# Performance Evaluation of CLAS and PPP Using Correction Data via QZSS

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***Abstract*—The need for high-accuracy positioning (centimeter level) has been increasing, particularly in self-driving cars, agriculture, and construction. In 2017, Japan launched a Quasi-Zenith Satellite System (QZSS) comprising three satellites successfully leading to a constellation of four satellites to strengthen the positioning services. The QZSS, which is scheduled to commence its operations in November 2018, is expected to implement three reinforcement services: centimeter level augmentation service (CLAS), precise point positioning (PPP), and sub-meter level augmentation service (SLAS). These new services would access the correction data via QZSS. In this study, we evaluated the efficacy of these systems by way of conducting experiments on static and kinematic positioning, whereby we used two new GNSS receivers to decode the L6 signals broadcast from the QZSS. We used the RTK Fix rate, standard deviation, and statistical percentile as the tools for evaluation. The experiments on static positioning using CLAS showed a positioning accuracy within 10 cm in both horizontal and vertical (height) directions. For kinematic experiments of CLAS, open-sky condition was applied. The overall results of the PPP experiments were similar to the previous research studies for both static and kinematic conditions, while the accuracy was up to 10 cm achieved after a convergence period of 15-20 min approximately. The experimental results of SLAS showed an improved accuracy for the static condition compared with a stand-alone system. We propose to continue the studies across Japan over a period of one year to confirm the sustained consistency of these correction services.**

***Keywords*—Quasi-Zenith Satellite System; Centimeter Level Augmentation Service; Precise Point Positioning; Sub-meter Level Augmentation Service***

## I. Research Background and Objective

In September 2010, the first Japanese Quasi-Zenith Satellite System (QZSS) was launched by the Japan Aerospace Exploration Agency (JAXA). The positioning service is found to be stable as recognized by the public through the academic societies in Asia. The new units (2, 3, and 4) of QZSS launched in 2017 are scheduled to commence the full-scale positioning service with effect from November 2018. In contrast to the present positioning services of QZSS that are confined only to the complimentary functions concerning GPS, the users are expected to have an enhanced access to three new services from QZSS: centimeter level positioning service (CLAS) and precise point positioning (MADOCA-PPP) in the L6 signal band, and sub-meter positioning service (SLAS) in the L1S signal band. These are positioning services of first kind not only to Japan but to the entire world, which would be achieved with the help of approximately 1300 electronic GNSS reference points of Geospatial Information Authority of Japan. The new services of QZSS are as shown below (Fig. 1).

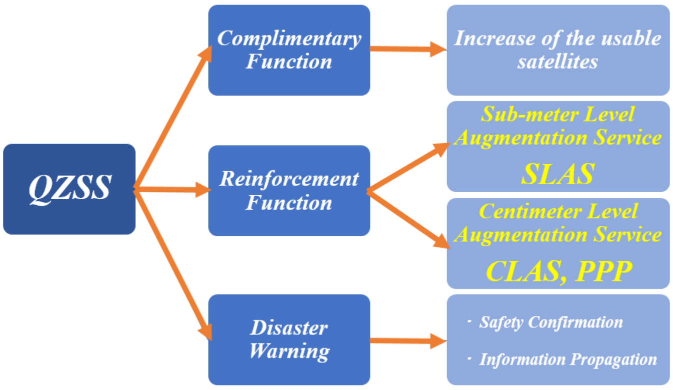


Fig. 1. New Services of QZSS

CLAS is an innovative system which employs the RTK positioning (PPP-RTK) through a single station and a one way communication from satellites, whereby the correction information from the base stations are captured at the rover side via QZSS using its L6 signal band.

On the other hand, PPP continues to receive the test signals from QZSS, and its performance has been verified by several research institutes and companies over the past few years. L6 signal band comprises two channels: one for the correction information for CLAS (D1 channel) and the second one for precise ephemeris and clock information (D2 channel) for PPP.

Both the CLAS and the PPP exhibit three advantages: first, there is no limitation on the baseline length; second, it is possible to perform high-accuracy positioning even in areas devoid of internet; finally, there is no need for a contract to obtain the correction information.

SLAS too has the same reinforcement function like CLAS, whereby pseudo-range correction information is superimposed on L1S signal band. It is a system that realizes the DGNSS positioning with single station and one way communication from satellites. It is expected to apply even to the pedestrians, cyclers, and ship because the position can be determined at sub-meter level on a terminal which can receive and decode the L1S signals.

In various industrial applications, there is a critical need for the positioning information with a centimeter level accuracy. Introduction and testing are most progressive in the Japanese agricultural field from the viewpoint of utilization of precise positioning. In 2017, Quasi-Zenith Satellite System Services

Inc., Hokkaido University in collaboration with three manufacturers of agricultural machinery succeeded to operate self-driving agricultural tractors using the positioning results of CLAS. Being a reinforcement function of QZSS, the CLAS is also expected to support self-driven cars owing to its compatibility with automatic systems. Thus, new products and proposals are expected to boom following the official commencement of QZSS operations.

In this study, we evaluated the positioning accuracy of CLAS, PPP, and SLAS based on the expansion of the QZSS services mentioned above. We present in this paper the experimental results of the static and kinematic positioning using CLAS and PPP. For SLAS, we present the static positioning accuracy of DGNSS positioning by baseline length using electronic reference points. We investigated the compliance of each of these reinforcement services to the specifications published by the cabinet office in Japan. In this regard, it is necessary to evaluate the positioning accuracy in open-sky condition, especially for CLAS; however, considering that the obstacles such as mountains and overpasses are practically inevitable in a real-time situation, we investigated the effect of overpasses on kinematic positioning. This research is also aimed at evaluating the effectiveness of these reinforcement services for automatic driving. The results helped establish that CLAS can be applied to the running cars if an accurate positioning, for example, within 10 cm, is achievable.

## II. Brief Descriptions of CLAS, PPP and SLAS

### A. Centimeter Level Augmentation Service (CLAS)

To carry out highly precise satellite positioning, the data from the Geospatial Information Authority of Japan's GNSS-based control stations called Japanese GEONET are gathered and used. Approximately 300 base stations are used. An image of Japanese GEONET is as shown below (Fig. 2). Correction used in CLAS is transmitted by QZSS L6 signals are not transmitted by GPS, hence dedicated receivers are required. The concept of CLAS is PPP-RTK positioning, and the concept image of CLAS is also as shown below (Fig. 3)

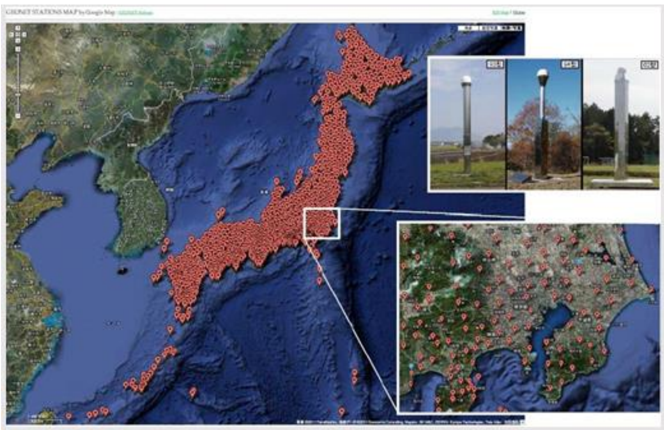

Fig. 2. Japanese GEONET *(Approximately 1300 Points)*

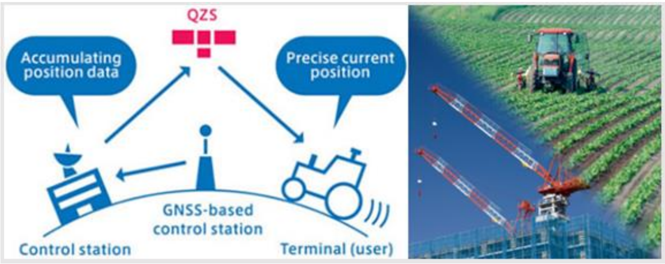


Fig. 3. Concept Image of CLAS

It is expected that this service will be used for surveying, intelligent construction (construction methods in which construction machinery is operated with high precision), and e-agriculture (methods for agricultural land management in which agricultural machinery is operated with high precision automatically) mentioned in Section I. This service can be used on L6-signals receivers.

### B. Precise Point Positioning (MADOCA-PPP)

PPP is also a technique to calculate accurate user positions using precise orbit and clock of GNSS without any reference stations. JAXA had been conducting real-time PPP experiments using L6 signals from QZSS. Moreover, JAXA had developed Multi-GNSS orbit and clock estimator called "MADOCA (Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis)" for PPP users in Asia and Oceania regions. The concept image of MADOCA-PPP and some target applications are as shown below (Fig. 4 and Fig. 5).

MADOCA-PPP is available in offshore and in some areas where infrastructures are undeveloped (buoys for tsunami, offshore platforms, mining areas and so on), thus it is expected that applications utilizing the characteristics is utilized in such areas. The difference between CLAS and PPP is the convergence time. The convergence time of CLAS is about 1 minutes and the convergence time of PPP is about 15-30 minutes.

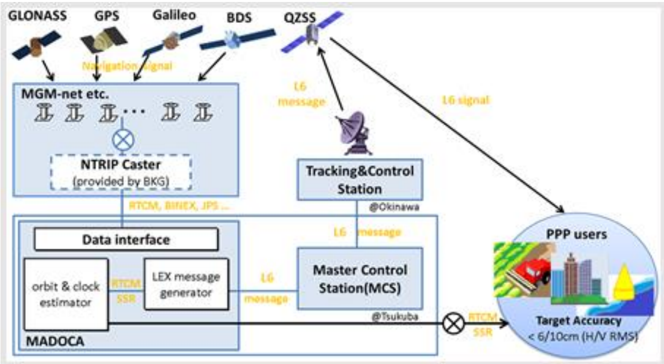


Fig. 4. Concept Image of MADOCA-PPP

Fig. 5. Target Applications of MADOCA-PPP

## C. Sub-meter Level Augmentation Service (SLAS)

To reduce errors in satellite positioning, information that can be utilized to decrease these errors (sub-meter level augmentation information) – such as ionospheric delay, orbit errors and clock errors – is transmitted by QZSS. The big difference between CLAS/PPP and SLAS is what type of observation is used in the positioning. As for SLAS, pseudo-range is used in the positioning, therefore, the accuracy is not cm level but sub-meter level.

Normally ionospheric delay errors can be solved by using dual-frequency receivers. However, these receivers are generally large and expensive, hence it is expected that existing single-frequency receivers can be improved and used for this purpose. L1S signals that transmit sub-meter level augmentation information is the same type of signal as the L1C/A positioning signals that is broadly used, therefore they can be received on existing single-frequency receivers that have been modified. The concept of SLAS is standalone DGNSS positioning like SBAS, and the concept image of SLAS is as shown below (Fig. 6).


Fig. 6. Concept Image of SLAS

This service is expected to be used mainly for purposes that are not heavily affected by time lags such as pedestrians, bicycles, and ships. This service can be used on L1S-signal receivers.

# III. CLAS EXPERIMENT

- *Experiment Description*

We conducted the experiments on static and kinematic positioning using CLAS at the rooftop of the number 4 research building in Etchujima campus of Tokyo University of Marine Science and Technology (TUMSAT), near the campus in Tokyo, and in Chiba prefecture. We used an AQLOC receiver manufactured by Mitsubishi Electric Corporation, comprising a L6 signal band decoder and a CLAS RTK positioning engine. As the experiments were conducted in winter season and in a specific location as mentioned above, the results may not apply to the country as a whole. The correction information sent from the unit 1 of QZSS (PRN number: 193) was used for the L6 signal band.

## A. Static Positioning Experiment

In the experiment on static positioning, the antenna (GrAnt-G5T of JANAD GNSS make) was installed on the rooftop of the number 4 research building, and the daily data (24 h approximately) was collected for the period from late December 2017 to late January 2018. The horizontal and height errors (in time series) were calculated by taking the difference of the data (AQLOC receiver) from the true positions (SPS855 receiver of Trimble Inc.). The photographs of the antenna and the two receivers are as shown below (Fig. 7).

Fig. 7. Antenna *(GrAnt-G5T)* and Receivers *(AQLOC and SPS855)*

## B. Kinematic Positioning Experiment

In the experiment on kinematic positioning, the data was collected on an ordinal road in nearly open-sky condition, on a highway (mainly in Metropolitan Expressway), and on the sea (Tokyo Bay). We adopted the RTK fixed solution of the SPS855 receiver for the true positions, and the horizontal and height errors were calculated by taking the difference of the data from the true positions. The schematic of the setup comprising various equipment used in the ordinal road experiment using a car is as shown below (Fig. 8).

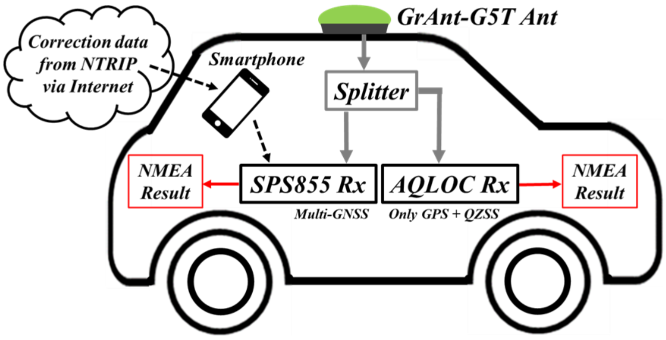


Fig. 8. Settings of Equipment in the Experimental Car

The data acquired in the sea experiment conducted on January 16th, 2018 was also evaluated in the same way as the car experiment. A photograph of the ship used in the experiment is as shown below (Fig. 9).

Fig. 9. Picture of the Experimental Ship *(Shioji Maru)*

## C. Results

The conditions of the analysis and the statistical parameters (standard deviation, 95 percentile) used to analyze the results are as shown below (Fig. 10).

**[Condition of Analysis]**

1. *More than 5 usable satellites*
2. *The delay of correction information is within 10 seconds.*
3. *Only RTK fixed solution is analyzed.*

**[Analysis Items]**

I. *Standard deviation of horizontal and height direction*
II. *95 percentile value of horizontal and height direction*

Fig. 10. The Condition of Analysis and Analysis Items

The specification of positioning accuracy of the CLAS service and a map of the service area (made public by the cabinet office formally) are as shown in the following page (TABLE I and Fig. 11), respectively.

TABLE I. POSITIONING ACCURACY OF CLAS

| Positioning Type | Positioning Error | |
|---|---|---|
| | Horizontal | Vertical |
| Static | Not exceeding 6.0 cm (95%) ( 3.47 cm (RMS) ) | Not exceeding 12 cm (95%) ( 6.13 cm (RMS) ) |
| Kinematic | Not exceeding 12 cm (95%) ( 6.94 cm (RMS) ) | Not exceeding 24 cm (95%) ( 12.25 cm (RMS) ) |

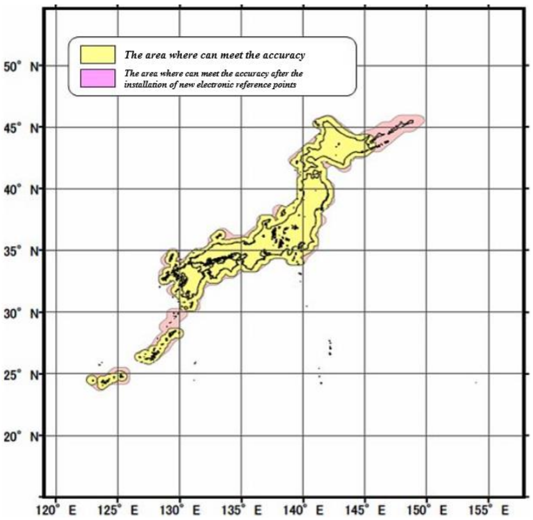


Fig. 11. Service Area of CLAS *(Yellow Area)*

(i.) The Result of CLAS Static Positioning

The 24-h data (January 7th-8th, 2018) of the horizontal and height errors of the static positioning of CLAS are as shown below (Fig. 12).

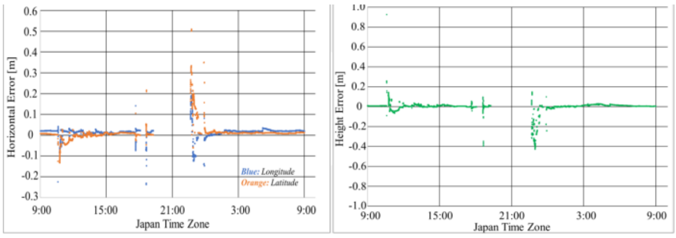


Fig. 12. Horizontal and Height Error of CLAS Static Positioning

The discontinuity in the data correspond to the period when the elevation angle of unit 1 of QZSS was less than approximately 10 degrees as shown below (Fig. 13). Evidently, the L6 signal band could not be captured during this period.

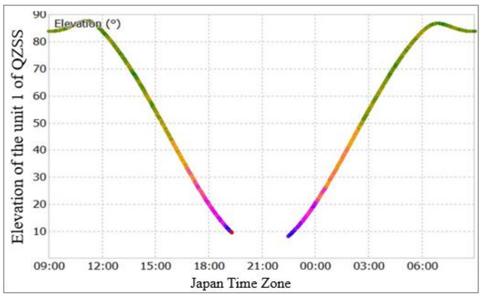


Fig. 13. Elevation of the unit 1 of QZSS

Even in the time zone in which the correction information was stably acquired, there are a few deviations of larger magnitude; however, the overall result is considered to be stable. The experimental data comprised 70024 time points (RTK fixed epochs) out of an opportunity of 86400 seconds (3600 s per hour x 24 h per day). The standard deviation and 95 percentile of horizontal and height errors are as shown below. (TABLE II).

TABLE II. RESULT OF CLAS STATIC POSITIONING *(JANUARY 7)*

| Number of RTK fixed solution 70024 [sec] / 86400 [sec] | Horizontal | Height |
|---|---|---|
| Standard deviation [m] | 0.025 | 0.037 |
| 95 percentile value [m] | 0.040 | 0.022 |

Moreover, as the above result is only for a day, the data for nine days are as shown below (TABLE III).

TABLE III. RESULT OF CLAS STATIC POSITIONING *(ALL DATA)*

| Date and Time | 95 Percentile Value of Horizontal Error [m] | 95 Percentile Value of Height Error [m] |
|---|---|---|
| December 23 - 24, 2017 | 0.059 | 0.083 |
| December 24 - 25, 2017 | 0.056 | 0.088 |
| December 25 - 26, 2017 | 0.080 | 0.105 |
| December 26 - 27, 2017 | 0.087 | 0.095 |
| December 29 - 30, 2017 | 0.055 | 0.071 |
| January 5 - 6, 2018 | 0.042 | 0.053 |
| January 7 - 8, 2018 | 0.040 | 0.022 |
| January 8 - 9, 2018 | 0.023 | 0.022 |
| January 9 - 10, 2018 | 0.032 | 0.032 |

It is observed that the horizontal error occasionally exceeds the specified accuracy, while all the data points of the height error are within the specified accuracy, especially within 10 cm. These results reveal that the positioning data obtained using the AQLOC receiver are satisfactory; thus, the RTK Fix rate and the correction information from unit 1 of QZSS are found to be in order, thereby confirming that the performance of CLAS with regard to static positioning is well demonstrated.

(ii.) The Result of CLAS Kinematic Positioning

First, the results of the experiment on CLAS kinematic positioning conducted in an ordinal road in Ariake city and the route of the car are as shown below (Fig. 14, Fig. 15, and TABLE IV). The experiment was conducted on December 21st, 2017.

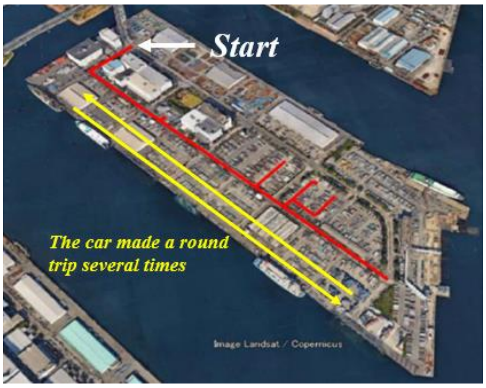


Fig. 14. Route of the Car *(CLAS Experiment in Ariake)*

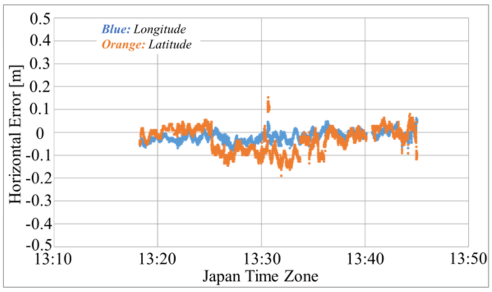


Fig. 15. Horizontal Error *(CLAS Experiment in Ariake)*

TABLE IV. RESULT *(CLAS EXPERIMENT IN ARIAKE)*

| Fix rate of CLAS: 97.79%<br>Fix rate of SPS855: 99.84% | Horizontal | Height |
|---|---|---|
| Standard deviation [m] | 0.060 | 0.308 |
| 95 percentile value [m] | 0.149 | 0.147 |

It is observed that the 95 percentile values for both horizontal and height errors are less than 15 cm.

Second, the results of the experiment on CLAS kinematic positioning conducted on a highway (Metropolitan Expressway) and the route of the car are as shown below (Fig. 16, Fig. 17, and TABLE V). The experiment was conducted on January $4^{th}$, 2018.


Fig. 16. Route of the Car *(CLAS Experiment in Highway)*

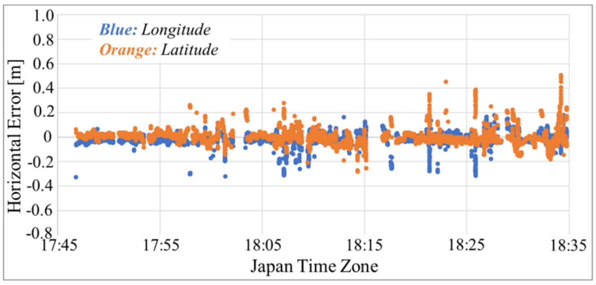


Fig. 17. Horizontal Error *(CLAS Experiment in Highway)*

TABLE V. RESULT *(CLAS EXPERIMENT IN HIGHWAY)*

| Fix rate of CLAS: 76.85%<br>Fix rate of SPS855: 90.32% | Horizontal | Height |
|---|---|---|
| Standard deviation [m] | 0.047 | 0.268 |
| 95 percentile value [m] | 0.139 | 0.152 |

It is observed that the 95 percentile value for the horizontal and height errors were within 14 cm and 15 cm, respectively.

We also investigated the time required in re-fixing the signal connection that gets lost while crossing an overpass on a highway. The pictures of the overpass are as shown below (Fig. 18).

Fig. 18. Pictures of Overpasses *(CLAS Experiment in Highway)*

Since CLAS is a system based on open sky and semi-open sky conditions such as a highway, a cycle slip is likely to occur while crossing the obstacles like an overpass. Considering the intended application of CLAS to automobiles as well, it is important to assess the time taken by CLAS in re-fixing the lost connection. The number of overpasses and the time taken for re-fixing the connection are as shown below (TABLE VI) for the survey grade receiver (SPS855) and the receiver for CLAS (AQLOC).

TABLE VI. TIME REQUIRED FOR RE-FIXING *(IN HIGHWAY)*

| | Total Time of No RTK fixed [sec] | Small Overpasses (25 Overpasses) | Big Overpasses (22 Overpasses) | Total Time Required for Re-fixing [sec] |
|---|---|---|---|---|
| SPS855 | 279.2 | 3.2 [sec] (Average)<br>Max is 4.0 [sec] | 7.5 [sec] (Average)<br>Max is 10.0 [sec] | 245 |
| AQLOC | 666.3 | 7.2 [sec] (Average)<br>Max is 9.0 [sec] | 14.0 [sec] (Average)<br>Max is 16.0 [sec] | 488 |

It is observed that a discontinuity in the time span (during which the RTK fixed solution could not be reached) is mostly attributable to a cycle slip when the car passed under the overpasses, and that the time taken by AQLOC receiver to recover RTK positioning was found to be fairly less compared with the conventional RTK positioning value. The time taken for re-fixing was 14 s for the big overpasses and 7 s for the small overpasses in this experiment.

Third, the results of the CLAS kinematic positioning on the sea (Tokyo Bay) and the route of the ship are as shown below (Fig. 19, Fig. 20, and TABLE VII). The experiment was conducted on January $16^{th}$, 2018.


Fig. 19. Route of the Ship *(CLAS Experiment on the Sea)*

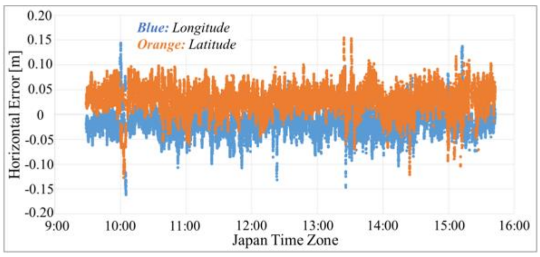


Fig. 20. Horizontal Error *(CLAS Experiment on the Sea)*

TABLE VII. RESULT *(CLAS EXPERIMENT ON THE SEA)*

| Fix rate of CLAS: 99.19%<br>Fix rate of SPS855: 99.99% | Horizontal | Height |
|---|---|---|
| Standard deviation [m] | 0.021 | 0.035 |
| 95 percentile value [m] | 0.079 | 0.091 |

It is observed that the 95 percentile value for the horizontal error was approximately 8 cm and that for the height error was approximately 9 cm on the sea. Owing to the open-sky condition and the speed of the ship, the result was better than the car experiment.

## IV. PPP EXPERIMENT

- *Experiment Description*

In September 2017, we conducted the static and kinematic positioning using PPP at the rooftop of the number 4 research building in Etchujima campus of TUMSAT and near the campus in Tokyo. We used the receiver manufactured by Magellan Systems Japan Inc. comprising a L6 signal band decoder and a PPP engine. The correction information sent from the unit 1 of QZSS was used for the L6 signal band.

### A. *Static Positioning Experiment*

In the experiment of the static positioning, GrAnt-G5T antenna was installed on the rooftop of the number 4 research building and data was collected starting from the evening of September 4th, 2017 until the moment the unit 1 of QZSS remained active (about 12 h). The antenna and receiver are as shown below (Fig. 21). An SPS855 receiver was used to derive the true position of the antenna.

Fig. 21. Antenna *(GrAnt-G5T)* and Receivers *(SPS855 and Magellan)*

### B. *Kinematic Positioning Experiment*

In the experiment of the kinematic positioning, data was obtained on the ordinal road in nearly open-sky condition near the Harumi Wharf in Tokyo on September 6th, 2017. A GPS-703-GGG antenna manufactured by NovAtel Inc. was installed on the roof of the car. The true value and the evaluated value are found to be the same as those described for the kinematic positioning of CLAS. The setup of the equipment in the experimental car and the route of the car are as shown below (Fig. 22 – Fig. 23). The unit 1 of QZSS was located at a high elevation angle.

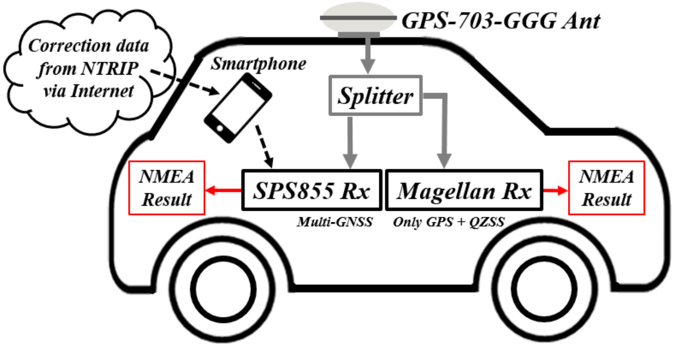


Fig. 22. Settings of Equipment in the Experimental Car


Fig. 23. Route of the Car *(PPP Experiment)*

### C. *Results*

(i.) The Result of PPP Static Positioning

The results of PPP static positioning are as shown below (Fig. 24 and TABLE VIII).

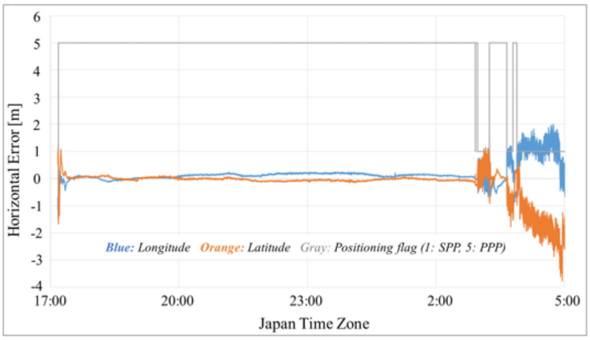


Fig. 24. Horizontal Error of PPP Static Positioning

TABLE VIII. RESULT OF PPP STATIC POSITIONING

| Accuracy | Horizontal | Height |
|---|---|---|
| Standard deviation [m] | 0.092 | 0.035 |
| Bias [m] | 0.108 | 0.091 |

Fig. 24 shows that the positioning flag indicates the positioning method used to output the solution: 1 means Single Point Positioning (SPP) and 5 means PPP. The positioning flag shifted from SPP to PPP within 1 min after switching on the receiver and a convergence within 10 cm in the horizontal direction was achieved in approximately 15 min. In fact, the bias shown in TABLE VIII occurred between the convergence value and the F3 solution (RTK fixed solution) of the Geospatial Information Authority of Japan in each direction; therefore, except for the bias, almost the same accuracy as CLAS can be expected after the convergence. Besides, the reason why the positioning flag was switched from PPP to SPP at the end of the session was that the time period when the elevation angle of unit 1 of QZSS was less than approximately 10 degrees came.

(ii.) The Result of PPP Kinematic Positioning

The results of PPP kinematic positioning are as shown in the following page (Fig. 25).

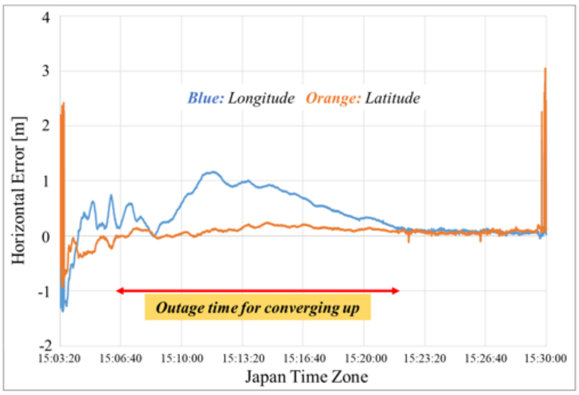


Fig. 25. Horizontal Error of PPP Kinematic Positioning

It is observed from the first part of Fig. 25 that the PPP was not initially converging because the car was travelling in urban areas. The car waited for 15 min to converge at the start point as shown in Fig. 23 before it started moving. A good accuracy within 10 cm was achieved in motion, considering the nearly open-sky condition; however, the same bias as the static positioning was observed. When the car entered a section surrounded by many obstacles, the output of the Magellan receiver immediately started deteriorating.

## V. Evaluation of SLAS

The static positioning experiment was conducted using SLAS for each baseline length (of the order of tens to hundreds of km) using the electronic reference points of the Geospatial Information Authority of Japan. The data of the Kanto area (around Tokyo) and Okinawa area (southernmost island in Japan) were acquired for each baseline length, and the DGNSS positioning results were examined using the post-processing function of RTKLIB (ver.2.4.3 b29). Since the correction information superimposed on the L1S signal band was also from the data of the electronic reference points like the CLAS, the post-processed result of DGNSS positioning using the data of the electronic reference points can be regarded as almost the same performance of the real-time DGNSS positioning via QZSS. The period of data used for the analysis was 24 h from 12:00 AM (UTC) on 15th July to 12:00 AM on 16th July, and the location information of the reference points is as shown below (Fig. 26 – Fig. 27).


Fig. 26. Location Information of Reference Points *(Okinawa Area)*


Fig. 27. Location Information of Reference Points *(Kanto Area)*

In Okinawa area, we selected five reference points for every baseline length: approximately 11 km (Naha), 52 km (Ginoza), 102 km (Kunigami), 175 km (Wadomari), and 312 km (Naze), considering "Itoman" as the reference station. In Kanto area, we selected five reference points for every baseline length: approximately 20 km (Jo-hoku), 50 km (Iwase), 100 km (Moriya), 204 km (YugawaraA), and 300 km (OmaezakiA), considering "Hitachi" as the reference station. The post-processed results of the DGNSS positioning for each region and each reference point are as shown in TABLE IX – TABLE X and Fig. 28 – Fig. 29. Furthermore, the receiver used by each reference point is NetR9 manufactured by Trimble Corporation, and the antenna (TRM59800.80) is also of Trimble, for the locations other than "Hitachi" and "Naze". For "Hitachi", the antenna was TPSCR.G5 manufactured by TOPCON Inc. For "Naze", the receiver was DELTA-G3T manufactured by JAVAD GNSS Inc., and the antenna was TPSCR.G5. Both equipment are intended for surveying.

TABLE IX. DGNSS Positioning Result in Okinawa Area

| Horizontal Errors [m] | Naha | Ginoza | Kunigami | Wadomari | Naze |
|---|---|---|---|---|---|
| Avg. | 0.0325 | 0.0387 | 0.0915 | 0.138 | 0.422 |
| Std. | 0.322 | 0.353 | 0.294 | 0.326 | 0.556 |
| RMS | 0.324 | 0.355 | 0.308 | 0.354 | 0.698 |

| Height Errors [m] | Naha | Ginoza | Kunigami | Wadomari | Naze |
|---|---|---|---|---|---|
| Avg. | 0.0227 | 0.0436 | 0.0822 | 0.163 | 1.17 |
| Std. | 0.587 | 0.613 | 0.514 | 0.559 | 1.18 |
| RMS | 0.587 | 0.615 | 0.521 | 0.582 | 1.66 |

TABLE X. DGNSS Positioning Result in Kanto Area

| Horizontal Errors [m] | Jo-hoku | Iwase | Moriya | YugawaraA | OmaezakiA |
|---|---|---|---|---|---|
| Avg. | 0.124 | 0.0586 | 0.0739 | 0.104 | 0.182 |
| Std. | 0.325 | 0.311 | 0.312 | 0.338 | 0.354 |
| RMS | 0.345 | 0.317 | 0.32 | 0.354 | 0.398 |

| Height Errors [m] | Jo-hoku | Iwase | Moriya | YugawaraA | OmaezakiA |
|---|---|---|---|---|---|
| Avg. | 0.0356 | 0.0299 | 0.12 | 0.114 | 0.1 |
| Std. | 0.558 | 0.513 | 0.53 | 0.572 | 0.578 |
| RMS | 0.559 | 0.513 | 0.543 | 0.583 | 0.586 |

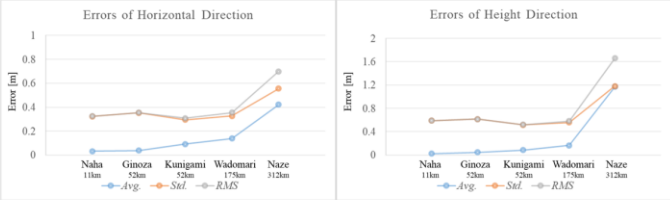


Fig. 28. Errors of Horizontal and Height Direction *(Okinawa Area)*

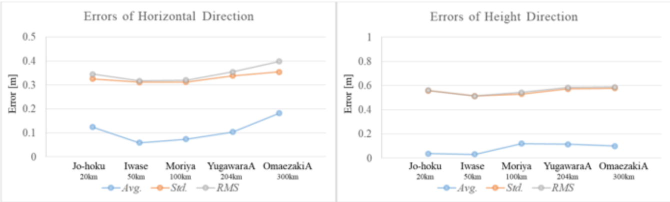


Fig. 29. Errors of Horizontal and Height Direction *(Kanto Area)*

The daily average values of the RTK fixed solution are uploaded on the Web of the Geospatial Information Authority of Japan on daily basis, using which the average (Avg.), standard deviation (Std.), and root mean square (RMS) were calculated for each reference point using the value in RTK positioning calculation as the precise position. The satellite system used for the positioning calculation comprised GPS, QZSS and Galileo. Fig. 28 and Fig. 29 show the graphical representations of TABLE IX and TABLE X, respectively. In Kanto area, even with the extension of baseline length to 300 km, the deterioration in accuracy was only marginal compared to the 20 km point. In contrast, the accuracy deteriorated in Okinawa area, where the baseline was extended to 312 km. The specification of positioning accuracy and service area of SLAS made public by the cabinet office formally are as shown below (TABLE XI and Fig. 30). Field (1) and Field (2) in TABLE XI support (1) and (2) in Fig. 30.

TABLE XI. POSITIONING ACCURACY OF SLAS

| Field type | Positioning Error | |
|---|---|---|
| | Horizontal | Vertical |
| Field (1) | Not exceeding 1.0m (95%) ( 0.58m (RMS) ) | Not exceeding 2.0m (95%) ( 1.02m (RMS) ) |
| Field (2) | Not exceeding 2.0m (95%) ( 1.16m (RMS) ) | Not exceeding 3.0m (95%) ( 1.53m (RMS) ) |

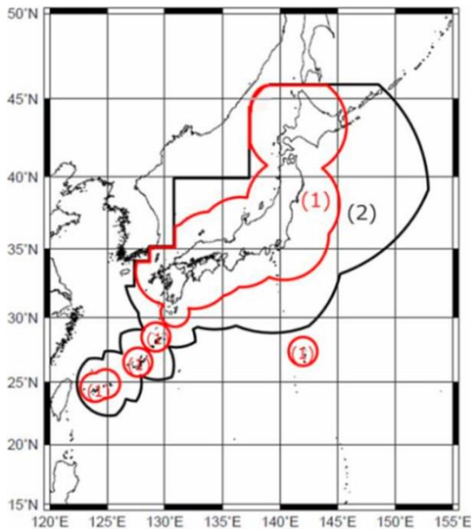


Fig. 30. Service Area of SLAS

The present data used for the analysis is subject to Field (1). It is observed that both the horizontal and the vertical directions are observed to meet the RMS value of the specification comfortably in Kanto area. The results of Okinawa area met the specification up to 175 km; however, the accuracy of DGNSS positioning deteriorated at the 312-km point, and the result did not meet the specification. It is also conceivable that the receiver and antenna used at "Naze" differed from other reference points; however, the effect of the ionosphere on the results must also be suitably considered because the data is obtained by the survey grade receiver and antenna. The actual reference points used for SLAS correction information (probably hundreds of reference points) are not published; however, it was confirmed that the possibility of deterioration in the positioning accuracy of SLAS in the southern island in Japan is larger compared with Kanto area.

## VI. SUMMARY AND FUTURE WORK

In this paper, we reported the performances of the new reinforcement functions of QZSS (CLAS, PPP, and SLAS) evaluated by means of suitable positioning experiments.

The experimental results of kinematic positioning using CLAS showed relatively less accuracy compared to published specifications; however, as the 95 percentile values were not perceptibly deteriorated, the overall result was considered to be satisfactory. In addition, even in the case of a cycle slip under the overpasses, it showed satisfactory performance as the results matched fairly with the normal RTK positioning, and the RTK Fix rate was also significantly high. The results were obtained only in Tokyo and Chiba prefecture; therefore, it is proposed to continue the investigation in other areas of Japan. The exact causes of the outliers will also be explored. Studies will also be conducted for the improvement of accuracy using other related factors such as Doppler velocity. The observations as above are applicable to the case of PPP as well.

In the case of SLAS, the ionosphere was found to be a critical factor as it varies with the geographical location in Japan. It was also confirmed that the deterioration of the precision differs when the baseline length extends. It is conceivable that the performance of SLAS (after official commencement of its operation) will be the same as the observed experimental results of the DGNSS positioning. As the experiments in the present study were conducted during summer, we propose to capture the seasonal influence of the solar activity in the next one year.

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Author's picture

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