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APPLICATION OF RTK-GNSS TECHNOLOGY FOR FIELD SURVEYS BASED ON CM-LEVEL HIGH-PRECISION POSITIONING INFORMATION

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Abstract High-precision positioning using the Real Time Kinematic (RTK) Global Navigation Satellite System (GNSS) has attracted attention among field researchers who need accurate positional data for recording field sampling sites or correctly georeferencing various maps and images. However, because of the cost involved in the purchase and running of RTK-GNSS receivers, it is imperative to choose the equipment with the most suitable positioning function. Positioning accuracy with and without RTK correction has been compared in this study during its use in field surveys. Furthermore, the benefits of RTK-GNSS location were discussed, along with applications to other research scenarios.

Keywords: Real time kinematic, Global navigation satellite system, Positioning accuracy

1. Introduction

For geographical research, the location data gathered in the field is critical. It is prudent to capture the location of an object using satellite positioning for spatial analysis utilizing geographic information systems (GIS). The global navigation satellite system (GNSS) refers to all satellite positioning systems, including the Global Positioning System (GPS, USA) and Global Navigation Satellite System (GLONASS, Russia). Japan has progressed in developing the Quasi-Zenith Satellite System (QZSS), and the "QZS-1R satellite" was launched on October 26, 2021, to replace the first quasi-zenith satellite. Positioning information obtained by GNSS, which is widely used in mobile devices such as smartphones and car navigation systems, is said to have an error of approximately 10 m. In recent years, with the development of technologies such as Satellite-based Augmentation Systems (SBAS) and Assisted-GNSS, obtaining positioning data with reduced errors has become easier.

However, depending on the research goals, location data with accuracies in meters is insufficient. Precision farming, for example, which is a data-driven cultivation management system, requires precise positions of the management objective in order to track the growth pattern of each crop and the distribution of soil properties. A positioning precision of a few meters is insufficient for precisely recording the location of the controlled object for this purpose. Additionally, as unmanned aerial vehicles (UAVs) have become increasingly common, aerial photos with high ground resolution (several cm/pixels) are readily available, and to georeference these high-resolution sensing images,

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numerous sensor data, and ground-truths based on high-precision location data must be precisely aligned. In traditional environmental research, survey points are recorded by using a quadrat to acquire accurate location and human geo-referencing is also employed to adjust the position. However, these methods are not efficient considering the time and effort required for on-site work and the possibility of human error.

In this regard, the application of centimeter-accurate positioning by interferometric positioning has gained prominence. For example, Real-Time Kinematic (RTK)-GNSS enables positioning with a few centimeters accuracy in real-time, by using carrier-phase measurements to reduce and remove errors common to a base station and rover pair. Although a related positioning method is applied in differential-GNSS (D-GNSS), RTK-GNSS using the carrier-phase measurements are more precise than D-GNSS (NovAtel Inc. 2015). Furthermore, network-based RTK uses correction data from widely spread permanent base stations, such as the Geospatial Information Authority of Japan's network of electronic reference points, so there is no need to set up a base station in the field. Thus, this technology makes it simple to obtain high-precision positioning data using RTK-GNSS. In recent years, network-based RTK-GNSS positioning has become easier due to the development of virtual reference station (VRS) technology (e.g. Tsuzuku *et al.* 2001).

Currently in Japan, there are several commercial services transmitting correction signals from real base stations or virtual reference stations that are required for RTK positioning, and these correction data are utilized in various situations. However, the operation of RTK-GNSS requires sufficient funding to cover the initial purchase cost of RTK-GNSS receivers and their running costs. Even as the prices are decreasing, in field studies, an appropriate positioning method should be selected for specific research purposes. Therefore, in order to provide information about the application of positioning devices in field surveys, this paper provides a comparison between the accuracy of positioning information obtained by GNSS receivers that support RTK correction in comparison to positioning information obtained by common tools without RTK correction support. In addition, the advantages of RTK-GNSS positioning were reviewed with some examples.

2. Comparison of positioning accuracy with and without RTK correction

2.1 Field observation and post-processing

A performance comparison test of various GNSS receivers was conducted on August 31, 2021, at a test field of the National Agriculture and Food Research Organization (Tsukuba City, Ibaraki, Japan). In the study area, ground marks were painted on the asphalt surrounding the paddy field. The position of the center point was measured (Fig. 1) using three GNSS devices. DG-PRO01RW (BizStation Corp., Nagano) was used for RTK-GNSS positioning. We used the VRS correction data provided by JENOVA Corp. (URL: https://www.jenoba.jp/, Last access date: November 11, 2021). GPS and QZSS were set as satellites for observation. The positioning data without RTK correction was also recorded using the same DG-PRO01RW device for comparison. Google Pixel 3a (Google LLC, California) was also used as a common Android device capable of positioning. BasicAirData GPS Logger (URL: https://www.basicairdata.eu/projects/android/android-gps-logger/, Last access date: November 11, 2021), an application for Android systems, was used to record location data. GPSMAP 62SCJ (Garmin Ltd, Kansas) was used as a common GNSS device for fieldwork. This device supports GPS and QZSS signals and positioning data corrected by MSAS (MTSAT (Multi-functional Satellite) Satellite based Augmentation System). The location data sampling rates were set at 10 times/sec for the DG-PRO01RW, and set at one time/sec for GPSMAP 62SCJ and Google

Fig. 1 DG-PRO01RW on the painted marker.

Pixel 3a. The location logging period was two minutes.

Positioning data from each device exported as CSV files was loaded into QGIS ver. 3.10 as point data. For each dataset, we calculated the mean coordinates (MC) and standard distance (QGIS plugin available, URL: https://github.com/GuillemHerrera/StandardDistance, Last access date: December 3, 2021). In addition, we calculated the distances from the MC of RTK-GNSS positioning datasets to the MC of other data sets. The aerial images taken by Phantom 4 RTK (DJI Co. Ltd., Guangdong) on 7th Nov. 2019 were orthorectified for use as a base map. This orthorectification was performed by SfM-MVS (Structure from Motion-Multi View Stereo) using Pix4D Mapper ver. 4.5.6 based on ground control points with RTK-GNSS positioning according to Sakamoto *et al.* (2019a). Therefore, the positional accuracy was comparable to DG-PRO01RW with RTK correction.

2.2 Positioning accuracy of each observation

Table 1 and Fig. 2 summarizes the positioning result of each observation. The result of observation I, II, II, and IV were obtained by DG-PRO01RW with RTK correction, DG-PRO01RW without RTK correction, Google Pixel 3a, and GPSMAP 62SCJ, respectively. The standard distance and distance from the MC of observation I for each observation were shown in Table 1. The points obtained by RTK-GNSS positioning (observation I in Fig. 2) were distributed near the painted marker with high accuracy. In contrast, the other observation results showed lower accuracy. The MC of observation II, which was obtained by the same device as observation I without RTK correction, was 0.49 m from the MC of observation I and outside of the painted marker. The location

Table 1 Positioning result of each observation

Observations		Number of recorded points	Number of satellites	Standard Distance [m]	Distance from MC of I [m]
I	**DG-PRO1RW RTK mode**	1200	10	0.001	—
II	**DG-PRO1RW 3D mode**	1200	10	0.097	0.491
III	**Google Pixel 3a**	120	12	0.114	1.942
IV	**GPSMAP 62SCJ**	120	12	0.707	2.598

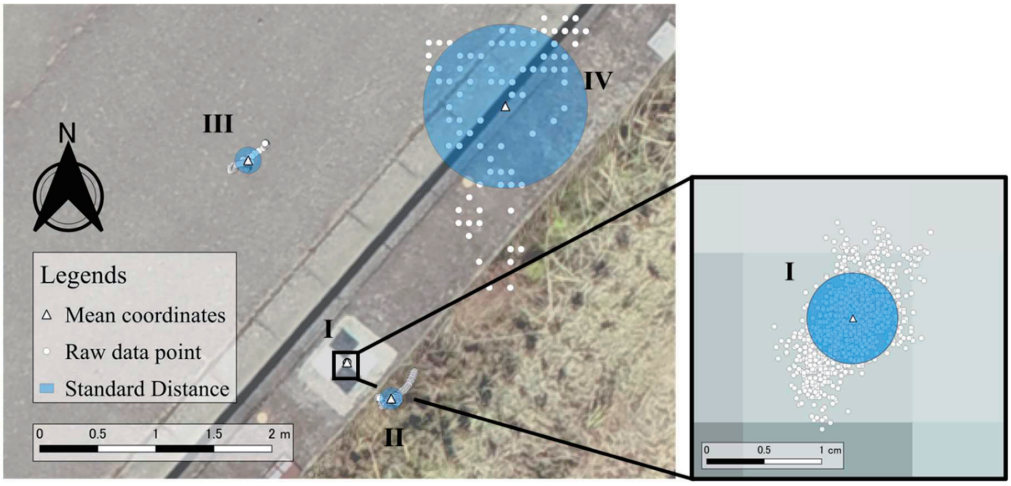

Fig. 2 Distribution of tracking points by each observation method of the painted marker. Roman numerals I, II, III, and IV correspond to the GNSS observations in Table 1.

data recorded by observation III and IV were farther from the target, and the distances from the MC to the painted marker were approximately 2 m.

As shown in the result of observation I, positioning by RTK-GNSS can record positions with extremely high accuracy. It is clearly superior to non-RTK positioning in situations requiring accurate location data. However, in order to use this, it is necessary to post-process using reference point data or to receive virtual reference point data by connecting to a network. The former requires time and expertise, and the latter requires a costly subscription plan to receive data. On the other hand, the results of non-RTK positioning using the same device (observation II) showed that sub-meter positioning was possible without RTK correction. This may be sufficient for a multi-point survey over a wide area, or for analysis overlaid with satellite images with a resolution of several meters. Even though the MC is far away from the markers, the result of observation III showed Android device is also useful because the standard distance is relatively small and smartphones are readily available. However, one of its drawbacks is that it is impossible to analyze the kind of correction being made. Because the positioning precision and technology employed are easier to understand, it would be safer to use a dedicated GNSS receiver for academic research in terms of dependability and reproducibility. The positioning result obtained by GPSMAP 62SCJ (observation IV) showed a clearly lower accuracy than the other devices, but this was designed for single-point positioning. It also has advantages in terms of ease of use and durability in the field environment.

All three devices are roughly the same price (initial cost) and are in the tens of thousands of yen range (a few thousand US dollars). In addition, using VRS RTK-GNSS requires a separate VRS subscription as mentioned above, which requires several ten thousand yen per year as running cost. Therefore, it is important to understand the positioning accuracy of each device and choose the one that best suits the observation target and situation. Some scenarios where RTK-GNSS placement is effective are mentioned in the next section.

3. Application examples of RTK-GNSS

Portable survey instruments and analyzers with the ability to ascertain locations have become increasingly popular in recent years. DIK-5532 (Daiki Rika Kogyo Co., Ltd., Saitama), for example, is a digital cone penetrometer controlled by an android device (Fig. 3). This instrument is ideal for data management in spatial surveys since the control device records the observed vertical hardness with location of the research site as digital data. However, because the location is gathered via Android devices, positioning precision is low and may not perform properly depending on the survey's scale. A comparison between the results of digital cone penetrometer positioning and RTK-GNSS positioning using a DG-PRO01RW is shown in Fig. 4. The survey points recorded in the digital cone penetrometer shown in Fig. 4(a) were obviously less accurate than those recorded by RTK-GNSS positioning, as shown in Fig. 4(b). This suggests that the positioning system equipped with DIK-5532 is deficient for investigating differences in soil properties at a scale of several meters. To accurately map the distribution of soil features at the scale shown in Fig. 4, soil information with high positional accuracy is required, and GNSS-RTK is a remarkably effective tool, as shown in Fig. 4(b).

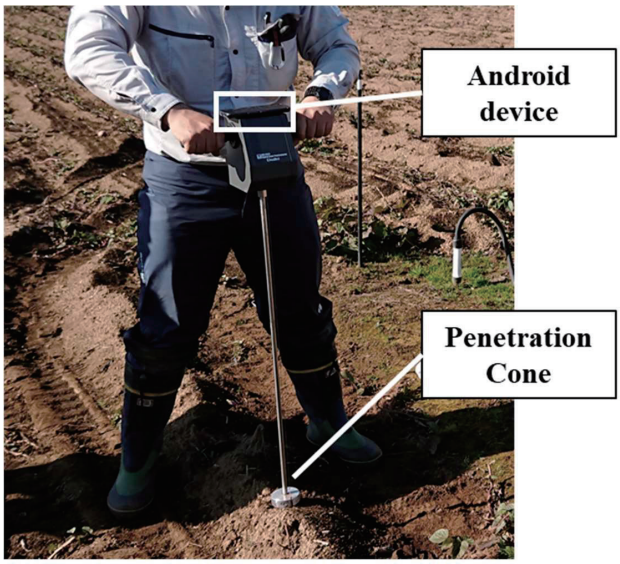

Fig. 3 Example of soil survey instrument (DIK-5532) with GNSS receiver in the Android device.

In spatial analysis using remote sensing, as the information obtained by each sensor is different, GIS analysis is generally performed by overlaying multiple observation results. Therefore, highly accurate location information is important for remote sensing image analysis. Figure 5 shows an example of a layered orthomosaic image of the normalized difference vegetation index (NDVI) on the Phantom 4 RTK (P4RTK)-derived base map. These images were obtained from individual observations in a paddy field using two different drones. The P4RTK records high-precision position data measured by RTK-GNSS in each aerial image, which were used to create the orthomosaic image (basemap) with centimeter-level accuracy. NDVI was calculated from the image taken by a Micasense RedEdge-M multispectral camera (MicaSense Inc., WA, USA) attached to the Spreading Wings S900 (DJI Co. Ltd., Guangdong, China). Because these drones and sensors support only

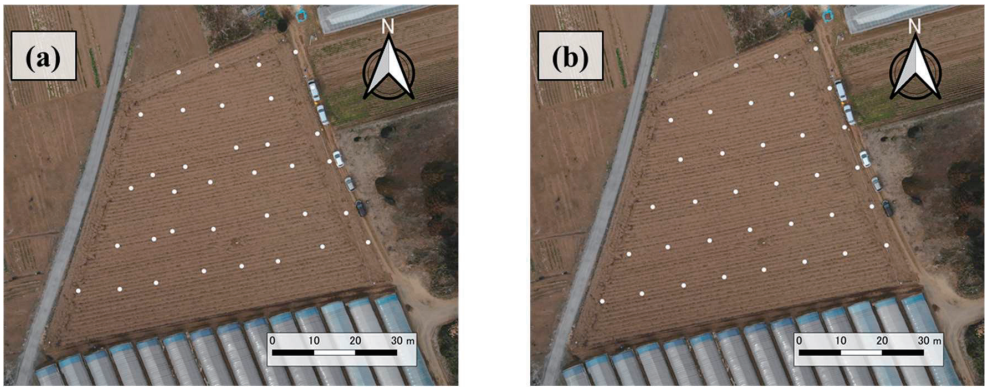

Fig. 4 Positioning result by (a) Android device equipped on DIK-5532 without RTK-correction and (b) DG-PRO 01RW with RTK-correction.

single-point positioning, ground control point data corrected by RTK positioning are necessary for accurate layering (Fig. 5(a)). On the other hand, as shown in Fig. 5(b), the NDVI image created without using RTK positioning was 3.3 m off from the base map. This misalignment makes difficult to link the same crop between images unless manually geo-referenced. Thus, RTK-GNSS is effective in integrating different observations, especially when comparing data or extracting changes, as it can accurately display the respective positions. In the case of aerial images, it is recommended to prepare RTK-corrected ground control points that can be acquired with low-cost RTK-GNSS receivers (e.g., Sakamoto *et al.* 2019b).

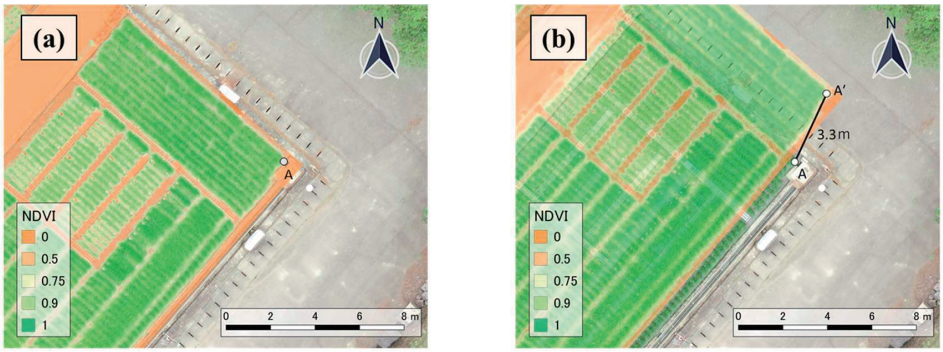

Fig. 5 NDVI with RTK-correction (a) and without RTK correction (b) overlaid on a basemap. A -A' shows misalignment between the NDVI without RTK correction and a basemap.

RTK-GNSS is also widely used as a convenient topographic surveying technology. Other technologies, such as aerial laser survey using LiDAR (light detection and ranging) and DSM (digital surface model) construction using SfM-MVS processing of drone aerial images can be used, but it is difficult to obtain accurate land surfaces in areas covered with vegetation. For example, Okumura and Izuho (2010) used RTK-GNSS positioning to obtain topographic information to compare the age of outcrops in a case where aerial laser surveying was difficult due to the dense growth of bamboo grasses. Thus, RTK-GNSS can be used as an alternative when other surveying techniques are difficult to apply.

4. Summary

Handheld or smartphone GNSS are adequate for many field research jobs requiring a few meters of accuracy, but they are insufficient for tasks requiring accurate sub-decimeter accuracy. The results of RTK-GNSS positioning and their applications are presented in this study. To use this technology, a specialized RTK-GNSS receiver, as well as a VRS subscription is required if there is no nearby base station. However, as the development of precise positioning technology has been spectacular in recent years, and the cost of RTK-GNSS receivers and VRS subscriptions has decreased. As a result, the required annual operating cost, which is approximately several ten thousand yen, is not high considering the accuracy achieved by RTK-GNSS as detailed in this study. Easy high-precision positioning is predicted to be used in geographic research for a variety of field surveys, such as analyzing changes in microtopography or mapping densely distributed items in small areas. In addition, the advantage of this technique is not only its high accuracy but also the ease and speed with which data may be acquired. The ability to facilitate tasks that need time-consuming field work, such as quadrat surveys, helps in collecting geo-spatial data quickly during field surveys. Consequently, the benefits of employing RTK-GNSS in field surveys are significant, and we anticipate that it will be widely used in related research.

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(*: in Japanese, **: in Japanese with English abstract)