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Development of a custom-built RTK-GNSS positioning system for agricultural operations

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Abstract. The objective of this research is to assess positioning accuracy of a custom-built RTK (Real Time Kinematic) base station. Setting up a RTK base station with open-source tools is rather straightforward process requiring only few components and basic programming skills. The base station and receiver unit were developed by using a SparkFun GPS-RTK2 Board with U-Blox ZED-F9P module. The board was paired with U-blox Multi band GNSS (Global Navigation Satellite System) antenna. The board can use GNSS satellite signals from Galileo, BeiDou, Glonass and GPS systems. The positioning accuracy was evaluated in a fixed position and during operations in agricultural fields. The RTK correction signal was used in connection with soil scanning measurements in different crop fields of the Viikki Research Farm of the University of Helsinki. For accuracy assessment, comparative measurements were carried out with a commercial network RTK (NRTK) correction signal. The vertical and horizontal accuracy of the positioning signal were evaluated based on the accuracy variables calculated by the receiver. The vertical accuracy was also evaluated by mapping the scanned trajectories on the height map which was obtained from NSL (National Land Survey of Finland) open map data service. The custom-built RTK positioning system accuracy was considered generally precise enough for autonomous field work, but the reliability of the observed accuracy should be confirmed with more extensive measurements. The commercial NRTK signal accuracy was considered very good and reliable also for the vertical direction.

Key words: satellite navigation, positioning accuracy, real time kinematics, RTK-station, precision farming.

INTRODUCTION

Nowadays the Global Navigation Satellite System (GNSS) provides a positioning accuracy that is quite useful for many consumer products, but it is not enough for applications that need centimetre level precision. The other challenge of precise positioning is rough terrain environments that have vegetation and other obstacles influencing on satellite signals. Satellite navigation has already been used successfully for many decades for variety of purposes from vehicle navigation to precision farming (Reckleben & Noack, 2012). The GNSS provides nowadays substantial number of visible satellites including all the four global satellite positioning system: GPS (Global

Positioning System), GLONASS (GLObal NAvigation Satellite System), Galileo by the European Union, and BeiDou from China. The navigation accuracy has been improved by additional systems that can mitigate signal disturbances and increase the positioning accuracy. Typical error sources in the satellite signals, such as troposphere and ionosphere variability, have been identified long time ago (Emardson et al., 2009; Zhou et al., 2022). It is also well-known that tall buildings or other similar obstacles causes multipath noise in the positioning signal and different solutions have been proposed on these problems (Takanose et al., 2021).

Single Point Positioning (SPP) is the default mode for open position services and provides only low accuracy positioning information regarding to the needs of precision agriculture or autonomous robots. Typical accuracy of SPP is 1–2 meters horizontally and 2–3 meters vertically (Zhang & Pan, 2021). Precise Point Positioning (PPP) can be considered as an alternative method for increasing the positioning accuracy. PPP needs a single GNSS receiver, direct observables, and ephemerides (Yi et al., 2021). The positional accuracy that can be achieved using DGNSS (Differential Global Navigation Satellite System) corrections is at best about half a meter depending on the distance of the ground-based reference station (Weng et al., 2021). DGNSS service is suitable, for example, in navigation or for several measurement/mapping tasks.

Real Time Kinematic (RTK) method is often considered as one of the most accurate methods to provide centimetre level positioning accuracy in open environments (Takanose et al., 2021). RTK method can estimate the FIX solution (a correct solution) therefore it can be used as a reference for evaluating the positioning accuracy of autonomous vehicles and robots. The commercial operators typically provide a service by using some form of network RTK which can combine data from several reference stations to provide a correction signal (Baybura et al., 2019). The positioning accuracy can be improved by shortening the distance between the reference stations (Emardson et al., 2009).

Typical challenge in agricultural context is the changing and uneven surfaces during field operations therefore an additional GNSS receiver would be needed for determining the implement position for active control of the implement (Reckleben & Noack, 2012; Ng et al., 2018). Some overlapping is accepted in field operations such as seeding and fertilizing but it can be significantly reduced by using RTK precision for tramlines in the field (Reckleben & Noack, 2012). Automatization of farming operations is being done in multiple ways for increasing the productivity, decreasing overlapping, saving production inputs (energy, fertilizer, pesticides, etc.). As there are a lot of existing machinery in farms, one way of increasing automatization is to retrofit the machinery with the modern positioning systems. There are lots of activities in designing new autonomous equipment for farming in general (Wang et al., 2021). Overall, it is crucial to determine the vehicle position accurately in order to implement precision farming methods or automated operation for robotic systems (Bakken et al., 2019; Le et al., 2019; Reckleben & Noack, 2012). In other words, if the positioning accuracy is poor, the automated machine cannot perform any path following or tracking activities (Pini et al., 2020).

As there is a crucial need for accurate positioning methods in agricultural and forestry environments, it is important to understand the potential accuracy of existing and custom-built systems. The latter enables flexible solutions especially in agricultural environments and distant areas where there is no guarantee for robust cellular network signals. A custom-built RTK positioning system, including the base station and a receiver board (often called as rover), can be very cost effective in comparison to the systems and devices offered by the established companies in agricultural field. It is especially practical in remote places and when the need for the correction signal is irregular. An application in which RTK correction signal could be easily transmitted is unmanned aerial vehicles (UAVs) which are increasingly been used for crop monitoring. Because custom-built RTK base station can be set up in any location, it can deliver the correction signal via a radio transmitter in places where no cell phone service is available. Even though, setting up a RTK base station would not need any specific skills, it would require understanding about the software and the configuration setting of the RTK-GNSS board. Therefore, the major challenge of using a custom RTK correction signal is the maintenance and updates of the system which would require a certain amount of knowledge and dedication.

This research focuses on evaluating the positioning accuracy of a custom RTK correction signal in agricultural and precision farming context. First, the setting up a base station is explained with the materials required, secondly the field measurements are described and finally the accuracy results are presented and explained. The use of the RTK correction signal has been done in conjunction with soil scanning measurements in actual cultivated fields. Also, the custom correction signal accuracy is compared to a NRTK signal that is commercial provided. Most of the previous research studies assessing the custom-built GNSS systems are focused on built environments and road navigation. This research focuses on the positioning accuracy in agricultural field conditions which is very weakly covered by the present scientific literature.

MATERIALS AND METHODS

System development

The RTK base station was developed by using a GPS-RTK2 Board (SparkFun Electronics, USA) with ZED-F9P module (U-Blox, Switzerland). The board was paired with Multi band GNSS antenna ANN-MB-00 (SMA) (U-blox, Switzerland). The board can use GNSS satellite signals from Galileo, BeiDou, Glonass and GPS systems. The correction signal was sent as the RTCM 3.2-standard correction signal via NTRIP (Networked Transport of RTCM via Internet Protocol) Caster application via the internet server rtk2go.com. Raspberry Pi minicomputer with RTK-LIB open-source program (Takasu, 2007–2013) was used for operating the RTK-station. The position recordings were carried out by using a similar GNSS Board and U-Blox u-center GNSS evaluation software. The RTK correction signal was received via the cellular network.

Multiple base station recordings were done for finding a suitable place for the antenna in terms of signal obstacles. The first locations turned out to be partly covered by buildings which was influencing the recording accuracy. Finally, the antenna of the base station was installed on the roof of one of the Viikki Research Farm buildings in a place that there are no tall trees or other buildings in vicinity. In November 2021, temporary RTK rover base stations were also set up in the Hyytiälä Forest station and in the middle of the forest close to Hörskönjärvi, in Karpanmaa area in South of Finland. The position accuracy in the forest environment was evaluated in the recent publication (Abdi et al., 2022). The RTK base station requires preferably 24 hours recording of satellite positioning signals which is used for determining the actual location of the station. The received signal accuracies during the recordings were evaluated and the final RTK base station signal accuracy was analysed with positioning recordings from distance about 37 kilometres to northeast from the Research Farm. Those recordings were done with different configurations of the receiver board: GNSS (without any correction), DGNSS (Differential Global Navigation Satellite Systems), and with the custom RTK correction signal. National Land Survey (NLS) of Finland provides real-time DGNSS corrections free of charge from the station closest to the user with the positioning accuracy at best about half a metre.

Field measurements

The positioning measurements were carried out in conjunction with field soil scanning measurements. The measurements were done in the cultivated fields of the Viikki Research Farm of the University of Helsinki located about ten kilometres northeast from the Helsinki city centre. The custom built RTK-GNSS station was set up during the summer of 2021 and the first soil scanning measurements with the custom correction signal were done in September 2021. The soil scanning was done by using Veris iScan+ soil scanner (Veris Technologies, USA) that has capability to measure apparent electrical conductivity (ECa), diffuse reflectance (red and near-infrared), temperature and moisture. Fig. 1 presents the scanner attached to a subframe for easy installation to the three-point linkage of agricultural tractors. The GNSS antenna was attached on the scanner as shown in Fig. 1. Accurate positioning is important for the soil measurements especially in terms of elevation which made this application an excellent way to evaluate the positioning accuracy of the RTK correction signal. The comparative measurement with a commercial network RTK (NRTK) correction signal were carried out in the fall of 2022. Horizontal, vertical, and 3D accuracy values were acquired from the u-center software and were called as PACC H, PACC V and PACC 3D.

Figure 1. Soil scanner iScan+. Left side: soil scanner in 2021, GNSS antenna installed on the scanner. Right side: soil scanner in 2022, GNSS antenna installed in the subframe on top of the pole.

The vertical accuracy of the positioning signal was also evaluated by mapping the scanned trajectories on the height map (Fig. 2) which was obtained from NSL open map data service. The vertical accuracy was evaluated by using the NSL height map as a reference. Fig. 2 illustrates the scanning trajectory of one field (Mehiläissaari) on geographical and height map, respectively.

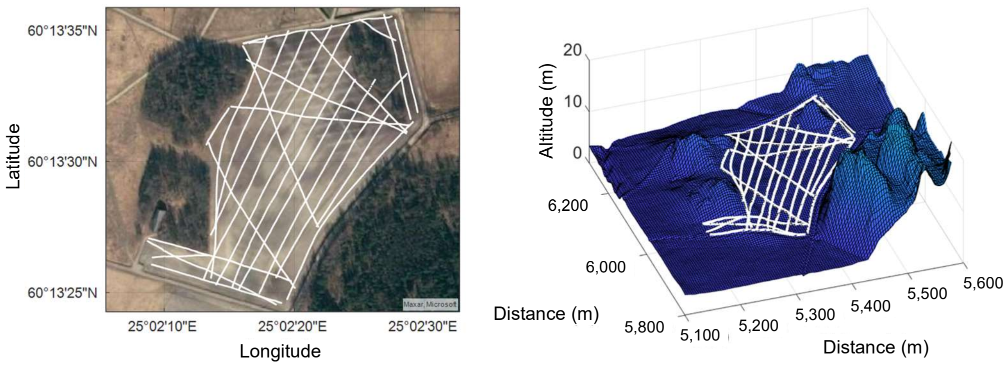

Figure 2. Scanning trajectory of the field Mehiläissaari. Left side: scanning trajectory on a satellite map. Right side: scanning trajectory on the NLS height map.

The scanning trajectories of the measurements in the six scanned fields are presented in Fig. 3. The fields are located quite close to the Viikki Research Farm, inside of a circle with a diameter of 4 km. The white markers in the Fig. 3 show the different locations where the recordings for the custom-RTK base station were done: circle = Research Farm 1, triangle = Research Farm 2, and diamond = Research Farm 3.

Figure 3. Scanning trajectories in a satellite map. From left to right: Patoniitty, Museopelto A, Alaniitty 1, Saunapelto, Alaniitty 2, and Mehiläissaari. The locations of base station recordings are shown in the zoomed figure in the right bottom corner.

The positioning information was recorded with the u-center software that offers dedicated interface for signal monitoring. The software can collect a vast amount of data to be used for the evaluation of positioning accuracy. After the measurement, the recorded data was saved in csv file format. All the measured data were processed in MATLAB software in which a specific program script was developed for analysing the positioning accuracy.

Positioning accuracy

There are several ways to present the accuracy of satellite positioning. Horizontal accuracy is a measure of how close the measured position is to the true position on the earth's surface. It is typically measured in meters or centimetres and can be presented as an average or a maximum value. Vertical accuracy is a measure of how close the measured height is to the true height above sea level. It is also typically measured in meters or centimetres and can be presented as an average or a maximum value. Dilution of precision (DOP) is a measure of how well the satellite signals are distributed in the sky. A lower DOP value indicates better signal distribution and higher precision. DOP values are typically presented as a number, such as 2 or 3, or as a ratio, such as 2:1 or 3:1. The number of satellites used to calculate the position can also give an indication of the precision. More satellites will typically provide a more precise position but nowadays there are plenty of available satellites therefore it is rarely influencing on the accuracy. Confidence intervals can be used to give an indication of the uncertainty associated with a particular position measurement. They are typically presented as a range of values, such as '95% of position measurements will be within ten centimetres of the true position'. An error ellipse can be used to give a graphical representation of the uncertainty associated with a particular position measurement. It shows the area in which the true position is most likely to be found and can be useful for visualizing precision in 2D space. In this research, the confidence interval was the main method for defining the positioning accuracy.

RESULTS AND DISCUSSION

The accuracy of the received GNSS signal for the base station recordings was determined based on the deviation to the mean value over the full recording. The cumulative frequency of different recordings and the deviation within a confidence interval of 95% were calculated. This has been typically used as accuracy metric for received RTK positioning signal (Jackson et al., 2018). The accuracy results for the base station recordings are presented in the Fig. 4. The deviation values are show in the legend box of the Fig. 4 for each signal ranging between 0.7 and 2.5 meters.

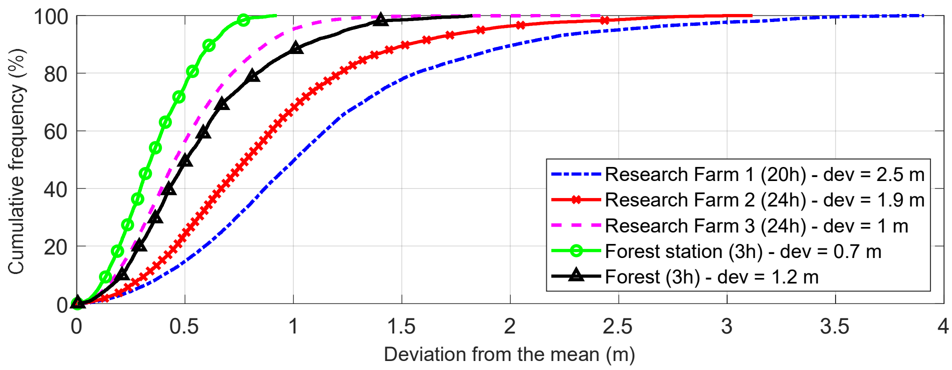

Figure 4. Accuracy of the received GNSS signal when recording the base station locations.

The location of Research Farm 1 and Research Farm 2 were not entirely open to all directions which can be seen in the lower accuracy of the received signal. The recordings for the forest base stations were much shorter in duration due to the fact that these stations were temporary and would be set up in short period of time. However, the recoding duration did not have almost any influence on the signal accuracy. Generally, these recordings illustrate the SPP accuracy which is about 1–2 meters. The soil scanning measurements in 2021 were done with the base station located in the Research Farm 1, which may not have been an ideal place of getting satellite signals. The Research Farm 3 location was set up in 2022 but the correction signal from this location has not yet been widely used in measurements.

The custom-built RTK base station correction signal accuracy was tested with a fixed place measurements in distance. Recordings of 37 kilometres from the base station location to northeast direction were done with and without the RTK correction signal. The results show in Fig. 5 that the GNSS and DGNSS signals have quite the same accuracy and the accuracy is very high with the RTK correction. There were two separate measurements with the RTK correction called here as RTK1 and RTK2. Due to the long distance to the base station, the accuracy of the RTK signal remains around five centimetres with the 95% confidence interval. The cumulative number of tracked satellites illustrated in the right side of Fig. 5 shows that there are small differences between the recordings as they were done in different dates.

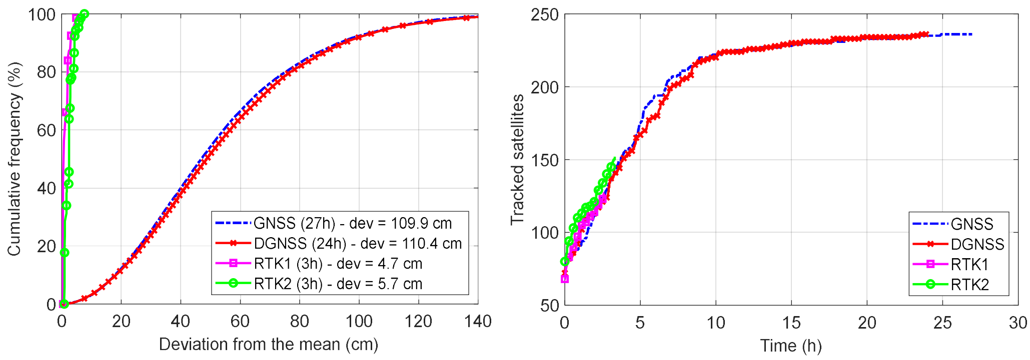

Figure 5. Accuracy of the received GNSS and custom RTK-GNSS correction signal in distance. Right side of the figure presents the cumulative number of tracked satellites during recordings.

Positioning accuracy was determined during soil scanning operations in different fields of the Viikki Research Farm. The results with the custom built RTK-GNSS station were compared to the results acquired by using a commercial service providing NRTK correction signal over the internet. Fig. 6 shows the cumulative frequency of the deviation as horizontal and three-dimensional accuracy during soil scanning of different fields. The values of accuracy presented in the legend boxes correspond to 95% of confidence interval. In one measurement (RTK-Alaniitty2), the RTK precision was in the FLOAT mode which means that no FIX solution was not reached for some period. This influenced significantly on the positioning accuracy which was then multiple times lower in comparison to the measurements when the precision was in the FIX mode all the time. Overall, the positioning accuracy was very good for both systems. With the custom RTK correction signal, there was more variability between measurements whereas the commercial NRTK provided very similar accuracy in all measurements.

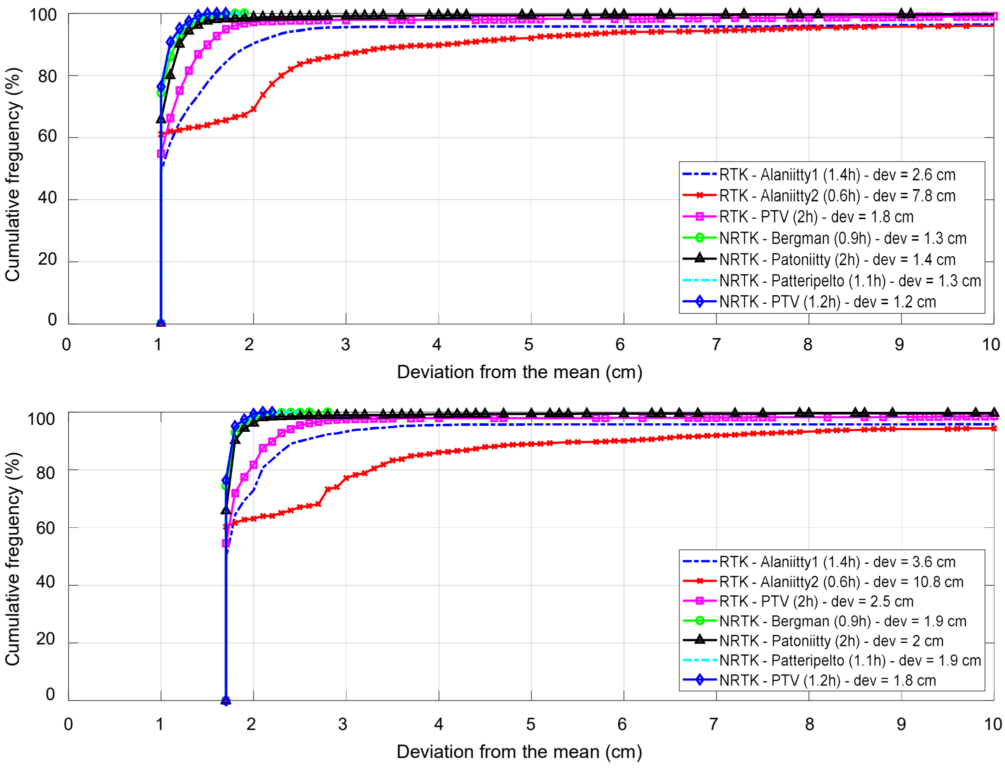

Figure 6. Positioning accuracies of the custom RTK and commercial NRTK signals in various fields during soil scanning. Top: horizontal accuracy, bottom: three-dimensional accuracy.

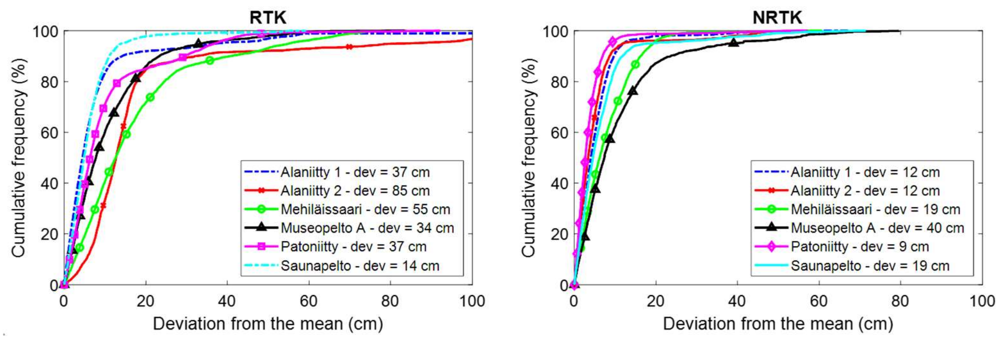

Figure 7. Accuracy comparison of the elevation measurement in different fields. Left side: custom RTK. Right side: commercial NRTK.

The horizontal accuracy was also evaluated by comparing the recorded elevation to the NSL elevation maps. The elevation results from six different fields were taken into account because the same fields were scanned with the custom RTK in the autumn 2021 and with the commercial NRTK in the autumn 2022. The reference elevation was interpolated from the NLS height maps and then the deviation was calculated for the scanning trajectory. Fig. 7 presents the accuracy results calculated as the cumulative frequency of the deviation: The comparative values of the deviation were calculated with 95% of confidence interval. For the NRTK, the positioning accuracy remains very high even in three-dimensional space.

CONCLUSIONS

Accurate positioning in agricultural operations is required for the implementation of semi- and fully autonomous systems in the fields. Over the years, satellite positioning systems have been gradually developed and with the RTK correction signal, the positioning can have centimetre level accuracy in good conditions. Agricultural and forestry operations are sometimes done in harsh conditions and covered areas where the cellular network reception for the correction signal can be compromised. Therefore, it is important to have solutions that are movable in their nature and are not dependent on the built environment. Often the supportive functions are the most vulnerable elements in the operation of autonomous vehicles and machinery.

This research showed that building and setting up a custom RTK base station can be rather straightforward task nowadays and also cost effective. Because the required equipment can be implemented in a compact package, a movable station can be also set up, for example, in the middle of a forest. The positioning accuracy with the custom built RTK signal can be generally considered to be very good in agricultural field conditions. However, the comparison with the commercial network RTK signal proved that a single station cannot provide as good positioning accuracy and may lack in reliability as there are no other stations in use to make any verifying corrections to the signal.

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