PERFORMANCE EVALUATION OF SINGLE FREQUENCY RTK-GNSS POSITIONING FOR STRUCTURE INSPECTION USING WEARABLE SENSORS

Kouki Kurita, Shigeki Takahashi, Masafumi Nakagawa

Shibaura Institute of Technology, 3-7-5, Toyosu, Koto-ku, Tokyo 135-8548, Japan
Email: ah16206@shibaura-it.ac.jp; mnaka@shibaura-it.ac.jp

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ABSTRACT: The efficient infrastructure inspection requires low-cost and high-precision positioning and 3D measurement technologies. In this paper, we focused on single-frequency precise point positioning (PPP) and single-frequency RTK-GNSS positioning to improve the positioning accuracy with low cost devices. Moreover, we focused on the performance of the antenna on positioning accuracy. First, we evaluated the positioning performance of PPP and single-frequency RTK-GNSS positioning with the same GNSS antenna. Second, we evaluated the positioning performance of GNSS antenna on positioning accuracy, using a low-cost GNSS antenna and professional GNSS antenna for surveying. Third, we conducted outdoor experiments to simulate bridge inspection work. Through our experiments, we verified that single-frequency RTK-GNSS positioning can be used for the improvement of positioning performance in infrastructure inspection work.

1. INTRODUCTION

There are approximately 700,000 bridges in Japan. The percentage of bridges over 50 years after construction will be 67% in 2033, because many bridges in Japan were built from 1950 to 1970. Thus, the efficient infrastructure inspection work is required for bridge maintenance projects. Currently, Japan is facing the issues of declining birthrate and aging population. The issues are related to the shortage of engineers in various fields including civil engineering. In the near future, demands of infrastructure inspection will increase even if there will be fewer engineers. Therefore, more efficient infrastructure inspection approaches should be developed. Low-cost and high-precision positioning is one of significant technologies to achieve higher speed and more efficient infrastructure inspection and maintenance. In our preliminary experiments, we used wearable sensors for bridge inspection with GPS point positioning. However, we have confirmed that positioning errors were too large to determine accurate inspector positions and behaviors. In particular, because the altitude accuracy was several meters, it was difficult to recognize detailed behaviors of inspectors. We have also confirmed that positioning accuracy is required within 20 cm to recognize inspector behaviors. Therefore, we focused on the improvement of positioning accuracy with low-cost real-time kinematic global navigation satellite systems (RTK-GNSS). Recently, we can use multi-GNSS environments, consisted of global positioning systems (GPS), BeiDou, GLONASS, and quasi-zenith satellite system (QZSS) to improve the availability, accuracy, continuity, and integrity in positioning. Moreover, precise point positioning (PPP) using SBAS and single-frequency RTK-GNSS positioning are expected to improve positioning performance with low-cost devices.

PPP is an improved point positioning using carrier waves, as shown in Figure 1. Distances between a receiver and each satellite are estimated using precise ephemeris and clock data of all visible satellites to improve the positioning accuracy without on-site base stations. Single-frequency RTK-GNSS positioning (Figure 2) is based on a carrier phase observation. A difference between conventional RTK positioning and single-frequency RTK-GNSS positioning is the number of signals used for positioning calculation. Conventional RTK positioning requires only GPS environments. On the other hand, single-frequency RTK-GNSS positioning requires multi-GNSS environments. In this paper, we apply PPP and single-frequency RTK-GNSS positioning for bridge inspection with wearable devices. We also evaluate the performance of GNSS antenna in positioning when we use low-cost GNSS receivers.

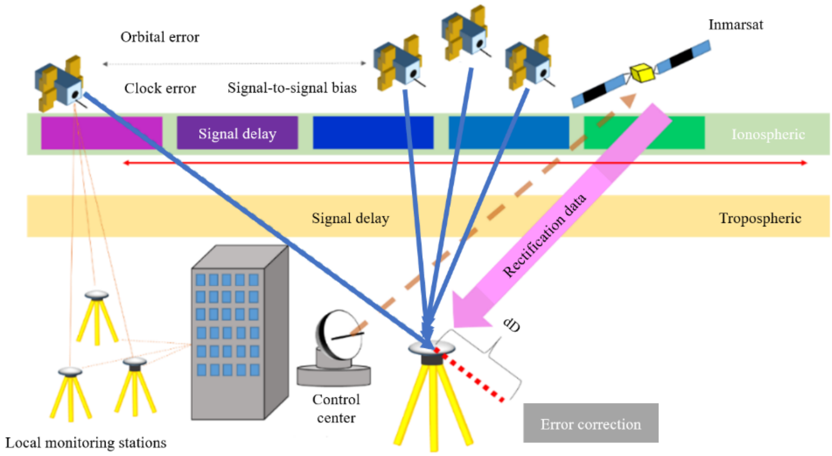


Figure 1. PPP

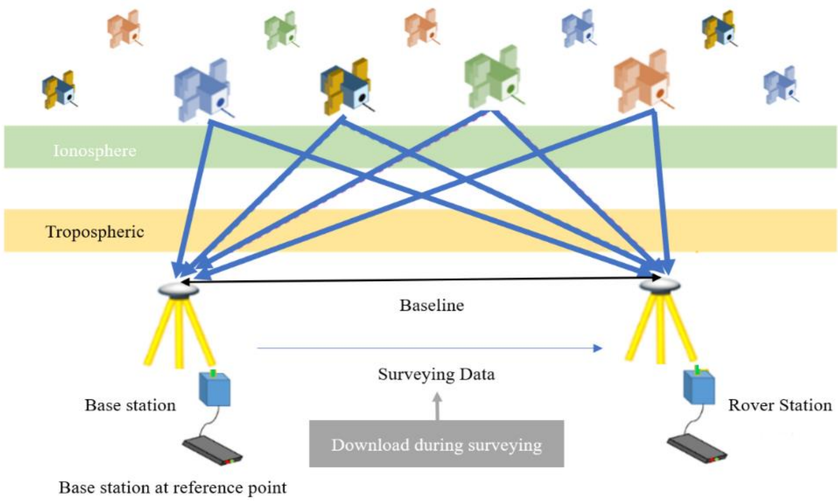


Figure 2. RTK-GNSS

2. METHODOLOGY

Generally, wearable devices consist of a low-cost GNSS receiver and antenna. In this paper, we focus on GNSS positioning with wearable devices to obtain inspector position and behavior data in infrastructure inspection work. We propose two types of experiments to evaluate the performance of low-cost GNSS positioning. In the first experiment, we evaluate the performance of PPP and single frequency RTK-GNSS using low-cost devices in infrastructure inspection work. In the second experiment, we evaluate the performance of GNSS antenna.

2.1 Performance evaluation of PPP and single frequency RTK-GNSS

We use the same GNSS antenna for PPP and single-frequency RTK-GNSS. We select two positions with different heights and move the antenna between the two positions. We estimate the height difference using PPP and single-frequency RTK-GNSS data, and we compare the positioning results with measured values with ground surveying.

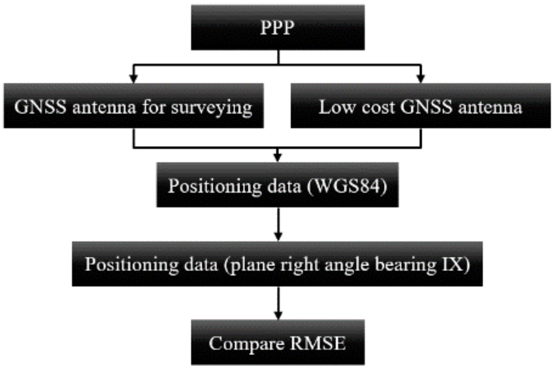


Figure 3. Experiment on performance evaluation of PPP and single-frequency RTK-GNSS

2.2 Performance evaluation of GNSS antenna

We compare a low-cost antenna with a professional antenna for surveying. We acquire temporal PPP data with static positioning, and we calculate the average value of these positioning data, as shown in Figure 4. In addition, VRS positioning is performed at the same point to be used reference data.

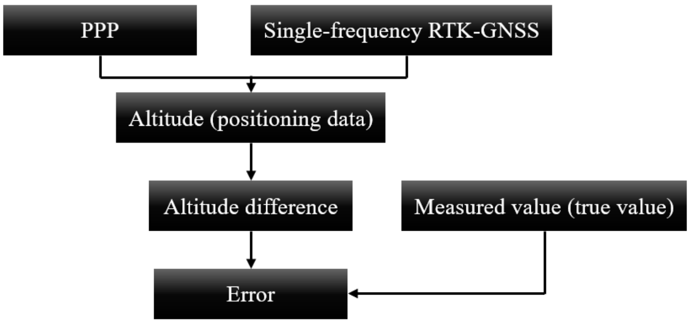


Figure 4. Experiment on performance evaluation of GNSS antenna

3. EXPERIMENTS

3.1 Used equipments

In our experiment, we used EVK-7P (u-blox) and C94-M8P (u-blox)) as low-cost GNSS receivers. Moreover, we used a professional antenna for surveying (Zephyr geodetic2, Nikon-Trimble), and low-price antenna (EVK-7P accessory, u-blox).

Table 1. Used equipments

	GNSS receiver		GNSS antenna
Name	EVK-7P (u-blox)	C94-M8P (u-blox)	Trimble Zephyr geodetic2 (NIKON)
Image			
Specification	**Electric power**: 5V **Dimensions**: 105 × 64 × 26mm **Interface**: RS-232 (max 921 k6 bps) **Raw data output**: ○ **Available satellites**: GPS,GLONASS,QZSS,SBAS	**Electric power**: 5V **Dimensions**: 76 × 55 × 14 mm **Protocol**: NMEA, UBS, RTCM **Available satellites**: GPS, BeiDou, GLONASS, QZSS, SBAS	**Electric power:** Low voltage / power saving **Dimensions**: 34.3 cm diameter x 7.6 cm height **Weight**: 1.36kg **Supported satellite signals**: GPS (L1, L2, L5), GLONASS (L1, L2, L3), Galileo (E1, E2, E5, E6), SBAS (WAAS, EGNOS, MSAS, QZSS, Gagan, Omnistar) **Trimble Stealth Ground Plane**: Lightweight / multipath removal

3.2 Performance evaluation of PPP and single frequency RTK-GNSS

We selected two points A and B on stepped ground surfaces at Toyosu campus in Shibaura Institute of technology in our experiment, as shown in Figure 5. The height difference between point A and point B was measured in manual as 423 mm. We selected low-cost antennae and metal disks (ground plane) were installed under each GNSS antenna to remove multipath effects, as shown in Figure 6. GNSS positioning data were obtained for 60 seconds or 120 seconds with five continuous observations. In PPP and single-frequency RTK-GNSS positioning, u-center (u-blox) was used.

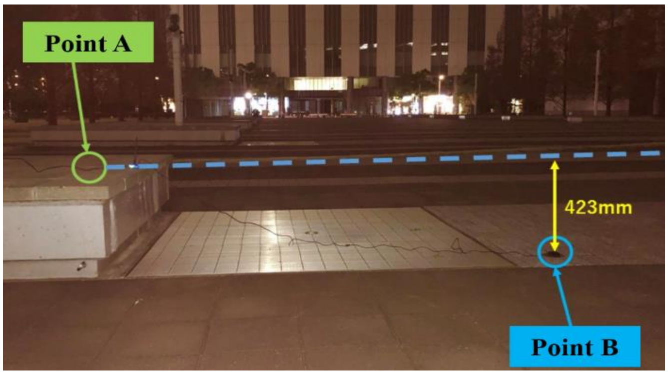


Figure 5. Positioning environment

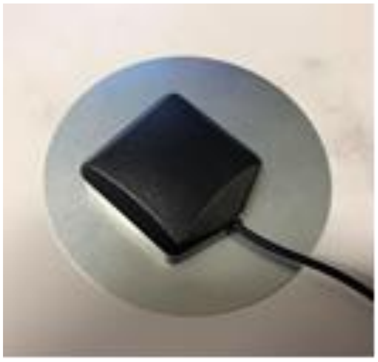


Figure 6. Used antenna (with a ground plane)

Table 2. Used satellite signals in GNSS positioning

	GPS	GLONASS	BeiDou	Galileo	QZSS	MSAS
PPP	✓	Not used	Not used	Not used	✓	✓
Single-frequency RTK-GNSS	✓	Not used	✓	Not used	Not used	Not used

3.3 Performance evaluation of GNSS antenna

We selected a reference point on a road in our experiment. First, the professional GNSS antenna was installed on the tripod. We connected the GNSS antenna to EVK-7P, and obtained PPP data with u-center. We obtained static PPP data for 30 minutes. Next, we immediately changed from the professional GNSS antenna to the low-cost GNSS antenna, and we obtained static PPP data for 30 minutes. Then, VRS-GNSS positioning was performed at the same position after PPP observations to evaluate PPP data.

Figure 7. Positioning environment (low-cost antenna)

Figure 8. Positioning environment (professional antenna)

4. RESULTS

4.1 Evaluation of positioning performance with a low-cost GNSS receiver

Figure 9 shows our positioning results (height data). We evaluated each positioning data in five observation sections. In PPP positioning, the minimum RMSE value was 399.2mm (the second section) and the maximum RMSE value was 703.6mm (the fourth section). In single frequency RTK-GNSS, the minimum RMSE value was 98.1 mm (the first section) and the maximum RMSE value was 174.9 mm (the fifth section). Moreover, we evaluated differences of height between positions A and B. Figure 9 indicates that single frequency RTK-GNSS provided more accurate and stable than PPP. The difference of the minimum RMSE values between the PPP and single frequency RTK-GNSS was approximately 300 mm.

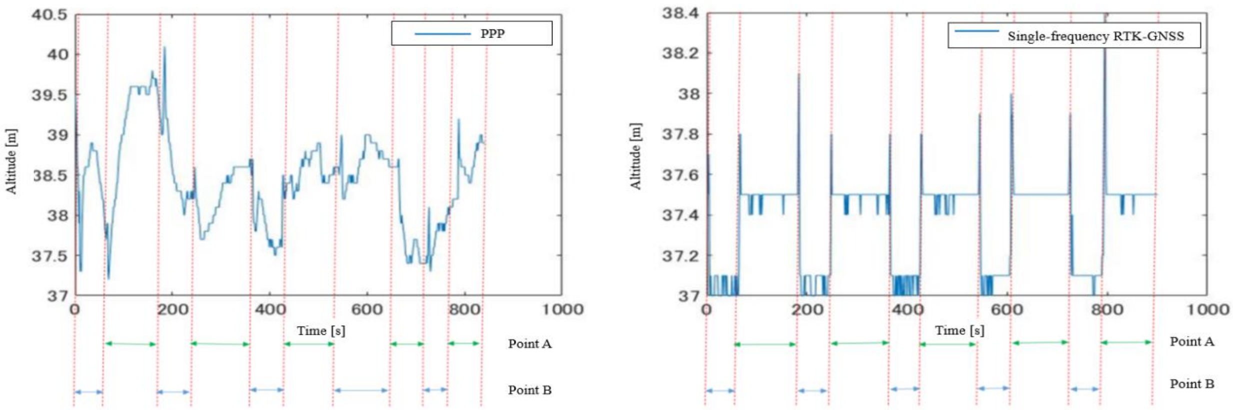


Figure 9. Positioning results (left: PPP, right: single-frequency RTK-GNSS)

4.2 Evaluation of GNSS antenna

Figure 10 shows the positioning results in our evaluation of GNSS antennae. The positioning data using the low-cost antenna was 0.3552 m (RMSE) in the X-axis direction and 0.3534 m (RMSE) in the Y-axis direction. On the other hand, positioning data using the professional antenna was 0.0552 m (RMSE) in the X-axis direction and 0.0442 m (RMSE) in the Y-axis direction. The center point (×) of each image indicates VRS positioning data. The error between the VRS positioning data and the positioning data using the low-cost antenna was 0.6313 m (RMSE) in the X axis direction and 1.5191 m (RMSE) in the Y-axis direction. On the other hand, the error between the VRS positioning data and the positioning data using the professional antenna was 0.1762 m (RMSE) in the X-axis direction and 1.1467 m (error) in the Y-axis direction.

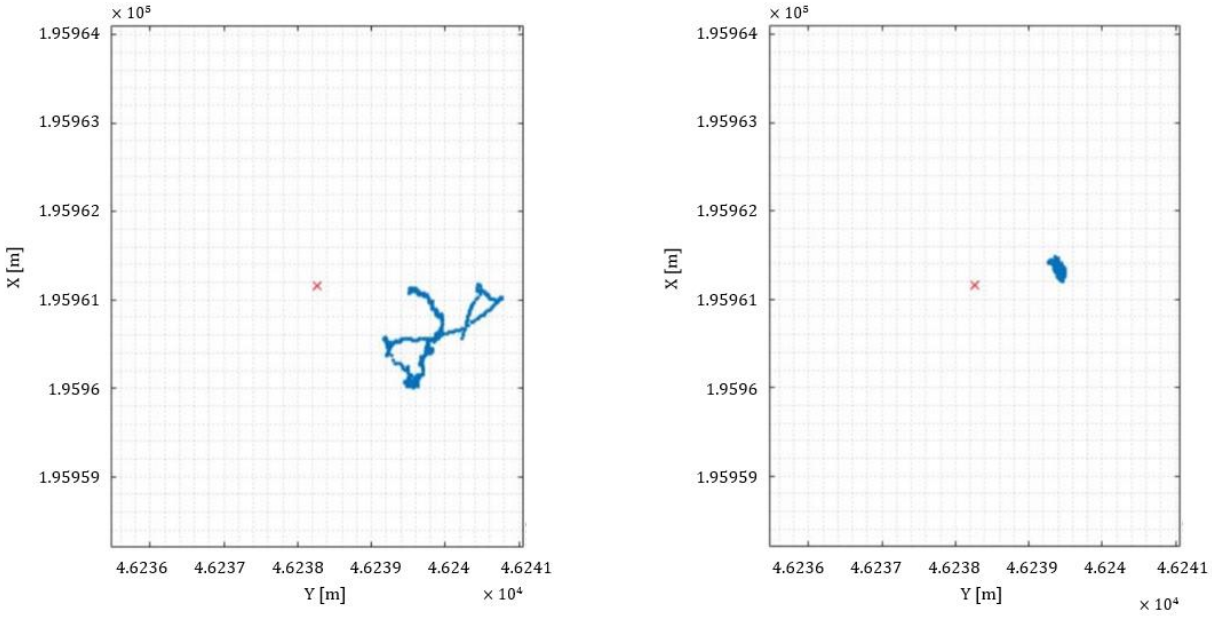


Figure 10. Static point positioning results (left: low-cost antenna, right: professional antenna)

5. DISUCUSSION

5.1 Evaluation of low-cost GNSS receivers

First, we evaluated low-cost GNSS receivers on the positioning accuracy. In our experiment with the PPP, the maximum error was 703.58 mm (RMSE) (the fourth section) and the minimum error was 399.22 mm (the second section), as shown in Table 3. In the single-frequency RTK-GNSS positioning, the maximum error was 174.88 mm (RMSE) and the minimum value was 98.13 mm (RMSE), as shown in Table 4. Experimental results indicate, that single-frequency RTK-GNSS positioning can provide higher accurate data than PPP. Experimental results also indicate that the single-frequency RTK-GNSS has possibility to recognize inspector behaviors such as standing and sitting in bridge inspection, because the single-frequency RTK-GNSS positioning provided height data within 20 cm accuracy.

Table 3. PPP positioning result

	Maximum error values [mm]	Minimum error values [mm]	RMSE [mm]	The number of visible satellites
1	2077	23	684.23	10
2	1977	23	399.22	10~13
3	977	23	410.29	13
4	1177	23	703.58	13
5	1477	23	509.72	13

Table 4 Single-frequency RTK-GNSS positioning result

	Maximum error values [mm]	Minimum error values [mm]	RMSE [mm]	The number of visible satellites
1	423	23	98.13	16
2	577	23	107.87	16
3	423	23	107.16	16
4	577	23	124.18	16
5	977	23	174.88	16

Second, we evaluated the continuity and availability based on fixed rates. In single-frequency RTK-GNSS positioning, the fixed rate was 100% in our experiments. However, when the open sky ratio is poor, the fixed rate would be decreased because the number of visible satellites would decrease. The positioning accuracy under the float status is generally worsened from 20 cm to 1 m. In bridge inspection work, fixed rates are significant values to evaluate the positioning accuracy under or around bridges.

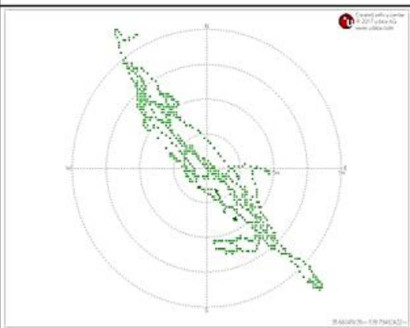
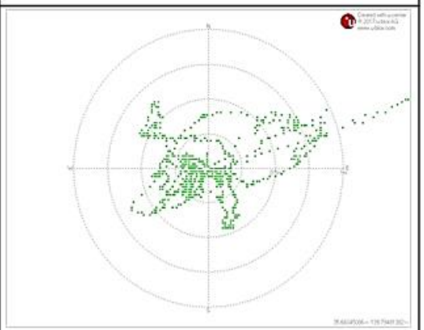
5.2 Evaluation of GNSS antenna

In the evaluation of GNSS antenna, a low-cost antenna was compared with a professional GNSS antenna under the same open sky environments with 1 hour time difference. Although the low-cost antenna received many satellite signals, Figure 11 shows that the low-cost antenna was affected by GNSS signals reflected from ground surfaces and the professional antenna rejected GNSS signals reflected from ground surfaces.

Figure 11. Satellite arrangements (left: low-cost antenna, right: professional antenna)

An additional experiment was conducted to confirm the performance of the ground plane under multipath problem, as shown in Table 5. First, a static PPP observation was performed using a low-cost antenna. Second, the additional static PPP observation was performed using the same low-cost antenna on an aluminium lid of pan. We confirmed that ground plane can improve the stability of positioning, even if we use a low-cost GNSS antenna.

Table 5. Additional experiments on multipath problem

	Without ground plane	With ground plane
Experiment environments		
Positioning results		

6. CONCLUSION

In this study, we focused on low-cost positioning in bridge inspection work using wearable devices. We conducted experiments to evaluate, PPP and single-frequency RTK-GNSS positioning using low-cost GNSS receivers. We also conducted experiments to evaluate the performance of low-cost GNSS antenna in positioning. We also discussed the continuity and availability of single-frequency RTK-GNSS positioning and antenna performance. Although wearable sensing requires 100% fixed rate in single frequency RTK-GNSS positioning, we confirmed that the fixed rate and positioning accuracy decrease in non-open sky areas. We also confirmed that positioning performance was improved by using a professional antenna for surveying. However, a large size antenna is unsuitable for wearable sensing. Therefore, a compact and precise GNSS antenna should be developed.

REFERENCES

Rui Tu, Jinhai Liu, Rui Zhang, Pengfei Zhang, Xiaodong Huang, 2019. RTK model and positioning performance analysis using Galileo four-frequency observations. Advances in Space Research, Volume 63, Issue 2, pp.913-926.

Nobuaki Kubo, 2015. High-precision positioning in the multi-GNSS era. System/Control/Information. Vol.59, No.4, pp. 120-125.

W. Stempfhuber, M. Buchholz, 2011. A precise, low-cost RTK GNSS system for UAV applications. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XXXVIII-1-C22-289.

Haibo He, Jinlong Li, Yuanxi Yang, Junyi Xu, Hairong Guo, Aibing Wang, 2013. Performance assessment of single- and dual-frequency BeiDou/GPS single-epoch kinematic positioning. GPS solutions, Volume 18, Issue 3, pp 393-403.