PERFORMANCE EVALUATION OF SINGLE AND MULTI-GNSS RECEIVERS IN AGRICULTURAL FIELD CONDITIONS

Md. Shaha Nur Kabir, Mingzhang Song, Sun-Ok Chung, Yun-Kun Huh, and Yong-Joo Kim

Dept. of Biosystems Machinery Engineering
Chungnam National University, Daejeon, Republic of Korea

ABSTRACT

Selection of appropriate receivers and utilization methods of positioning systems are important for better positioning in different applications of precision agriculture. Objective of this research was to evaluate the performance of single and multi-GNSS receivers at stationary and moving conditions in typical Korean agricultural sites such as open field, orchard area, and mountainous area A single-GNSS receiver (Model: R100; Hemisphere GNSS, Scottsdale, AZ, USA) and a multi-GNSS receiver (Model: SIGMA-G3T; JAVAD GNSS Inc., San Jose, CA, USA) were selected for this experiment. Data were measured using GPS and DGPS modes for the single GNSS receiver, and single point positioning mode (sp); code differential mode (cd); and carrier phase differential (RTK) with fixed ambiguities (pd) modes for the multi-GNSS receiver, including and excluding the differential correction signals from the Quasi-Zenith Satellite System (QZSS). Along with number of satellites being tracked, accuracy of the GNSS receivers were evaluated in terms of Circular Error Probability (CEP) and Twice the Distance Root Mean Square values. During the stationary tests, 2DRMS values were found as 0.162 m, 0.196 m, and 1.720 m for the single-GNSS receiver at open field, orchard area, and in mountainous area, respectively. In case of the multi-GNSS receiver, 2DRMS values were found as 0.077 m, 0.162 m, and 0.929 m for pd with QZSS mode at open field, orchard area, and in mountainous area, respectively. For the moving tests, RMSE values were found as 0.502 m, 0.346 m, and 3.052 m for the single-GNSS receiver at open field, orchard garden and in mountainous area, respectively. In moving tests, for the multi-GNSS receiver the RMSE values were found as 0.424 m, 0.127 m, and 1.821m for pd with QZSS mode at open field, orchard garden, and in mountainous area, respectively. The multi-GNSS receiver showed better accuracy than the single-GNSS receiver in all experimented conditions. Moreover, number of satellites tracked by the multi-GNSS receiver was also greater than the single-GNSS receiver in all of the cases. This research provides the capability and accuracy of a multi-GNSS receiver and comparison with a single-GNSS, which would be helpful for selecting appropriate receivers and methods in various agricultural conditions.

Keywords: Precision agriculture, Global Navigation Satellite System (GNSS), Positioning accuracy, Differential correction

INTRODUCTION

Position accuracy is the prime importance for precise management of agricultural operations. Yield mapping, autonomous guidance systems, variable-rate technology require very accurate positioning systems. Selection of appropriate receivers and utilization methods are also important for better positioning in different applications of precision agriculture. Knowing accuracy of different GNSS receivers is a matter of concern to growers and farmers considering purchasing one of these systems and the accuracy requirements determine the appropriate GNSS capability and technique (Borgelt et al., 1996).

Global navigation satellite systems (GNSS) is the collective term for those navigation systems that provide the user with a three-dimensional positioning solution by passive ranging using radio signals transmitted by orbiting satellites (Groves, 2008). GNSS plays a key role in modern navigation services and provides opportunities for agriculture producers to manage their land and crop production more precisely. As with any application of GNSS, the ability to accurately determine geographic coordinates is essential to assure the quality performance of autonomous vehicles. At present, there are several different GNSS systems either in use or under development (Adamchuk et al., 2008). The American Global Position System (GPS) and the Russian Global Navigation Satellite System (GLONASS) both qualify as GNSS. Two other satellite localization systems, the Galileo (European Union) and the Compass (Chinese), are expected to achieve full global coverage capability by 2020 (Perez-Ruiz and Upadhyaya, 2012).

Japanese Quasi-Zenith Satellite System (QZSS) constellation comprises with three satellites in separate geosynchronous orbits, inclined to the equator at 45°. They are phased in such that all satellites would share the same asymmetric figure-of-eight ground track over the Asia-Pacific region and broadcast differential correction signals. This ensures that there is always at least one satellite over the Japan and Asia-Pacific region at a high elevation angle (Maeda, 2005). The QZSS enable to expand the areas and time duration of the positioning service provision in mountainous and urban regions, also improving positioning accuracy of one meter to the centimeter level compared to the conventional GPS error of tens of meters (JAEA, 2012). The coexistence of the three GNSSs would either result in an alternative use or in a combination of the services and signals to gain a combined solution. An increasing number of systems and signals would provide an increasing number of observations and, in general with an increasing number of satellites, the DOP (Dilution of Precision) values decreases in the common case. From the increasing redundancy in the adjustment process, the position accuracy, availability, integrity, and continuity would benefit (Hofmann-Wellenhof et al., 2008). In the coming years, the evolution of Global Navigation Satellite Systems (GNSSs) would have a revolutionary impact on the positioning performance. More GNSSs would become available with improved signal characteristics (Verhagen et al., 2010).

The GNSS positioning accuracy can be expressed as a percent of the data within a distance from the averaged location, and more common terms used are Circular Error Probable (CEP), Root Mean Square error (RMS), and Distance Root Mean Square error (DRMS). CEP is the value at which half of the data points fall within a circle of this radius centered on the true location and a half lie outside that circle and 2DRMS is the 95-98% probability that the position locate within the stated 2 dimensional accuracy (Rodriguez-Perez et al., 2006). Min et al. (2008) stated the main factors contributing to the total GNSS error are the satellite position in orbit (ephemeris), receiver clock timing, ionospheric and atmospheric delays, and multipath effects. The geometry of the satellites (dilution of precision, DOP) and number of satellites in use influence the GPS errors with changes in time and location.

Previous researchers have evaluated the performance of GNSS receivers in different conditions but there is a scope to evaluate the performance of single and multi-GNSS receivers in different agricultural conditions. Objectives of this research was to evaluate the performance of single and multi-GNSS receivers and the different capability under different modes of the multi-GNSS receiver for positioning assessment, in different fields such as open field, orchard area, and mountainous area, under stationary and moving conditions.

MATERIALS AND METHODS

GNSS receivers and experimental sites

A GNSS receiver is a combination of hardware and software capable of receiving signals from several GNSS satellites, and processing them into position, velocity, and timing information. Scientific and technical advances in GNSS receiver design are being considered to enhance overall navigation, guidance, and timing functions (Gleason and Gebre-Egziabher, 2009). A single-GNSS receiver (Model: R100; Hemisphere GNSS, Scottsdale, AZ, USA) and a multi-GNSS receiver (Model: SIGMA-G3T; JAVAD GNSS Inc., San Jose, CA, USA) were selected for this experiment. The single-GNSS receiver consists of multiple Global Positioning System (GPS) receiver models that track GPS and Satellite Based Augmentation System (SBAS) with 0.6 m DGPS positioning accuracy. The multi-GNSS receiver is able to calculate position, velocity and time by receiving the satellite signals broadcasted from multiple global navigation satellite systems.

The multi-GNSS unit was a 216-channel GNSS receiver with DGPS post processing measuring accuracy less than 0.25 m and could receive and processes multiple signal types (including the latest GPS L2C, GPS L5, GLONASS C/A L2, and Galileo signals) which could improve the accuracy and reliability of the measurements, especially under unfavorable jobsite conditions. The specifications and configurations of the tested receivers for this study are listed in Table 1 and different modes of operation during stationery and moving conditions are shown in Table 2. Data were measured using GPS and DGPS modes for the single-GNSS receiver, and single point positioning mode (sp); code differential mode (cd); and carrier phase differential (RTK) with fixed ambiguities (pd) modes for the multi-GNSS receiver, including and excluding Quasi-Zenith Satellite System (QZSS) signals. RTKLIB 2.4.2 software program package (Takasu, 2013) was used for processing of the multi-GNSS receiver data.

Table 1. Specifications and configurations of the GNSS receivers.

GNSS Receivers	Item						
	GPS	GLONASS	Galileo	SBAS	QZSS	Cha-nnels	Up date
Single GNSS	GPS L1, C/A	-	-	Yes	-	12	Up to 20 Hz
Multi-GNSS	GPS C/A, P1, 2, 2C,L5	GLONASS C/A, L2C, P1, P2, L3	Galileo E1,E5A E5B	Yes	Yes	216	Up to 100 Hz

Table 2. Different modes of data measurement for the stationery and moving test conditions.

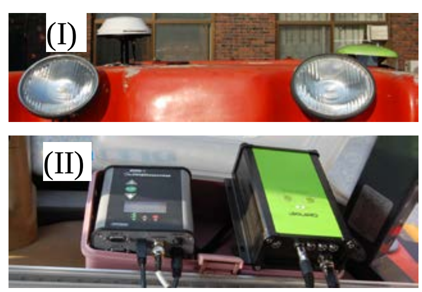
GNSS Receivers	Modes of operation during stationery and moving tests					
Single GNSS	GPS	DGPS	-	-	-	-
Multi-GNSS	SP	SP + QZSS	CD	CD + QZSS	PD	PD + QZSS

In order to evaluate performance of the receivers, experiments were conducted in stationary and moving conditions at three different conditions such as open field, orchard area, and mountainous area in the vicinity of Chungnam National University, Daejeon, South Korea as displayed in Figure 1.

(a) Open field

(b) Orchard area

(c) Mountainous area



(d) Mounting of antennas (I) and receivers (II)

Figure 1. Photos of the experimental sites and GNSS receiver mounting.

There were no sight-blocking buildings and trees or any kind of obstacles in the open field. In the orchard area, on an average the tree height, distance between the trees in line, and distance between the trees across the line were 3 m, 7.5 m, and 8 m respectively. In mountainous area, an 8.5 m wider road passes through the mountain having height of the mountain about 20-25 m on both sides of the road.

Stationery tests

Stationery tests were conducted to identify the positioning performance of single and multi-GNSS receivers in large paddy filed, orchard garden and mountainous area. Antennas were placed at a height of 1.8 m on tripod stands above the ground surface. Data were taken for a short period of 15 minutes for GPS and DGPS modes of single GNSS receiver and sp, cd, and pd modes of multi-GNSS receiver. QZSS signals were included and excluded together with GPS, GLONASS and Galileo signals for multi-GNSS receiver. For each receiver, stationery accuracy were calculated and described in terms of circular error probability (CEP), root mean square error (RMS), and twice the distance root mean square error (2DRMS). DRMS is the square root of the average of the squared horizontal position errors and 2DRMS is twice of the DRMS, the radius of a circle in which 95-98% of the values will occur. CEP refers the radius of circle centered at the true position, containing the position estimate with probability of 50%.

$$2DRMS = \sqrt{(\sigma_x{}^2 + \sigma_y{}^2)} \quad (1)$$

$$CEP = 0.59(\sigma_x + \sigma_y) \quad (2)$$

Where, σ_x: Standard deviation of the easting value, and
σ_y: Standard deviation of the northing values.

The Precise point positioning (PPP) is a novel positioning methodology to increase the position accuracy in single-point positioning mode which uses accurate satellite clock information and accurate ephemerides data. This technique has been originally introduced for efficient analysis of GNSS data from large networks (Zumberge et al. 1997). Both antennas of the receivers were mounted on tripod stands and data were collected by connecting receivers with a notebook. RTKLIB 4.2.4 software program package was used for processing of multi-GNSS receiver data such as extraction of position file from JSP file of SIGMA-G3T receiver using PPP static option. Longitude, latitude and height values were extracted JSP file and the difference in East coordinates (δ'East) and difference in North coordinates (δ'North) were calculated to convert these values to Universal Transverse Mercator (UTM) coordinates. CEP and 2DRMS values were found by plotting in Matlab R2010a programme package.

Moving tests

Straight roads about 400 m and 40 m were selected for moving tests in large open field and orchard garden, respectively. A curved road about 350 m was selected for moving tests in mountainous area. In orchard garden both the GNSS receivers and measurement units were mounted on a trolley type vehicle and was manually driven as straight as possible. In open field and mountainous area two antennas were mounted on the roof of a tractor and driven at a constant speed. During moving tests various modes of the receivers were used also during data measurements as described in the stationery tests. While measuring data three replications were done for each of the modes. The term Root Mean Square Error (RMSE) was used to describe the errors measurements for moving tests.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(E_i - \overline{E})^2} \quad (1)$$

Where, $RMSE$: RMSE is the Root Mean Square Error.

E_i: Location of i^{th} measurement along Northing and Easting directions

$\overline{E}$: Sample mean of measurements

n: Total number of measurements.

RESULTS AND DISCUSSION

Stationery tests

Analysis of the stationery tests data showed that the type of receivers and the modes of operation of multi-GNSS receiver had significant effects on the accuracy parameters (CEP, 2DRMS). The 2DRMS and CEP circles representing stationery test accuracies in large open field for single and multi-GNSS receivers are shown in Figure 2. DGPS modes showed better accuracies compared to GPS mode and 2DRMS values for DGPS modes were found as 0.162 m, 0.196 m, and 1.720 m for large open field, orchard garden and in mountainous area, respectively. Stationery test accuracies of multi-GNSS receiver for Precise Point Positioning (PPP) modes in all experimented field conditions are shown in Figure 3. Better stationery accuracies were found after adding QZSS option. The better 2DRMS values of multi-GNSS receiver along PD with QZSS mode were found as 0.077 m, 0.162 m, and 0.929 m for large open field, orchard garden and in mountainous area, respectively.

Stationery test accuracies for single and multi-GNSS receivers in all field conditions and modes are summarized in Table 3. Better accuracies were found after adding QZSS mode of multi-GNSS receiver. The multi-GNSS receiver showed better stationery accuracies than the single-GNSS receiver in all the experimented conditions and PD with QZSS showed better accuracies among other modes of multi-GNSS receiver. Highest stationery test accuracies were found in the large open field as there were no sight-blockings, following orchard area and mountainous area. However, the multi-GNSS receiver showed it capabilities in sight-blocking conditions such as garden and mountainous area.

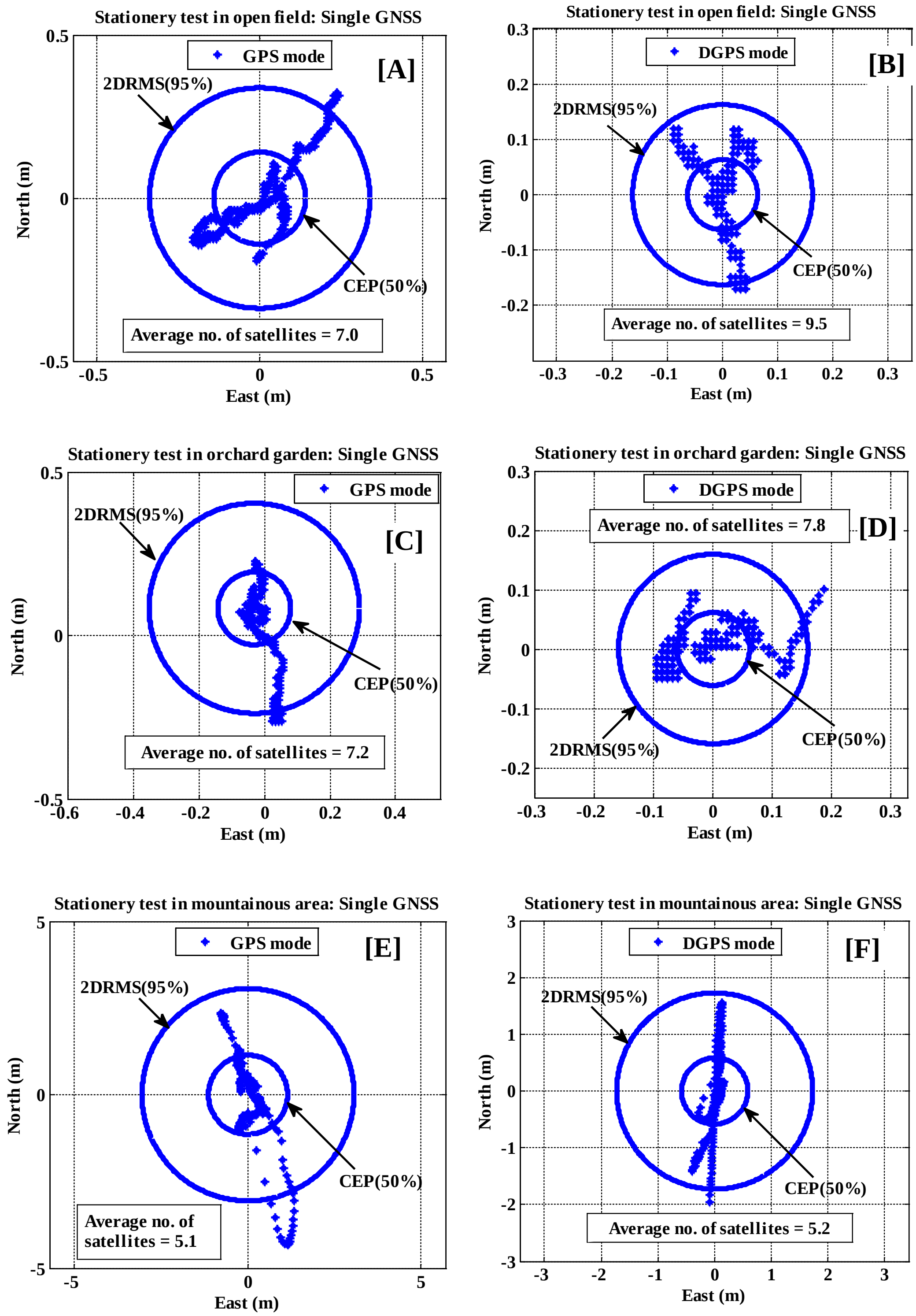


Figure 2. Stationery test accuracies of single GNSS receiver for GPS and DGPS modes in open field (A, B); orchard garden (C, D); and in mountainous area (E, F).

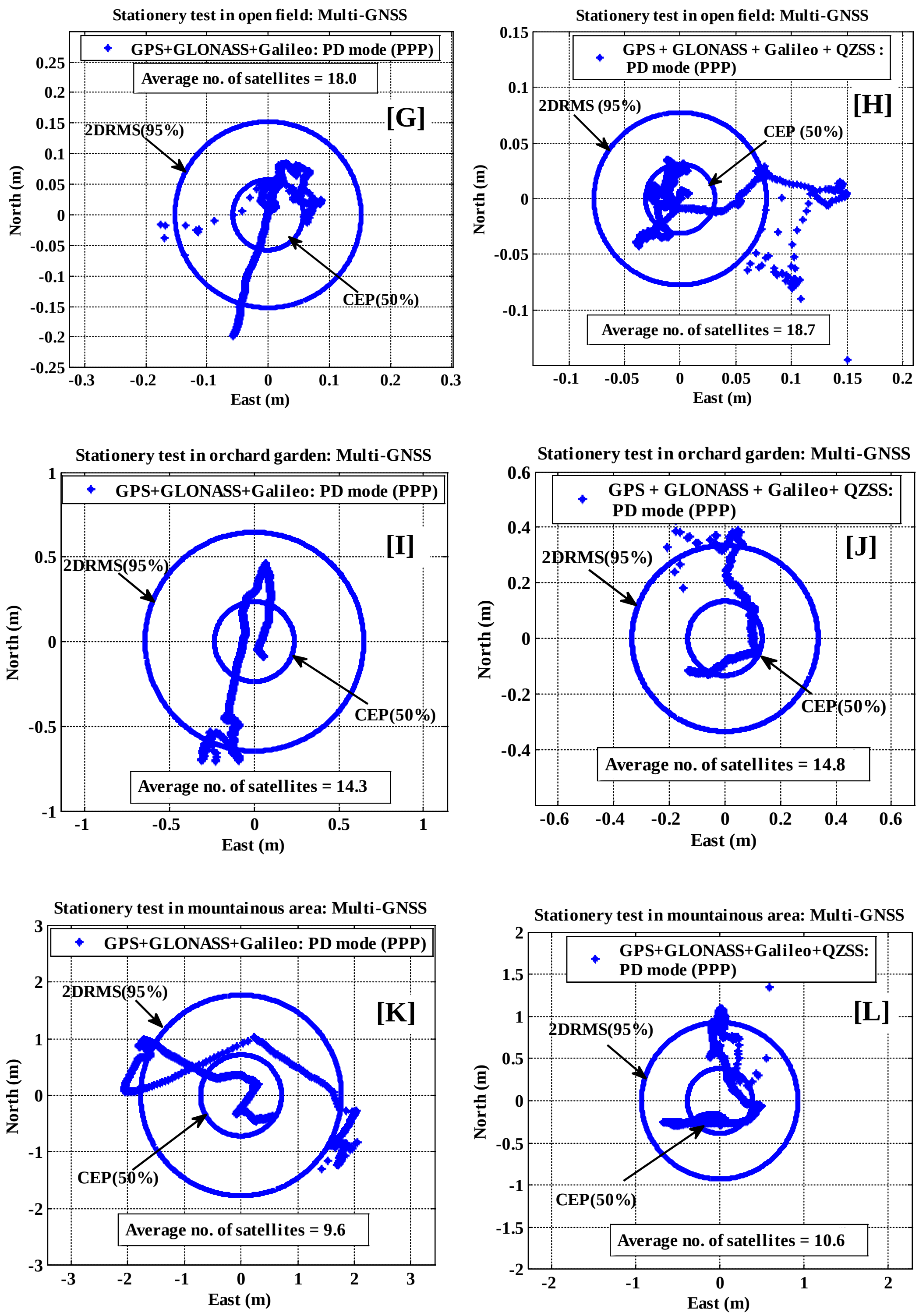


Figure 3. Stationery test accuracies of multi-GNSS receiver with and without QZSS mode in open field (G, H); orchard garden (I, J); and in mountainous area (K, L).

Moving tests

Like stationery tests, the type of receivers and the modes of operation of multi-GNSS receiver had a significant effect on the accuracy parameters (RMSE). After extraction of position file from JSP file of multi-GNSS receiver, data were filtered for the starting and ending point of the distance travelled. A reference regression line was created along the travelled path to calculate the RMSE values.

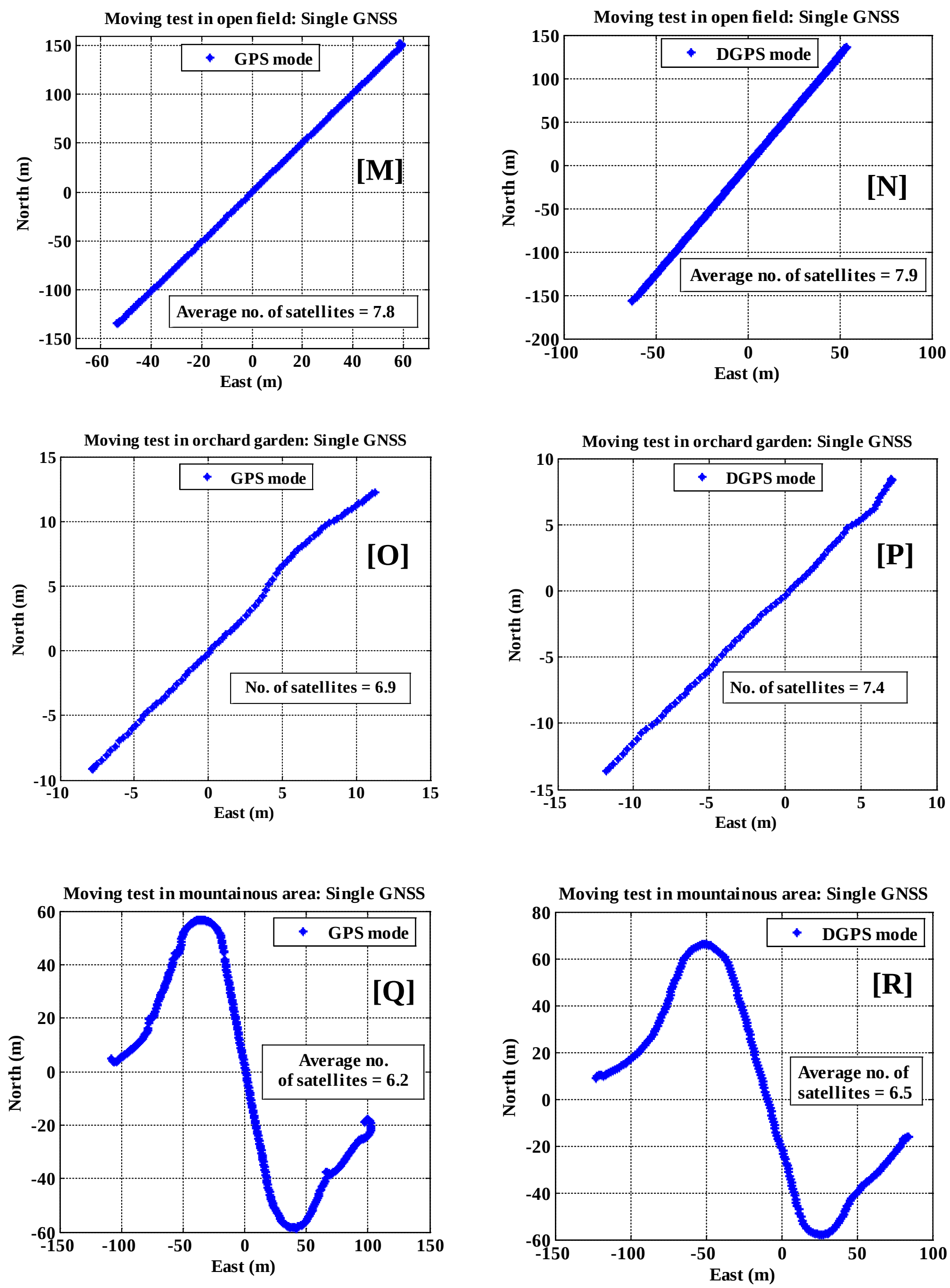


Figure 4. Moving test accuracies of single GNSS receiver for GPS and DGPS modes in open field (M, N); orchard garden (O, P); and in mountainous area (Q, R).

The RMSE representing moving test accuracies of single GNSS receivers in all experimented field conditions for GPS and DGPS modes are shown in Figure 4. The RMSE values were found as 0.502 m, 0.346 m, and 3.502 m for large open field, orchard garden, and in mountainous area, respectively.

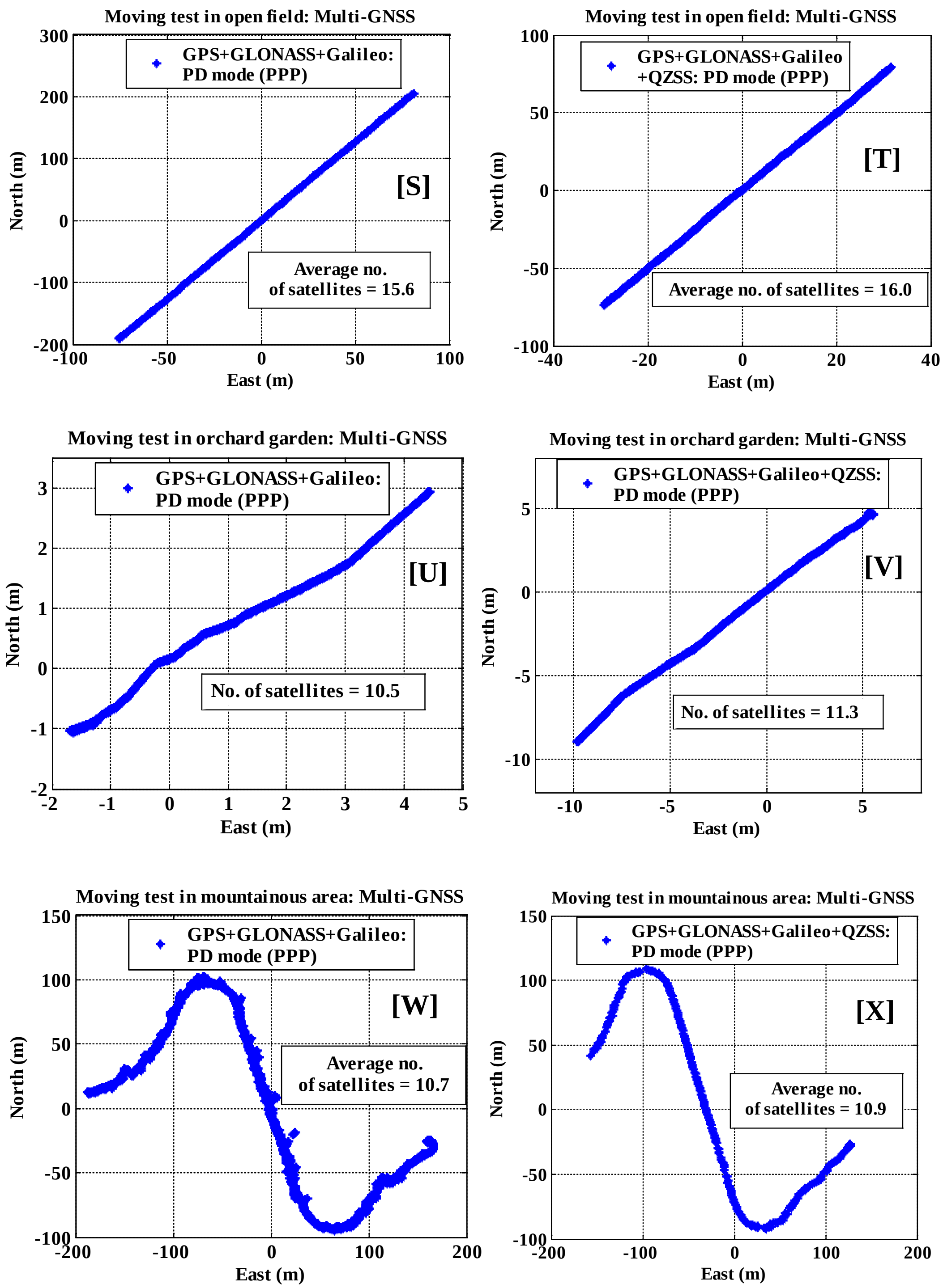


Figure 5. Moving test accuracies of multi-GNSS receiver with and without QZSS mode in open field (S, T); orchard garden (U, V); and in mountainous area (W, X).

Moving test accuracies of multi-GNSS receiver for Precise Point Positioning (PPP) mode in all experimented field conditions are shown in Figure 5. Better RMSE values were found after adding QZSS option and the best accuracy mode with QZSS options are showed in the figures only. Best accuracies for multi-GNSS receiver of PPP mode along PD with QZSS option were found as 0.424 m, 0.127 m, and 1.821 m for large open field, orchard garden, and in mountainous area, respectively.

Table 3. Stationery and moving test results.

GNSS Receivers	**Measuring mode**	**Stationery conditions**			**Moving conditions**	
		Avg. CEP 50% (m)	Avg. 2DRMS 95% (m)	Avg. no. of satellites	Avg. RMSE (m)	Avg. no. of satellites
Large open field						
Single GNSS	GPS	0.141	0.337	7.0	0.842	7.8
	DGPS	0.063	0.162	9.5	0.502	7.9
Multi-GNSS	SP	0.048	0.130	16.0	0.516	14.0
	SP + QZSS	0.034	0.094	16.1	0.450	14.0
	CD	0.049	0.119	18.3	0.466	15.3
	CD + QZSS	0.040	0.104	16.8	0.447	14.2
	PD	0.057	0.152	18.0	0.488	15.6
	PD + QZSS	0.031	0.077	18.7	0.424	16.0
Orchard garden						
Single GNSS	GPS	0.111	0.321	7.2	0.346	6.9
	DGPS	0.082	0.196	7.8	0.286	7.4
Multi-GNSS	SP	0.116	0.311	14.7	0.237	10.2
	SP + QZSS	0.101	0.244	13.0	0.200	12.6
	CD	0.068	0.165	14.0	0.281	11.7
	CD + QZSS	0.078	0.198	14.0	0.252	11.2
	PD	0.074	0.189	14.3	0.202	10.5
	PD + QZSS	0.056	0.162	14.8	0.127	11.3
Mountainous area						
Single GNSS	GPS	1.14	3.058	5.1	5.261	6.0
	DGPS	0.583	1.720	5.2	3.502	6.8
Multi-GNSS	SP	0.533	1.360	9.8	4.198	12.1
	SP + QZSS	0.456	1.090	10.2	3.255	12.1
	CD	0.456	1.120	10.3	3.042	11.7
	CD +QZSS	0.379	0.975	9.8	2.763	11.8
	PD	0.717	1.773	9.6	3.794	10.9
	PD +QZSS	0.386	0.929	10.6	1.821	11.2

Moving test accuracies in all test field conditions are also summarized in Table 3. Best accuracy was found for large open field compared to the distance travelled because there were no sight-blockings around the open field, following orchard area and mountainous area. The multi-GNSS receiver showed better moving test accuracies here also than the single-GNSS receiver in all the experimented conditions and PD with QZSS mode showed better accuracies among other modes of multi-GNSS receiver.

The average no. of satellites tracked by both of the receivers in all experimented conditions is shown in Figure 6. During stationery test, the number of satellites tracked by the single GNSS receiver with DGPS mode was 9.5, 7.8, and 5.2 for large open field, orchard garden, and in mountainous area, respectively. For multi-GNSS receiver in PPP mode along PD with QZSS option the average no. of satellites tracked was found as 18.7, 14.8, and 10.6 for large open field, orchard garden, and in mountainous area, respectively.

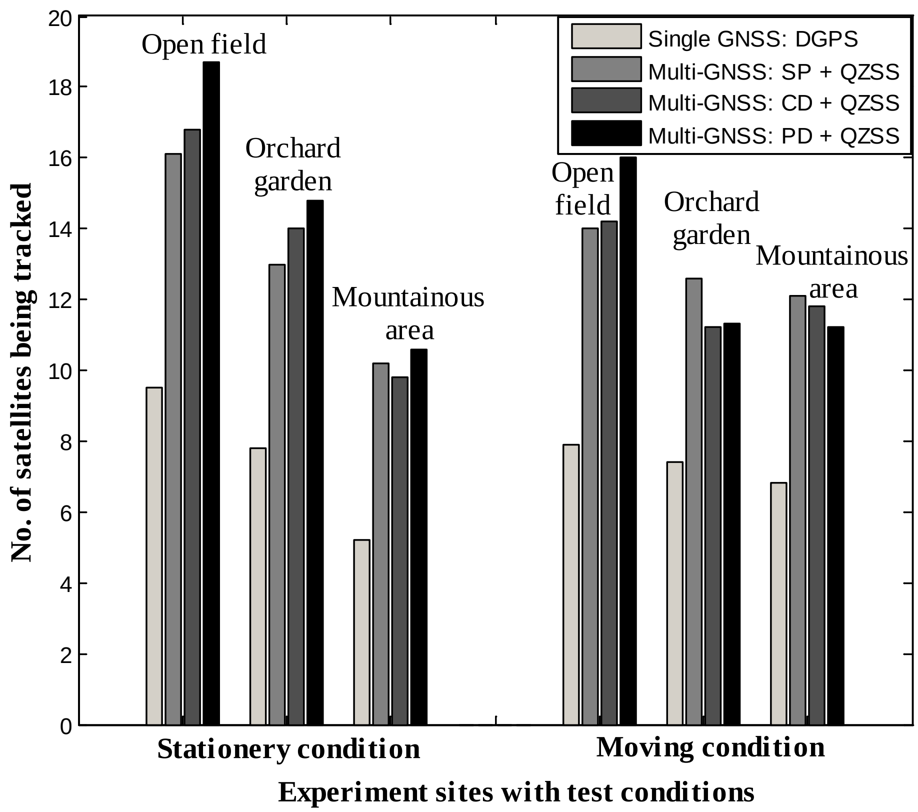


Figure 6. Number of satellites tracked by the both receivers in all experimented conditions.

During moving test, the number of satellites tracked by the single GNSS receiver with DGPS mode was 7.9, 7.4, and 6.8 for large open field, orchard garden, and in mountainous area, respectively. For multi-GNSS receiver in PPP mode along PD with QZSS option the average no. of satellites tracked was found as 16.0, 11.3, and 11.2 for large open field, orchard garden, and in mountainous area, respectively.

CONCLUSIONS

In this research, the accuracies of two commercially available GNSS receivers were studied under stationery and moving conditions in typical Korean farm conditions such as open field, orchard garden, and in mountainous area. The selected receivers were: A single-GNSS receiver (Model: R100; Hemisphere GNSS, Scottsdale, AZ, USA) and a multi-GNSS receiver (Model: SIGMA-G3T; JAVAD GNSS Inc., San Jose, CA, USA). The following concluding remarks can be drawn from this study:

- Multi-GNSS receiver showed better accuracies in all experimented field conditions for stationery tests and carrier phase differential (RTK) with fixed ambiguities (pd) with QZSS modes for multi-GNSS receiver showed better accuracy among the other modes. Importantly, the multi-GNSS receiver showed better stationery accuracy in mountainous area and in garden field which shows its potentiality to work in conditions of poor visibility.
- Like as stationery tests, the multi-GNSS receiver showed better accuracies in all experimented field conditions for moving tests also; and code differential mode (cd) with QZSS and carrier phase differential (RTK) with fixed ambiguities (pd) with QZSS modes for multi-GNSS receiver showed better accuracy among the other modes.
- The no. of satellites tracked by the multi-GNSS receiver was also higher than the single-GNSS receiver in both stationery and moving conditions.

ACKNOWLEDGEMENTS

This research was supported by Japan Aerospace Exploration Agency (JAXA), Tokyo 100-8260, Japan. Special thanks to Prof. Noboro Noguchi for giving us an opportunity to conduct this join experiment with JAXA.

REFERENCES

Adamchuk, V.I., T. S. Stombaugh, and R.R. Price. 2008. GNSS-Based Auto-Guidance in Agriculture. The Site-Specific Management Guidelines (SSMG) series, International Plant Nutrition Institute (IPNI), Georgia, U.S.A.

Borgelt, S. C., J. D. Harrison, K. A. Sudduth, and S. J. Birrell. 1996. Evaluation of GPS for Applications in Precision Agriculture. Applied Engineering in Agriculture, 12(6):633-638.

Gleason, S., and D. Gebre-Egziabher. 2009. GNSS applications and methods. Norwood, MA: Artech House.

Groves, P. D. 2008. Principles of GNSS, Inertial, and Multisensor Integrated Navigation Systems. Boston, London: Artech House.

Hofmann-Wellenhof, B., H. Lichtenegger, and E. Wasle. 2008. GNSS – Global Navigation Satellite Systems GPS, GLONASS, Galileo, and more. New York: Springer Wien.

JAEA. 2012. “MICHIBIKI: Current status of rubidium atomic clock 2, Japan Aerospace Exploration Agency (JAEX), Tokyo 100-8260, Japan.

Maeda, H. 2005. QZSS Overview and Interoperability. Proc. 18th International Tech. Meeting of the Satellite Division of the Institute of Navigation (ION GNSS), Long Beach, U.S.A.

Min, M., R. Ehsani, and M. Salyani. 2008. Dynamic accuracy of GPS receivers in citrus orchards. Applied Engineering in Agriculture 24(6):861-868.

Perez-Ruiz, M., and S. K. Upadhyaya. 2012. GNSS in Precision Agricultural Operations. New Approach of Indoor and Outdoor Localization Systems, CH-1, pp. 3-26. InTech Europe, Janeza Trdine 9, 51000 Rijeka, Croatia.

Rodriguez-Perez, J. R., M. F. Alvarez, E. Sanz, and A. Gavela. 2006. Comparison of GPS receiver accuracy and precision in forest environments. Practical recommendations regarding methods and receiver selection. *Proceedings of XXIII FIG Congress*, Munich, Germany.

Takasu, T. 2013. RTKLIB: An open source program package for GNSS positionin g. http://www.rtklib.com.

Verhagen, S., D. Odijk, P. J. G. Teunissen, and L. Huisman. 2010. 5th ESA Workshop on *“Satellite Navigation Technologies and European Workshop on GNSS Signals and Signal Processing (NAVITEC)”*, Noordwijk, The Netherlands.

Zumberge J.F., M. B. Heflin, D.C. Jefferson, M.M. Watkins, and F. H. Webb. 1997. Precise point positioning for the efficient and robust analysis of GPS data from large networks. Journal of Geophysical Research 102(B3): 5005–5017.