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Assessment of the location accuracy of points obtained with a low-cost Lidar scanning system and GNSS method

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Abstract

In the geomatics discipline, the most important element in road works, infrastructure works, excavation and filling applications, forest inventory determination, geological studies, deformation detection, and even smart cities and digital twins with developing technology, transportation-based applications, infrastructure works and renovations is location information. 3D location information can be obtained in many different ways using ground surveying methods and satellite technologies. Although these methods have various advantages over each other, the main objective is to obtain precise location information quickly and accurately according to the projects. Speed and cost are considered to be the most important criteria for users when obtaining location information. Today, using ViDoc- Real Time Kinematic (RTK) antennas integrated with Iphone/Ipad Pro devices with IOS operating system, high accuracy laser scanning operations and 3D position acquisition are possible. The ViDoc RTK antenna is an RTK antenna that can be attached to the Apple IPad Pro tablet, iPhone 12 Pro and iPhone 12 Pro Max and higher model phones equipped with Lidar sensors. In this study, 13 points with different heights homogeneously distributed in the study area were identified and their positions were obtained with the RTK-GNSS receiver using the CORS-TR. Subsequently, the positions of these points were also determined using the ViDoc RTK antenna. The positions of these points obtained with the help of RTK-GNSS were accepted as correct and the position accuracies obtained by both methods were compared. ViDoc resulted in an average accuracy of 4.9 cm horizontally and 5.6 cm vertically. These results show that ViDoc RTK antenna integrated with IPad/IPhone with IOS system equipped with Lidar sensors can be used in sensitive studies such as 3D documentation of historical and cultural buildings and feature data collection.

1. Introduction

Point clouds with precise location accuracy are essential for many studies related to the geomatics discipline, such as 3D modeling of objects, excavation and filling studies, road information extraction, forest inventory studies (1), geological studies (2) and indoor mapping (3). Point measurement or point cloud generation can be performed with methods such as total station, GNSS and Light Detection and Ranging (Lidar). These methods have their own advantages and weaknesses. With Lidar sensors, point clouds can be created by capturing points even in areas where optical sensors have difficulty in seeing, and measurements can be made in difficult to measure areas. For studies carried out in this direction, it is known that the accuracy and reliability of real-time instantaneous data obtained with the Network RTK (Continuously Operating Reference Station CORS) method as reference location data is high. Thus, the ability to provide precise and accurate data for mapping applications as a result of the integrated use of LIDAR and RTK systems makes this system useful.

Several studies have been conducted in the literature to investigate the positional accuracy of Apple mobile devices with IOS operating system in the use of Lidar systems. Tavani et al. (4) evaluated the geo-location accuracy of the iPhone's GNSS receiver, the effectiveness of the IMU and magnetometer, the imaging capabilities and the internal Lidar performance of the device. Although the position error was a few meters, the level of accuracy and the fast stabilization of the signal showed that the iphone's geo-location capabilities are acceptable for field work that does not require very high precision. Lose et al. (5) investigated the usability of three different IOS applications and Apple Lidar sensors by examining their 3D spatial accuracy. Considering the studies conducted in this direction in the literature, the researchers concluded that Iphone location accuracy is insufficient for geomatics discipline studies that require precise location information, and suggested that it can be used in studies requiring high accuracy by integrating it with devices that can receive RTK location data as well as using built-in Iphone location. In the study performed by Kuçak et al. (6), the scanning and accuracy performance of the Apple iPad Pro LiDAR sensor is investigated comparatively with the performance of a professional Terrestrial Laser Scanner (TLS). Martino et al. (7) evaluated the quality and accuracy of point clouds by comparing the data sets obtained using the built-in GNSS location information of the Iphone 15 Pro and the ViDoc RTK antenna of the Iphone 15 Pro without using any additional tools. Tamimi and Toth (8) conducted a feasibility study by collecting high-accuracy spatial data with the help of an e-scooter using the camera and lidar sensors of Iphone 14 Pro. Büyükmıhçı et al. (9) emphasized that it has become possible to perform laser scanning for documenting historical buildings using the cameras of IOS devices with Lidar feature, but when these devices use their own location services, the images obtained in the scans cause shifts in the images obtained in the scans and it becomes difficult to place the scans in the coordinate system, in addition, when IOS devices are integrated with ViDoc RTK receiver, precise location information below 5 centimeters can be obtained.

The ViDoc RTK antenna is an RTK antenna that can be installed on Apple iPad Pro tablets, iPhone 12 Pro and iPhone 12 Pro Max and higher model phones equipped with Lidar sensors. In this study, 13 points with different heights distributed in the study area were identified and their positions were obtained with the RTK-GNSS receiver using the CORS-TR system. Subsequently, the positions of these points were also determined using the ViDoc RTK antenna. The positions of these points obtained with the help of RTK-GNSS receiver were accepted as accurate and the position accuracies obtained by both methods were compared.

2. Material and Method

In this study, Sivas Cumhuriyet University campus was determined as the study area (Figure 1).

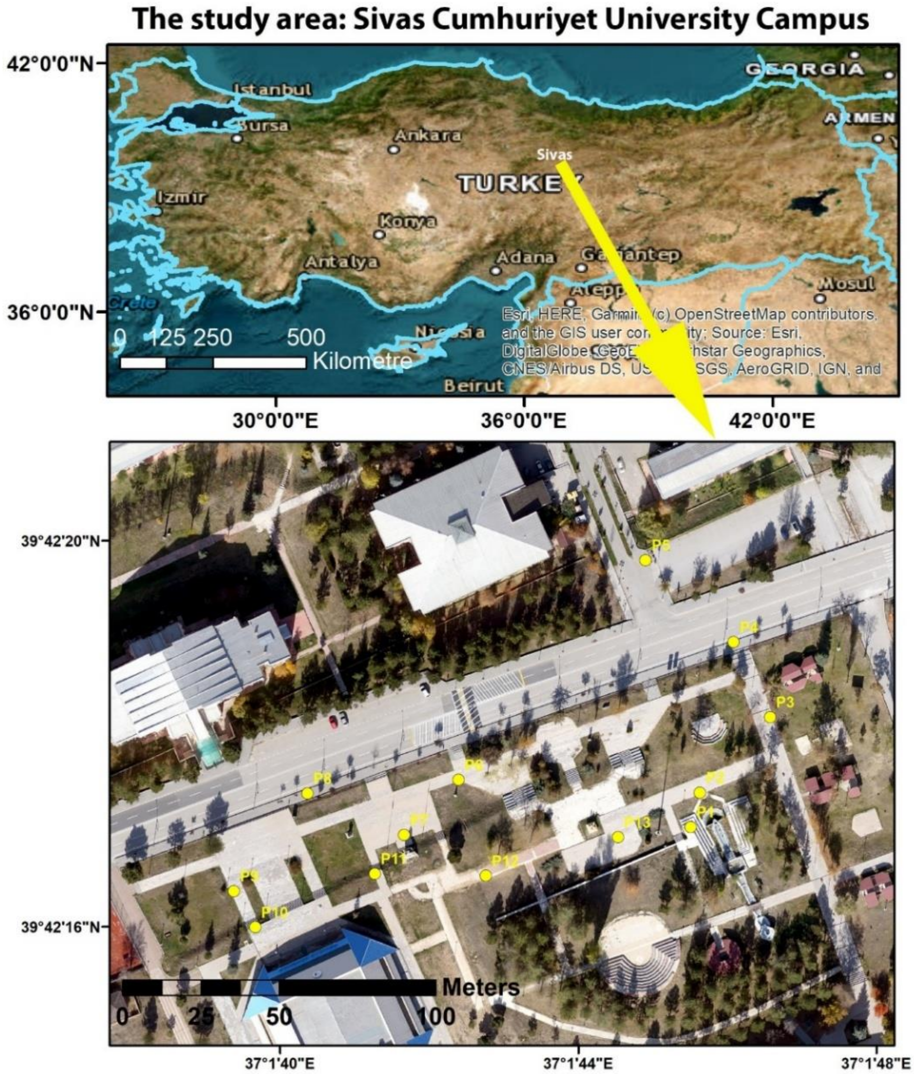

Figure 1. Study area.

Two different methods were used for position determination and compared. Firstly, for 13 check points whose locations were determined by surveying in the field, 3D position information was obtained by RTK method by receiving instant correction information from CORS-TR stations with a conventional GNSS receiver (CHC NAV i80 GNSS Receiver, Figure 3). Shortly after, an iPad Pro device (IPad Pro M4) with an integrated camera and LIDAR sensor was used with a ViDoc RTK antenna to receive instantaneous correction information from CORS-TR stations to obtain instantaneous 3D position information by RTK method (Figure 2).

In the coordinate control phase of the study with a conventional GNSS receiver, measurements were made with a CHC NAV i80 smart GNSS receiver (Figure 3), which has satellite signals that can be tracked by GPS (L1C/A, L1C, L2C, L2E, L5), GLONASS (L1C/A, L1P, L2CA, L2PL3), SBAS (L1C/A, L5(QZSS, WAAS, EGNOS, GAGAN)), Galileo (E1, E5A, E5B) and BEIDOU (B1, B2), and has a measurement accuracy of 8mm+0. 5ppm RMS (root mean squared mean error) in horizontal and 15 mm + 0.5 ppm RMS measurement accuracy in vertical (Figure 3), and the positions were obtained with the help of the corrections obtained from the CORS TR station according to the WGS 1984 geographic coordinate system (10). For the same points in the study area, coordinate measurements were also made with the ViDoc RTK Rover. ViDoc RTK Rover connects to the Ipad Pro M4 via Bluetooth and receives real-time corrections to improve the internal position of the Ipad. In other words, since ViDoc RTK Rover is connected to the NTRIP (Network Transport of RTCM via International Protocol) service simultaneously with Pix4D Catch during scanning, 3D models and georeferenced images can be produced with RTK accuracy. Pix4D catch software is an application that can provide cm-level absolute accuracy in real time while increasing model accuracy and accelerating data capture (11). In order to compare the accuracy of the coordinates measured by both methods, WGS 1984 geographic coordinate data measured by the conventional GNSS receiver were converted to TUREF TM 36 (3-degree slice width) coordinates and comparisons were made.

Thus, the accuracy of using the iPad Pro and ViDoc RTK antenna together in obtaining position information was compared to conventional GNSS measurement. The ViDoc RTK antenna (Figure 4) is an important component of the precise positioning process and provides RTK positioning using the CORS-TR system to improve the accuracy of the coordinate determination process of the GNSS receiver built into the iPad.

Figure 2. Measurement of check point locations with ViDoc.

Figure 3. CHC NAV i 80 GNSS receiver.

Figure 4. Integrated use of ViDoc RTK Rover with iPad Pro device.

CORS-TR system is a system that has been established and continues its activities in order to obtain real-time geographical position information with centimeter accuracy within a few seconds at any place and time where a sufficient number of GNSS satellites can be seen in our country and communication facilities are possible. In this context, CORS-TR stations can provide centimeter-level positioning by transmitting signals from satellites to the ViDoc RTK receiver. The data collected by the iPad Pro and the RTK receiver system were recorded through the Pix4D-Catch application.

3. Results and Discussion

In order to investigate the usability of ViDoc RTK Rover for point coordinate determination, measurements were made on 13 Check Points. The consistency between the coordinates of the check points measured by the CHC NAV i80 GNSS receiver and the coordinates simultaneously measured by the ViDoc RTK Rover was evaluated according to the root mean square error in 2D (RMSE 2D) and root mean square error in 3D (RMSE 3D) (Table 1).

Table 1. Coordinates and error values measured by CHCNAV i 80 GNSS receiver and ViDoc RTK Rover.

Check Point GNSS	East (m)	North (m)	Ellipsoidal Height (m)	Check Point ViDoc	East (m)	North (m)	Ellipsoidal Height (m)	ΔE (m)	ΔN (m)	Δh (m)	Δ2D	Δ3D
GNSS1	588272.383	4397249.195	1318.26	ViDoc1	588272.393	4397249.219	1318.24	-0.009	-0.024	0.02	0.026	0.033
GNSS2	588275.394	4397260.168	1316.929	ViDoc2	588275.369	4397260.183	1316.918	0.03	-0.015	0.011	0.034	0.035
GNSS3	588297.85	4397284.327	1316.436	ViDoc3	588297.871	4397284.321	1316.413	-0.02	0.006	0.023	0.021	0.031
GNSS4	588286.182	4397308.301	1314.176	ViDoc4	588286.132	4397308.289	1314.18	0.05	0.012	-0.004	0.051	0.052
GNSS5	588258.014	4397334.521	1312.998	ViDoc5	588258.041	4397334.593	1312.989	-0.027	-0.072	0.009	0.077	0.077
GNSS6	588198.264	4397264.283	1315.001	ViDoc6	588198.23	4397264.349	1315.014	0.03	-0.066	-0.013	0.072	0.074
GNSS7	588180.776	4397246.62	1315.213	ViDoc7	588180.773	4397246.699	1315.254	0	-0.079	-0.041	0.079	0.089
GNSS8	588149.913	4397259.984	1314.163	ViDoc8	588149.91	4397259.974	1314.212	0	0.01	-0.049	0.01	0.05
GNSS9	588126.394	4397228.695	1315.169	ViDoc9	588126.42	4397228.716	1315.197	-0.025	-0.021	-0.028	0.033	0.043
GNSS10	588133.272	4397217.17	1316.556	ViDoc10	588133.232	4397217.262	1316.616	0.04	-0.092	-0.06	0.1	0.117
GNSS11	588171.492	4397234.255	1316.571	ViDoc11	588171.491	4397234.238	1316.595	0	0.017	-0.024	0.017	0.029
GNSS12	588206.945	4397233.619	1316.713	ViDoc12	588206.985	4397233.57	1316.755	-0.04	0.049	-0.042	0.063	0.076
GNSS13	588249.171	4397245.948	1316.976	ViDoc13	588249.17	4397245.99	1317.018	0	-0.042	-0.042	0.042	0.059
RMSE2D (m)	0.049			RMSE3D (m)				0.056				

In this context, locations were measured with a conventional GNSS receiver and ViDoc RTK antenna for all points related to position and height differences. It was observed that there was a maximum difference of 0.05 m in the easting direction, a maximum of 0.09 m in the northing direction and a maximum of 0.06 m for the ellipsoidal height values. In line with these values given in Table 1, it was observed that the 2D difference in the coordinate values of all points changed between min. 0.01 m and max. 0.1 m, while the 3D difference changed between min. 0.03 m and 0.11 m. Thus, in line with the equations given below, it was seen that the average 2D RMSE value was 0.049 m and the average 3D RMSE was 0.056 m. As a result, it was understood that ViDoc RTK Rover can be used in high accuracy location determination studies with acceptable precision and error margin.

The coordinate difference values for the E, N and h coordinate components were calculated using the Equation 1.

$$\begin{bmatrix} \Delta E \\ \Delta N \\ \Delta h \end{bmatrix} = \begin{bmatrix} E_{GNSS} - E_{ViDocRTK} \\ N_{GNSS} - N_{ViDOCRTK} \\ h_{GNSS} - h_{ViDOCRTK} \end{bmatrix} \quad (1)$$

Equation 2 was used in the calculation of the bases for determining the 2D and 3D location accuracies:

$$\begin{bmatrix} \Delta_{2D} \\ \Delta_{3D} \end{bmatrix} = \begin{bmatrix} \sqrt{\Delta E^2 + \Delta N^2} \\ \sqrt{\Delta E^2 + \Delta N^2 + \Delta h^2} \end{bmatrix} \quad (2)$$

RMSE values for coordinate and 2D/3D location accuracies were calculated using the differences given above using the Equation 3.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} {d_i}^2}{n}} \quad (3)$$

Here d_i and coordinate differences (ΔE, ΔN, Δh) for the i. CP, 2D location error (Δ_{2D}) or 3D location error (Δ_{3D}) value are expressed.

Considering the previous studies, the lidar sensor integrated in Apple devices has been used in many applications such as 3D mapping of rocks and cliffs for geological purposes (2), industrial 3D scanning on small objects (12), determinations for forest inventory (1), snow depth monitoring (13) or human body measurements (14). These studies have provided researchers with the opportunity to question the usability of lidar data with location accuracy in larger and more sensitive projects. When the studies conducted in this context are examined, Tavani et al. (4) examined the GNSS accuracy, inertial measurement unit (IMU) and magnetometer efficiency, photo and video capture capacities, and LiDAR sensor of iPhone 12 Pro used in geological investigations. According to the results of the research, the GNSS receiver of the iPhone 12 Pro can provide meter-level accuracy. For studies requiring higher accuracy, Martino et al. (7) tested the iPhone 15 Pro using the iPhone 15 Pro integrated with the ViDoc RTK antenna and the iPhone 15 Pro without any additional tools. They observed that a 1.4 m planar error and a height error of more than 5 m were converted to a position accuracy of more than 3 cm with the use of the ViDoc RTK Rover. Tamimi and Toth (8) emphasized that they were able to obtain precise location data in accordance with RTK standards when they integrated the RTK antenna into the Iphone 14 Pro device for location collection while traveling on an e-scooter. In another study, Büyükmıhçı et al. (9) emphasized that precise location can be obtained below 5 cm by integrating ViDoc RTK Rover receiver to Apple devices for precise modeling of historical buildings in 2023.

In this context, considering the previous studies, the accuracy of the coordinates obtained from the ViDoc RTK antenna integrated into the iPad Pro device was analyzed for 13 control points located at different locations and different heights (Table 1). As reported in the literature, it was confirmed that the accuracies at the meter level obtained without the use of an external sensor were replaced by centimeter-level accuracies. In the study most similar to our study in the literature, (7) obtained more than 3 cm accuracy for each location component in their measurements on a lion statue and a castle portico, compared to classical GNSS measurements. Differently, in this study, instead of testing on any structure, 13 control points measured on the ground were tested in order to make a more precise evaluation, and as a result, an average of 4.9 cm 2D RMSE and an average of 5.6 cm 3D RMSE values were obtained for 13 points. As stated in the studies conducted in the literature, it was confirmed in the study that the accuracies obtained at the meter level without the use of a sensor dropped to the cm level. In this context, the compatibility of classical GNSS coordinates with the coordinates measured with the ViDoc RTK antenna is shown to scale in Figure 5.

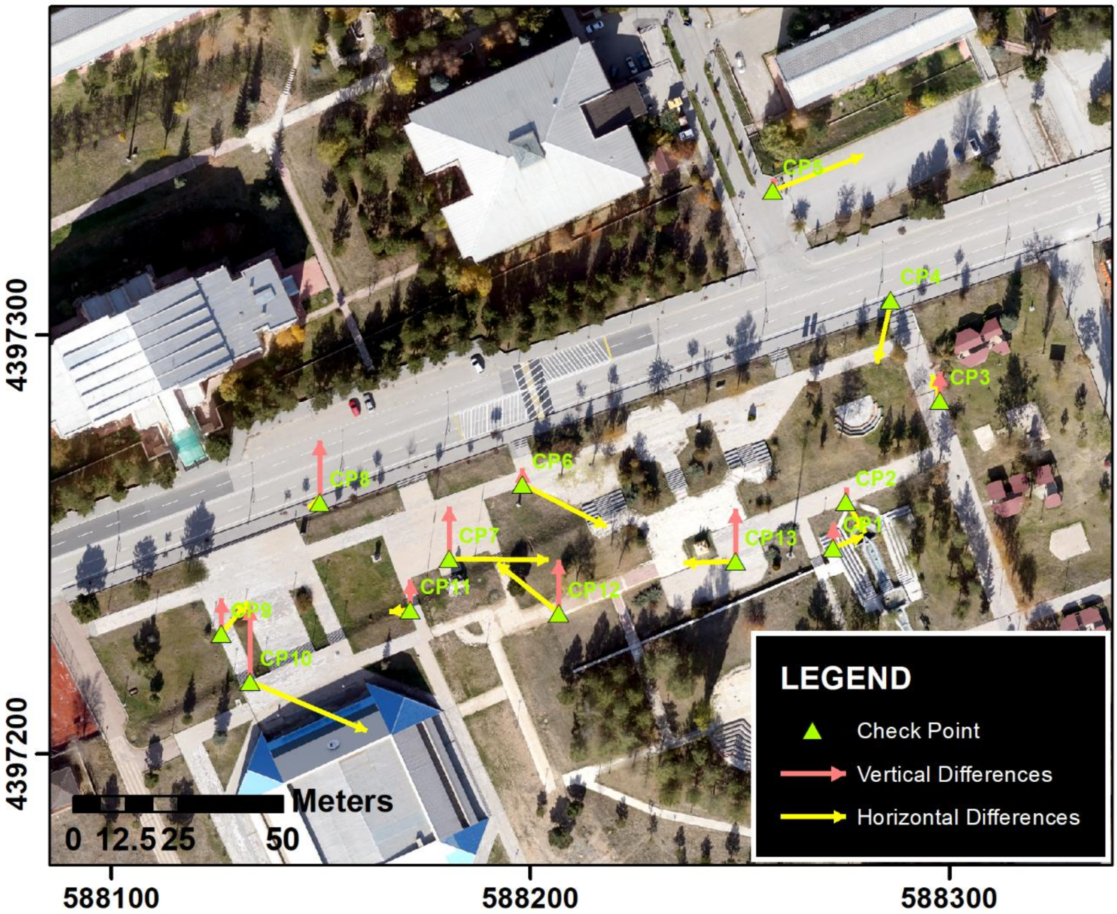

Figure 5. Representation of coordinate differences with vectors (scaled 1/300)

4. Conclusion

In this study, the absolute position accuracy of 13 points at different altitudes with the integrated use of ViDoc RTK receiver and iPad Pro devices was evaluated based on the measurements obtained from CHC NAV i80 GNSS receiver with the classical Network RTK method. The results show that the iPad Pro device integrated with the ViDoc RTK receiver can obtain the data received from the CORS-TR station with a high accuracy of 4.9 cm in the horizontal direction (2D) and 5.6 cm in the 3D analysis taking into account the vertical direction. As a result, this study has demonstrated the accuracy and usability of the ViDoc RTK receiver integrated with the Apple iPad Pro device in determining points at different altitudes. Thus, this system can be used as a stand-alone GNSS receiver in larger projects and area mapping processes. In future studies, PPK and PPP measurement methods can be integrated into the system and georeferencing can be further strengthened. In addition, it is thought that by integrating machine learning and multi-point cloud production systems, it can be used in studies such as detection of roads, excavation and filling areas or automatic modeling of any object with instantaneous precise location accuracy.

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Author contributions

Yasin Demirel: Literature Review, Land Measurement, Data Analysis, Map Visualizations, Writing, Tarık Türk: Land Measurement, Data Analysis, Writing, Supervision and Control.

Conflicts of interest

The authors declare no conflicts of interest.

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