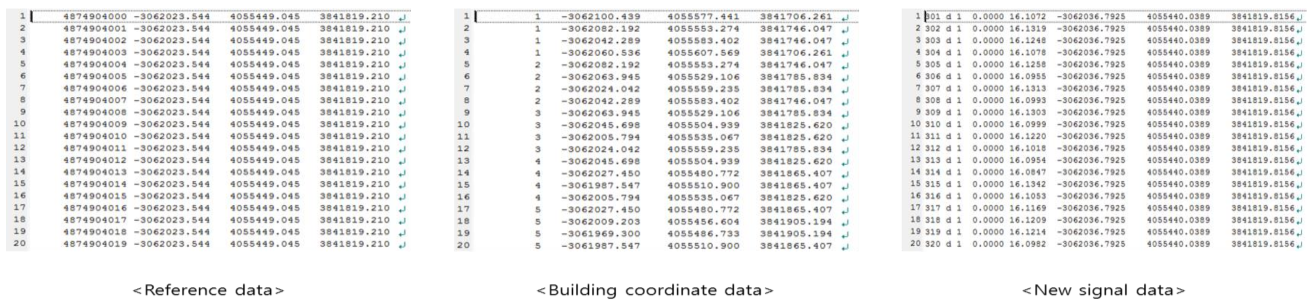

Figure 2. Output data example from the urban environment data-generating module

The configuration of the simulator consists of three modules [4]: the urban environment data-generating module, the GPS data-generating module, and the error data-generating module. Figure 1 shows the configuration of the simulator.

The urban environment data-generating module produces building coordinate data based on a reference position, the GPS data-generating module makes the observation data similar to actual GPS observation data, and the error data-generating module calculates observation errors based on models.

A. *Simulator configuration*

The input parameters – the observation time, receiver's reference position coordinates, the road width, the building height and the new signal generator interval for generating simulation data – are set in the urban environment generating module. According to the parameter settings, three-dimensional coordinates of virtual buildings, the new signal generator and the receiver position data (reference data) are generated with an Earth-Centered Earth-Fixed (ECEF) coordinate. Figure 2 shows an example of the output data from the urban environment data-generating module.

The GPS data-generating module generates the Receiver Independent Exchange Format (RINEX) as a GPS observation file and performs GPS positioning and integrated positioning. This module imports the reference data and extracts the observation time and receiver's position coordinates from the data. The satellites orbit information, clock data and other parameters are downloaded from the International GNSS Service (IGS) [5] site to determine the satellite's position and generate the error data. Next, this module calculates the satellite position at every epoch using this data. The Line-Of-Sight (LOS) is calculated based on the satellite and receiver position, and visible satellites are filtered at the receiver's position. Some errors are added to this LOS using the error data-generating module, and the final observation data are generated in the RINEX format after line (LOS)-polygon (building data) collision checking [6]. Using the GPS and new signal data or only GPS data, positioning is performed in this module. Stand-alone L1 Coarse/Acquisition (C/A) code positioning and an integrated positioning algorithm (the least-squares method) were used in this study, and the results are in ECEF coordinates [3].

The error data-generating module simulates errors related to GPS observations. These errors are classified into four types: satellite-dependent errors, atmosphere-induced errors, receiver-dependent errors, and other errors. Table 1 presents the details of the error modeling step. Each error can be modeled or calculated using a model and data files from the IGS and the Center for Orbit Determination in Europe (CODE) sites.

Finally, the positioning error is analyzed compared with the reference data and a plot of a related graph. For directional analysis, the positioning results are converted to North-East-Down (NED) coordinates.

TABLE I. SIMULATED MODELING ERROR

	Error	**Error model**
Satellite-dependent error	GPS orbit	Broadcast ephemerides (IGS orbit)
	Satellite clock error	Final clock file (IGS clock file)
Atmosphere-induced error	Ionospheric delay	IGS TEC (total electron content) map
	Tropospheric delay	Saastamoinen model [7], Chao mapping function [8]
Receiver error	Receiver clock error	Two-state random process model[9]
	Differential Code Bias (DCB)	CODE (center for orbit determination in Europe) DCB file
Other error	Random error	0.3m
	Relativity affecting the earth rotation	Sagnac effect

B. *Simulator verification*

For verification of the developed GPS simulator, a GPS observation file was generated and positioning was performed using C/A code data. The detailed settings are shown in Table 2.

TABLE II. DETAILED SIMULATION SETTINGS FOR VERIFICATION

Observation time	2013. 8. 1. 01:00:00～12:59:59 (12hours, 150 sec. interval, 288 epoch)
Receiver's position	Suwon continuously operating GPS/GNSS reference stations (ECEF coordinates:-3062023.544m, 4055449.045m, 3841819.210m)
Cut-off angle	15 degree
Adjustment computation model	Gauss-Markov model
Code random error	0.3m

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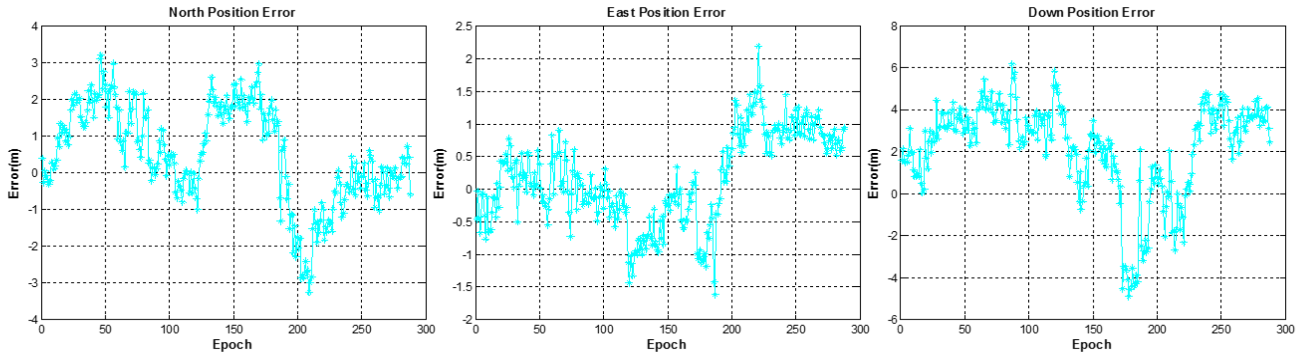

Figure 3. GPS positioning error for simulator verification

TABLE III. GPS POSITIONING ERROR FOR SIMULATOR VERIFICATION

	MAX	MIN	MEAN	STD	RMS
North(m)	3.22	-3.27	0.51	1.34	1.43
East(m)	2.19	-1.62	0.15	0.7	0.71
Down(m)	6.17	-4.9	2.17	2.23	3.12

Table 3 and Figure 3 show the error analysis by the simulator. Generally, a horizontal error in GPS positioning using C/A code data is 2-3 m and the vertical error is twice as much [10]. Through the error analysis result, the simulator is verified.

III. GPS POSITIONING ERROR ANALYSIS IN A DIVERSE ROAD ENVIRONMENT

Diverse road environments were formulated by the proposed simulator. The number of visible satellites, the number of estimated positions, the directional error, and other factors are analyzed in this section. Four types of simulation environments were set. CASE 1 assumed an open sky environment without any buildings as a reference for comparison with other scenarios. CASE 2 was set as a housing area that has two-story buildings (height 5 m) and a road width of 16 m. A commercial area was assumed in CASE 3, which has ten-story buildings (25 m) and a road width of 36 m. Finally, CASE 4 was set as an urban canyon that is surrounded by thirty-story buildings (height 75 m) and a road width of 68 m. For convenient analysis, some conditions were fixed in all cases: the road was assumed to run from south to north and the buildings were built next to the road (west and east) [4].

The above scenario's observation period was from 2013.09.01 00:00:00-11:59:59 and the time interval was 150 seconds. Since the orbital period of GPS satellites are about 12 hours, the observation time should be 12 hours for a reliable analysis. The receiver's position was identical to that of the Suwon continuously operating GPS/GNSS reference stations, which is the national reference station.

The results of the simulation analysis are as shown below.

TABLE IV. GPS POSITIONING ERROR ANALYSIS IN THE SIMULATED ENVIRONMENTS

		MAX	MIN	MEAN	STD	RMS
CASE 1	*North (m)*	3.39	-3.79	0.36	1.34	1.39
	East (m)	2.42	-0.99	0.56	0.63	0.84
	Down (m)	6.43	-9.71	1.97	2.83	3.45
	Number of estimated positions: 288 / 288					
CASE 2		**MAX**	**MIN**	**MEAN**	**STD**	**RMS**
	North (m)	8.89	-4.24	0.42	1.72	1.77
	East (m)	3.88	-1.12	0.68	0.91	1.13
	Down (m)	13.16	-36.71	1.19	6.28	6.39
	Number of estimated positions: 287 / 288					
CASE 3		**MAX**	**MIN**	**MEAN**	**STD**	**RMS**
	North (m)	10.83	-25.21	-1.31	6.74	6.87
	East (m)	27.67	-30.27	-0.87	9.87	9.9
	Down (m)	15.21	-62.66	-4.93	15.79	16.55
	Number of estimated positions: 159/ 288					
CASE 4		**MAX**	**MIN**	**MEAN**	**STD**	**RMS**
	North (m)	1328.4	-59.28	14.25	180.57	181.14
	East (m)	46.74	-1487	-20.6	201.22	202.29
	Down (m)	2314.6	-55.13	63.92	310.67	317.29
	Number of estimated positions: 56/ 288					

In CASE 2 (the housing area), the positioning error did not increase compared to CASE 1 (open sky). However, CASE 3 (the commercial area) and CASE 4 (the urban canyon) had greater positioning errors than CASE 1. In particular, the positioning of CASE 4 was virtually impossible with the number of estimated positions at 56 during the observation time

Figure 4 shows sky plots of all scenarios. The sky plots express the satellite's azimuth angle and elevation angle based on the receiver's position. The buildings that occlude the signals are illustrated in blue masking. The visible satellites of CASE 2 are similar to those of CASE 1. Satellites are visible above 60-degree elevation angles in the worst environment, which is CASE 4.

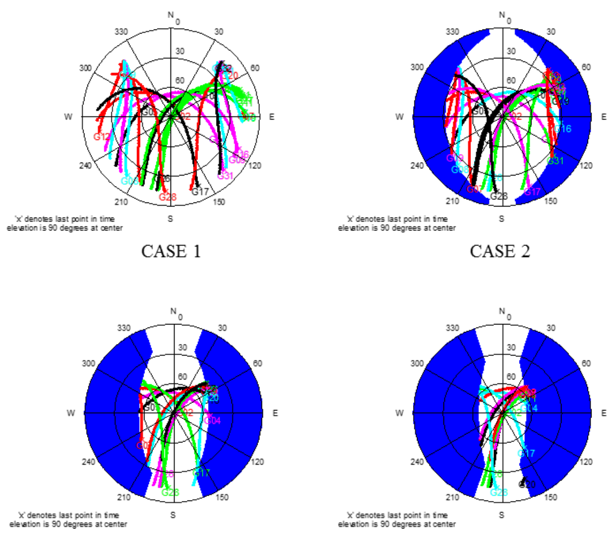

Figure 4. Sky plots for all of the scenarios

Figure 5 shows the number of satellites in the four cases.

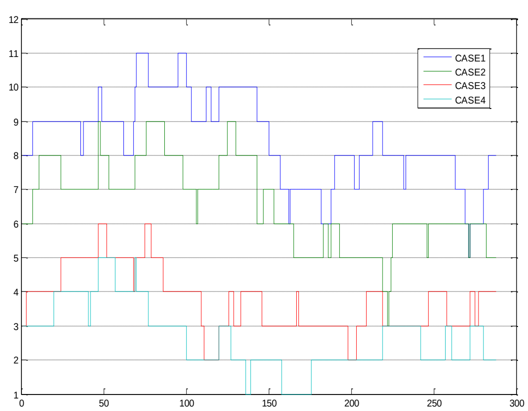

Figure 5. Number of visible satellites in each environment

The number of satellites ranges from 0 to 5 in CASE 4, indicating that the CASE 4 environment is the worst. Although the number of satellites occasionally exceeds four, it is less than four during most observation periods. Therefore, the position coordinate cannot be calculated and GPS positioning is useless in the urban canyon environment. Hence, new signals that offset GPS for stable positioning should be installed.

IV. INTEGRATED POSITIONING ERROR ANALYSIS IN A DIVERSE ROAD ENVIRONMENT

Using the results from section 3, we discuss integrated positioning in this section. Unlike other studies, this study focused on the relationship between the signal generator's position and the signal's error instead of the integrated positioning algorithm. Pseudolite positioning and vision-integrated positioning both use distance data from the generator (landmark) to the receiver (camera) as observation values when using the least-square model. Therefore, the generator's placement or the landmark's placement has the same effect on the integrated positioning error. Hence, a new signal is used as a representative term.

Because CASE 4 is the worst environment, we assumed a situation in which the signal generator is installed in that environment. Under this assumption, an integrated positioning error analysis depending on the generator position was performed.

The position of the new signal generator was assumed to be on the building's roof with a height of 75 m, and it was installed from 10 m to 200 m at 10 m intervals. Because the minimum number of satellites is zero, four new signal generators needed to be installed for stable positioning. The position was set on both sides of the receiver. The signal had a 10% systemic error according to its distance, and random error of 0.3 m.

Because the total number of observation signals was always four in this case, the possibility of integrated positioning was 100% (288/288 epoch). Its directional error according to the generator's installation interval is shown in Figure 6.

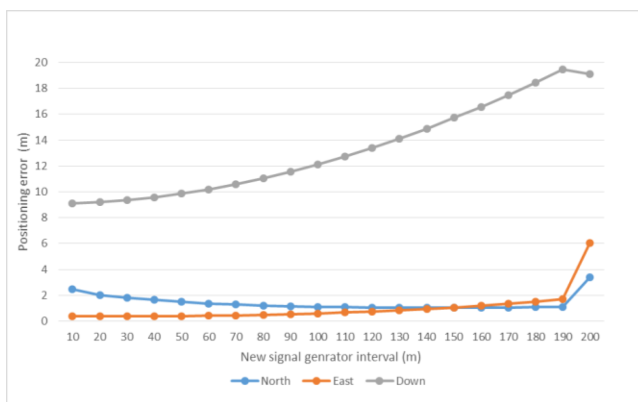

Figure 6. Directional error of the integrated positioning

The horizontal error was worse at the 10 m interval than the others, though the signal error was lowest. A 100 m interval resulted in the best performance in the simulation. This was caused by geometric stability; but the positioning error started increasing at the 200 m interval on account of the increase in the new signal error. This analysis is confirmed by Figure 7. Figure 7 shows a sky plot, with the generator positions of the new signals illustrated as white

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dots. This figure confirms that the geometrical placement of the interval at 10 m is very unstable. When the interval increases, the geometrical stability improves.

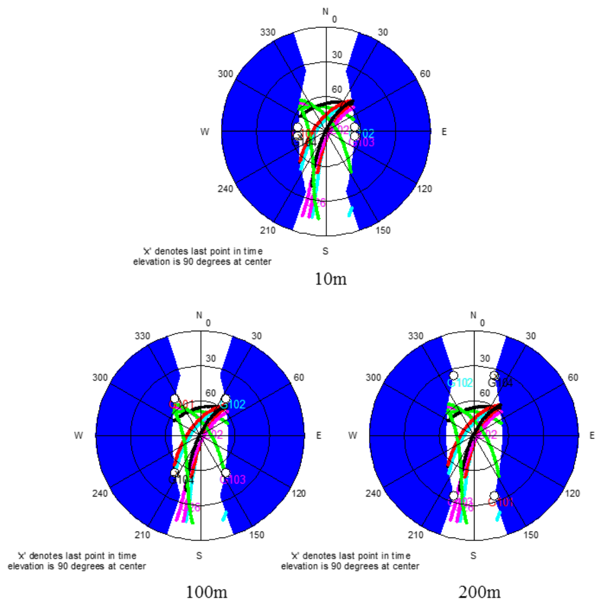

Figure 7. A sky plot and the generator positions of new signals

Consequentially, the degree of geometrical stability and the amount of signal error should be considered at the same time during the installation of a new signal generator. This will guarantee the best positioning performance and stability.

V. CONCLUSION AND FUTURE WORK

In this paper, for GPS, which is a general GNSS, positioning errors were analyzed according to diverse environments for land vehicles using a custom-made simulator. GPS positioning was impossible in some epochs, or the errors were too large to use it in areas with buildings over ten stories. Especially in road environments surrounded by thirty-story buildings, it was almost impossible to calculate the position. In such areas, new signal generators were installed from 10 m to 200 m at 10 m intervals in a simulated environment, and the integrated positioning was performed using the new signals and GPS. The simulator generated the new signals with a 10% systemic error rate. Our results confirm that a 100 m interval gives the best performance in this type of simulation. This is due to the feasible geometric stability, but the positioning error started increasing at a 200 m interval on account of the new signal error.

Through this simulation analysis, we confirmed that the accuracy of signals and their degrees of geometric stability should be considered simultaneously when attempting to solve GPS shaded areas. The proposed simulator can be used in the planning step for solving systems in GPS shaded areas.

This developed simulator can also be used for analyses of multipath effects because simulation data does not have multipath errors despite the fact that it is used for general positioning error analysis. In the future, phase positioning errors will be analyzed by an upgraded simulator. This study will also be used to investigate diverse GPS environments and integrated positioning errors with new signals.

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