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Feasibility of Using Handheld GPS for Topographic Mapping: Review Study

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Abstract: Global Positioning System (GPS) has drastically improved the technique for ground point location with high accuracy. One of the parameters that affect the accuracy of position using GPS is the receiver in use and observation technique adopted. Handheld GPS receivers are drastically cheap if compared with geodetic ones. That is because they are mainly manufactured for navigation and sporting activities. The accuracy of ground point location they produce need to be assessed.

Some researchers conducted geometric tests to investigate the possibility of these receivers for mapping purposes regarding their accuracy for determining ground coordinates.

This article aims to collect and present results obtained by such researchers in order to investigate the feasibility of using handheld GPS for topographic mapping.

The study concluded that raw Handheld GPS data can be used to provide topographic maps of scale 1:50000 scale. With the improvement in the receiver design and the procedures of data collection accuracy of few centimeters can be achieved and large-scale mapping of 1:10000 can be produced.

Keywords: Handheld GPS; topographic mapping; Accuracy; mapping specifications.

I. INTRODUCTION

Global Positioning System (GPS) helps users to determine their geographical position with sufficient accuracy. Accuracy of the obtained coordinates depends on number of parameters such as the type of GPS receiver used, and observation technique adopted. Now a day, GPS become one of the important tools of map data collection. It preserves time, reduces cost, provides reliable accuracy, digital data transferring and manipulation, more over data can be collected at any time. (Nagi, 2012). The disadvantage is the high cost required to earn receivers that can provide accuracy required for surveying topographic mapping. GPS has become an important tool in geodetic positioning and land use study.

As a result of advances in technologies, the raw GNSS measurement (i.e., pseudo range, phase, and Doppler) can now be collected with smartphones, tablet computers, and handheld GNSS receivers/chipsets. On the other hand, some manufacturers (like Garmin Ltd.) have allowed GNSS raw measurements to be recorded with handheld GNSS devices, which are mostly used for navigation, outdoor and sporting activities. This has paved the way for handheld-type GNSS devices to be used as 3D positioning systems. Since handheld GPS receivers of cheap prices are mainly manufactured for navigation purposes, sometimes users utilize these receivers for mapping purposes regardless of the accuracy of obtained coordinates and suitability for particular mapping scale.

The main objective of this article is to review publications concerned with the geometric accuracy of the handheld GPS and decide whether obtained results can be used for producing topographic maps regarding accuracy specifications.

II. HANDHELD GPS

As a result of advances in technologies, the raw GNSS measurement (i.e., pseudo range, phase, and Doppler) can now be collected with smartphones, tablet computers, and handheld GNSS receivers/chipsets. Some manufacturers (like Garmin Ltd.) have made it possible that GNSS raw measurements can be recorded with handheld GNSS devices, which are mostly used for navigation, outdoor and sporting activities. This has paved the way for handheld-type GNSS devices to be used as accurate 3D positioning systems in addition to their standard functions, Alkan, et al, 2023. The GPS receiver calculates distances between satellites and the device, using triangulation to determine precise coordinates. User-friendly software allows for effortless recording and storing of location data, mapping topography and notable features. Surveyors can now swiftly gather invaluable data on land attributes using handheld GPS. Some of the handheld receivers use phase-smoothed code for positioning. This means that the phase signal is available and may be used for Precise Differential GPS (PDGPS) positioning. Using GARMIN handheld receivers, the phase and the code information may be transferred in real-time to a computer and stored in a RINEX file.

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The performance and characteristics (Battery life; Navigation performance; Ease of use; Portability (weight) and Versatility) ranking test carried out at Gear Lab of 5 Garmin handheld GPS units under different conditions including desert, high mountains, clear and fog covered forests (Christ McNamara, 2025) arrived to the results shown in Figure 1.

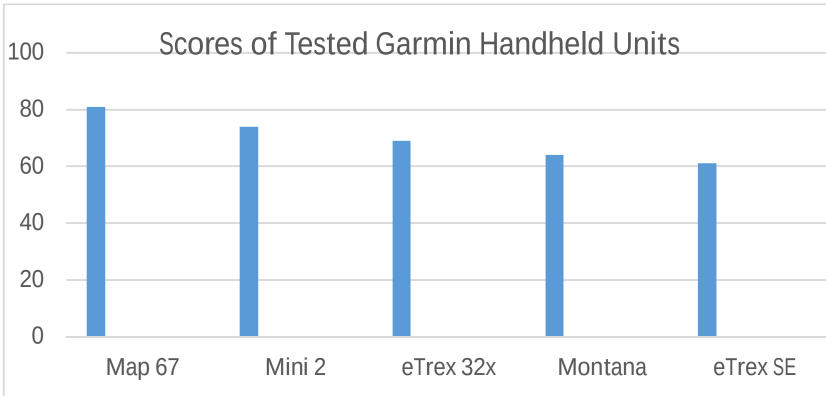

Fig. 1: Results of Overall Score of tested Garmin Handheld Units, from Christ McNamara, 2025, https://www.outdoorgearlab.com

Images in Figure 2 shows some samples of handheld GPS units.

GPSMAP® 67 Mini 2 Garmin eTrex 22X Montana 710i
SR: 2729 249 979 3979

Fig. 2: Samples of Handheld GPS Units and Prices in Saudi Riyal https://www.garmin.com/.

Like Geodetic GPS Handheld GPS units rely entirely on satellite signals. This dependency means that atmospheric conditions, satellite geometry, and obstructions like buildings or heavy tree cover can affect their accuracy and functionality.

Despite these potential issues, advancements in GPS technology and multi-GNSS support have mitigated most of these limitations.

In 2020, Garmin released a handheld GPS device with a dual-frequency GNSS chip and a quadrivial helix antenna: GPSMAP 66sr. The device is intended to serve as a positioning and navigation device for outdoor recreation purposes with positioning accuracies on the few meter accuracy level. However, due to its highly accurate GNSS dual-frequency carrier-phase observations, the equipment can also be used for centimeter-accurate positioning, Wanninger et al. (2022).

The main issue to be resolved is how accurate the data provided by handheld GPS is and whether it can be feasible to be used to produce topo maps and to with what scale.

III. TEST RESULTS FROM LITERATURE

As far as is known, the first scientific research on handheld receivers was conducted by Hill et al. 1999. They described a software package, GRINGO which extracts and records raw L1 pseudorange data from Garmin 12- channel hand-held GPS receivers. The output from GRINGO is a properly formatted RINEX (Receiver INdependent Exchange) file, containing decoded data. It offers owners of these receivers the possibility of post-processing to an accuracy of approximately 5 m (with pseudo ranges) or a few cm (with carrier phase), with low cost compared to expensive geodetic receivers.

Volker Schwieger, 2003, described the possibilities and limits of static and kinematic positioning using the handheld GPS phase information by using commercial post-processing software (GRINGO, P4, SKI-Pro). Results, shown in Table 2, indicate that accuracy and availability can be reduced using the corrected P4 and SKI-Pro. In general, the investigations of the GARMIN eTrex showed that the static accuracy is well suitable for GIS applications.

Table 2. Standard Deviations (m) and availabilities of software Schweiger, 2003

Standard deviation	Northing	Easting	Horizontal	Availability
SKI-Pro	±9.43	±9.01	±13.04	100%
P4	±9.07	±9.18	±12.90	100%
Corr. SKI-Pro	±4.64	±3.95	±6.09	97.2%
Corr. P4	±5.42	±4.74	±7.20	95.2%

Tiberius, 2003 tested Garmin GPS 76 handheld receiver accuracy. Seven satellites or more were available during observations. Using Single point positioning with respect to known reference over almost 14.5 hours of data at 30sec sampling interval he obtained results shown in Table 3 below. All data are in meters. The test based on kinematic positioning gave the standard deviations and maximum range of horizontal, across track and height error in meters, shown in Table 3.

Table 3. Test results using single point positioning and kinematic positioning (Tiberius, 2003)

Standard deviation	Horizontal	Height
Single point positioning	2.55	3.11
Kinematic positioning	1.03*	3.67
*Across track		

Elmowafy, 2005 carried out several tests in static and kinematic modes to check the performance of a proposed system that download carrier-phase data of GPS handheld receivers online and simultaneously registers the point code and description and processes the data in a differential post-mission mode. Results of four kinematic tests (average and maximum deviations) for horizontal and vertical positions are shown in Table 4.

The maximum error reached throughout any of the four tests was approximately 14 cm, for horizontal and 10cm for vertical. This clearly proves the success of the proposed system for position computations and generation of base maps using cheap measuring tool.

Table 4. Summary of Kinematic Testing Results, from El-Mowafy, 2005

Tests	Average Standard Dev. (m)		Maximum stand Dev. (m)	
	Horizontal	Vertical	Horizontal	Vertical
Oct. 10	0.057	0.031	0.093	0.071
Oct.23	0.080	0.051	0.128	0.104
Oct.30	0.055	0.039	0.141	0.081
Nov. 6	0.039	0.024	0.129	0.082

Volker Schwieger and Andreas Gläser, 2005 verified that baselines up to approximately 8 km may be measured with two Garmin eTrex Vista in half an hour with deviations up to 8 cm under low multipath conditions. They concluded that Handheld GPS receivers are a cost-effective tool to solve problems like rough setting out within construction processes or to achieve medium or low accuracy in engineering surveys as well as for control networks. Table 5 shows receiver class, used signal, application, accuracy and cost Volker and Andreas Glaser, 2005

Table 5. Receiver classes, applications and accuracy of static positioning (Volker and Andreas Glaser, 2005)

Receiver class	Signal used	Applications	Accuracy (m)	Approximate cost (Euro)
Low cost	Code or phase-smoothed code, 1 frequency	Car navigation, sailing, mass market	1 to 10	100 - 500
Geodata acquisition	Phase-smoothed code, 1 frequency	Infrastructure planning, GIS applications	0.5 to 3	5000 - 10000
Geodetic	Code and phase, in general 2 frequencies	Surveying, geodynamics	0.001 to 0.1	10000 - 30000

Michael W. Gerling, 2006 The GPS receiver used was the Garmin GPS-72. The GPS-72 model was among the lowest-price GPS receivers ($150) offering Wide Area Augmentation System (WAAS). WAAS provides the potential to obtain a level of accuracy of ten feet (3m). Typically, the GPS-72 receiver will provide a level of accuracy between 10 (3m) and 50 feet (15m).

The paper by Volker SCHWIEGER, 2007 dealt with quality characteristics like availability and accuracy of high sensitivity GPS receivers as well as navigation receivers. Recent results obtained at University Stuttgart are presented. As expected availability increases, but accuracy is reduced, if low quality signals are tracked. Low cost GPS receivers that are equipped with HS GPS chips may be used for precise GPS positioning as well as for precise kinematic applications. The accuracy is at the level of 2 cm for baselines up to 1.1 km and measurement times of approximately 30 minutes. These results are sufficient for surveying applications like cadaster and construction projects. The use of HS GPS for geodetic purpose seems to be possible in future.

Table 6. Accuracy of three receivers under free horizon, from Volker SCHWIEGER, 2007

Scenario	Receiver No.	Horizontal RMS (m)	Height RMS (m)	3D RMS (m)
Free horizon	1	2.59	5.57	6.34
	2	3.90	4.71	6.32
	3	4.24	2.01	4.74

Zupan R. and Miljenko Lapaine, 2007 described precision of measurements with the small hand-held GPS-device GPS-MAP and explored correlation between reading “accuracy” during survey and deviations of individual measurements from their average value. The calculated average of horizontal deviations of each point from the average point was 5.9 m. That means the precision or repeatability was a little better (15.7%) than the accuracies shown by the device. It is not possible to give a conclusion about the read accuracy on the basis of average horizontal deviations of each measured coordinate and obtained from the adjustment because these two variables are proportional. Residuals vary between 2.8 and 7.7m with RMSE 4.85m in planimetry. Statistical Results are shown in Table 7.

Table 7. Accuracy Read from GPS in meters, from Zupan and Miljenko, 2007.

Statistics	Values (m)
Maximum Accuracy	±10.0
Minimum Accuracy	±4.0
Average	±6.9

In the study by Halim, et al, 2010 a mapping procedure of an area (i.e. UTM campus) by combining the digitized images of Google Maps and the road features collected by handheld GPS (i.e. Garmin GPSMAP 76CSx) was developed. The accuracies of coordinates obtained from Google Maps and handheld GPS are compared against five known GPS points. The results show that the accuracy of Google Maps is between ±1.3m to ±10.5 m, while the accuracy of handheld GPS is in the range of ±0.2m to ±3.5 m. The distance comparison between points shows that handheld GPS is more accurate than Google Maps.

Nagi Zomrawi and Iman Issa, 2012 concluded that the handheld GPS receiver can practically provide horizontal accuracy of about ±4m. This result indicates that handheld GPS can be used for collecting data to produce planimetric maps at scale 1:7,500 and smaller. The table below shows their test results.

Table 8. Statistical Results (Zomrawi and Issa, 2012)

Statistics	Differences (m)	
	E	N
Maximum	2.00	4.00
Minimum	-5.00	-5.00
Average	-1.56	-0.69
RMSE (m)	±2.65	±2.98
Horizontal Accuracy (m)	±3.98	

In their study, Kamruzzaman, et al, 2014 land use analysis was carried out using handheld GPS and Total Station. Garmin GPS was used to locate ground position and track logs of different objects within the study The aim of the study was to compare the land use survey results conducted by both GPS and Total Station. They concluded that accuracy of handheld GPS is not high and is thus, not recommendable to use in any precise survey, rather it can be used in preliminary survey.

Mohammed Fator and Nagi Zomrawi, May 2015 tested the feasibility of using Etrex Garmin hand held navigation GPS receiver for mapping purposes. Their results showed that Etrex Garmin GPS receiver produced planimetric accuracy of ±3.16m. The study area of their research work was extended to cover about 15×15 km of Khartoum capital area (Sudan). The approach of estimating the accuracy of Etrex Garmin GPS receiver is using it for observing coordinates of precisely known 25 points. These points were precisely observed in the field using Deferential Global Positioning System (DGPS) model R8- GNN from Trimble Company. Static mode was used every 45 minutes to observe each point. Unexpected amount accuracy was equal to 0.5 cm ±1ppm. Differences between these coordinates and Etrex Garmin observed coordinates are then analyzed and statistical results are shown in table 9.

Table 9. Test Results (Fator and Zomrawi, 2015)

Statistics	Differences (m)		
	E	N	H
Maximum	4.07	3.62	16.62
Minimum	0.10	0.24	2.52
Average	1.93	1.96	4.96
RMSE (m)	±2.26	±2.20	±7.68

Hussein, Zahraa Ezzaddin, 2016 tested a software NMEA (National Marine Electronics Association) using least squares adjustment to improve the accuracy of coordinates obtained using handheld GPS. The test showed significant decrease in root mean square error (RMSE) in both horizontal and vertical directions from 9.4 m to 3.2 m and 6.8 m to 2.4 m respectively (Table 10). This study showed the possibility of enhancing the quality of handheld GPS signals using a designed program for receiving and processing NMEA files. Improvement of standard deviation to around 75% refers to the homogeneity improvement regarding distribution of errors on all GPS track points.

Table 10. Accuracy improvement of Handheld GPS Results (Hussein, 2016)

GPS Points	RMSE Horizontal (m)	RMSE Vertical (m)
Before Adjustment	9.3847	6.8131
After Adjustment	3.1667	2.4012

Abdallah, A. and Abazeed Amgad, 2018 studied the performance of kinematic Precise Point Positioning (PPP) solutions for handheld GPS receiver and dual frequency geodetic GPS receiver. For this purpose, a kinematic trajectory has been observed in New Aswan City by using Topcon GRS-1 handheld GPS receiver and Topcon HiPer Ga dual frequency geodetic GPS receiver. The results indicated that less than half meter positioning accuracy can be achieved using handheld GPS receiver and few centimeters positioning accuracy can be achieved using dual frequency GPS receiver. To evaluate the positioning accuracy of PPP solution for the geodetic receiver and the handheld receiver, numerical computations have been conducted. The obtained Root Mean Square Error (RMSE) is presented in Figure 3. For PPP solution for the geodetic receiver, the RMSE in east or height direction does not exceed 6 cm, also the RMSE in north is 2 cm, that makes PPP solution for geodetic receivers suitable for production of topographic maps at scale 1:500 with contour interval 0.2 m (Federal Geographic Data Committee, 1998). The PPP solution for handheld receiver show a RMSE of 32, 23 and 27 cm in east, north, and height, respectively. The accuracy of PPP solution for handheld receiver meets the requirements of the hydrographic surveys and topographic maps at scale 1:2000 with contour interval 1m (Federal Geographic Data Committee, 1998; IHO, 2005). To achieve cm accuracy, they used Differential GPS (DGPS) technique. They investigated the performance of kinematic PPP solutions for handheld GPS receiver and dual frequency geodetic GPS receiver. A kinematic trajectory has been observed using two geodetic GPS receivers and one handheld GPS receiver. The observation data was processed by CSRS-PPP online service.

The results showed that the accuracy of the kinematic PP solution for handheld GPS receiver can achieve less than 30 cm. On the other hand, the accuracy the kinematic PPP solution for geodetic GPS receiver can achieve few cm. See comparison of handheld GPS and Geodetic GPS PPP results in figure 3 below.

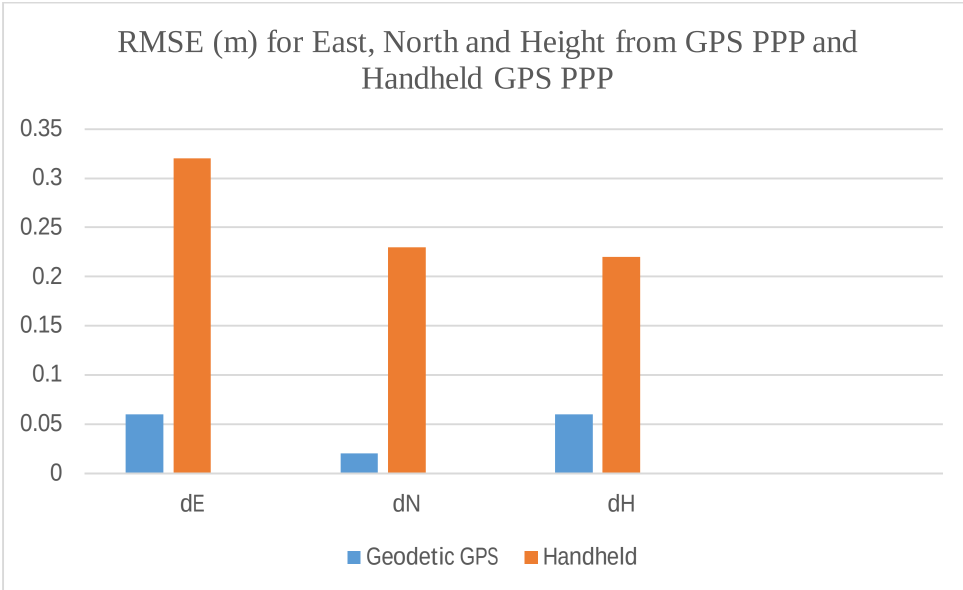

Fig. 3: RMSE values for east, north and height (m), from Abdallah and Abazeed, 2018

Lachapelle et al,2018a carried out an extensive and realistic accuracy performance assessment of the Garmin Rino 750 handheld unit. This unit is equipped with a high-sensitivity single frequency GPS/GLONASS chip and a quad helical antenna. GPS static and kinematic tests have been carried out under a wide range of field conditions. Derived coordinates were assessed through comparisons with coordinates obtained independently with high performance multi-frequency geodetic receivers operating in differential mode using a base station with coordinates precisely known in WGS84 via ITRF, thereby ensuring proper absolute position evaluation. This test is under ideal horizon-to-horizon line-of-sight conditions achieved on mountain summits where multipath is low. Table 11 shows results of the test.

Precise Point Positioning (PPS) static testing in ideal (clear signal horizon and low multipath) conditions

Precise Point Positioning (PPS) static testing in ideal (clear signal horizon and low multipath) conditions

Table 11. Static single point positioning of Trimble R10 and Garmin Rino 750 RMSE in meters, from Lachapelle, et al, 2018a.

Unit	Latitude	Longitude	Horizontal	Height
Trimble R10	0.55	0.34	±0.65	±0.79
Garmin BLK	1.01	0.74	±1.25	±1.34
Garmin RED	0.85	0.68	±1.09	±2.37

Lachapelle et al, 2018b assessed a handheld GPS unit, GPSMap 66, with GNSS raw data recording capability to determine static and kinematic position accuracy in various environments. The unit can track single frequency GPS, GPS + GLONASS or GPS + Galileo and record code, Doppler and carrier phase data every second**.** The evaluation presented **focused** on GPS and Galileo. Static and kinematic test results obtained under a wide range of realistic field conditions **we**re reported. Differential GNSS methods and Precise Point Positioning (PPP) **we**re used to assess absolute position accuracy in ITRF coordinates, which is sufficiently close to the GPS and Galileo reference frame**.** Under low multipath conditions, measurements are found to be sufficiently accurate to provide single epoch, bias free position accuracy of a few meters. Accuracy is a function of signal attenuation and multipath conditions. The use of an external geodetic antenna (EGA) significantly reduces noise and multipath in high multipath environments. Carrier phase measurements, available continuously under open sky conditions, significantly improve performance in differential mode. This test was carried out on the roof top of a building at the University of Calgary, a high multipath environment. The corresponding GPS and Galileo epoch-by-epoch coordinates during the test period for two handheld GPSMap 66 units are summarized as in Table 12.

Table 12. Two GPSMap 66 Units (BL and GR) Test Results in meters, from Lachapelle et al, 2018b

Unit	Latitude	Longitude	Horizontal	Height
Trimble R10	±0.8	±0.6	±1.0	±2.0
Garmin BL RTk GPS	±6.5	±3.5	±7.4	±12.2
Garmin GR RTK GPS	±4.5	±3.0	±5.4	±10.1
Garmin BL Galileo	±6.6	±2.4	±7.0	±8.4
Garmin GR Galileo	±6.6	±4.2	±7.8	±11.9
Garmin GPS EGA	±1.6	±0.9	±1.9	±3.8
Garmin Galileo EGA	±2.2	±1.1	±2.5	±4.0

AISYAH, S. and MOHD NOOR, 2021 carried out tests involving the positional accuracy of portable Global Positioning System (GPS) in open and closed spaces. Results of latitude (dN) and longitude (dE) errors and positional accuracy in open and closed spaces are shown in Table 13.

Table 13. The distance from mean position for open and closed spaces, from Aisyah and Noor, 2021.

Closed Space Case			Open Space Case		
dN (m)	dE (m)	dP (m)	dN (m)	dE (m)	dP (m)
-7.281	-6.45	±9.73	3.896	0.14	±3.90
-7.403	-10.55	±13.72	3.896	0.13	±3.90
-7.781	-10.70	±13.23	3.674	0.12	±3.68
-8.069	-10.88	±13.55	3.452	0.12	±3.45
-8.215	-6.52	±10.49	3.230	0.10	±3.23
-8.081	-3.26	±9.38	3.008	0.09	±3.01

The accuracy of positioning using portable USB GPS antenna system shows that positioning in open spaces, the errors are much better than those in closed spaces, which is obvious.

Study by Jayasekara and Munasinghe, 2021 verified the capability of the handheld GPS to replace the Total Station in land use survey. The aim of the study was to evaluate the land use survey results with handheld GPS and total station. GPS (Leica GS 15) instrument was fixed at a Base station named NSG 01 and data collection was done using handheld GPS (Leica Zeno 20) unit with different modes such as Satellite-Based Augmentation System (SBAS) off and SBAS on. Further the collected data were processed with the Differential GPS (DGPS) and without DGPS approaches using Leica infinity and QGIS software and four plans were prepared. Then the area was calculated for each land use category. The most accurate results were given by the handheld GPS in SBAS on mode. Its error level was 0.46% with correlation factor 0.99995 which was the closest value to 1.

Tomasz Szot, et al, 2021 carried out comparative assessment of the absolute positioning accuracy of 12 Garmin GNSS devices in kinematic measurements for three values of the speed, namely: 10, 30 and 50 km/h. Analysis of the location accuracy of the tested handheld receivers as a function of the number of GNSS systems used was performed. The Handheld RTK Device provides centimeter-level accuracy by using Real-Time Kinematic (RTK) positioning, which corrects GPS signals. Professionals such as land surveyors, construction engineers, GIS specialists, precision farmers, and field researchers use this portable device to get very accurate location data.

Krystina. et al, 2022 explored the positional accuracy of five GPS units for a micro mobile vehicle during three different ride conditions: acceleration, deceleration, and constant speed. The same devices were also tested for stationary accuracy and power cut-off scenarios. To obtain precise data from GPS units, tests were performed with an electric scooter ridden in rural landscapes with clear skies. Location data from the portable GPS devices were compared to reference data obtained from photogrammetry methods based on video recorded by DJI Mavic 2 drones. It was found that the overall average positional deviation from baseline across the devices and three ride conditions was 6.68 ft (2.00m).

Wanninger et al. (2022) investigated the performance of the Garmin GPSMAP® 66sr handheld-type GNSS device. They performed extensive test measurements and analyzed the quality of its code and carrier-phase observations. They calibrated the Garmin GPSMAP 66sr antenna with respect to its phase-center offset and phase-center variations.

We also performed dual-frequency GPS/Galileo precise point positioning (PPP) and precise relative positioning in baselines to virtual reference stations (VRS). We demonstrate and explain how centimeter-accurate positioning can be achieved with this novel kind of equipment. They concluded that, with this kind of Garmin receiver, ITRF coordinates can be determined in PPP mode on the accuracy (RMS) level of 10 cm after about 1 h, 5 cm after a few hours, and a few centimeters after many hours of static observations at a favorable site. Figures 4 & 5 below show the RMSE values function of observation period in hours for roof top installation (Clear condition) and for adverse environmental conditions.

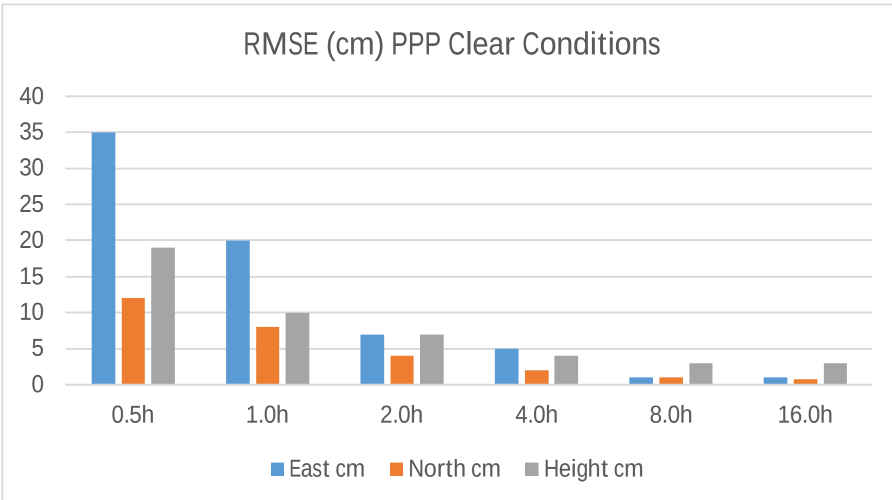

Fig. 4: PPP coordinate errors (RMS values) as a function of session length for the static, roof-top observations - Wanninger et al., 2022.

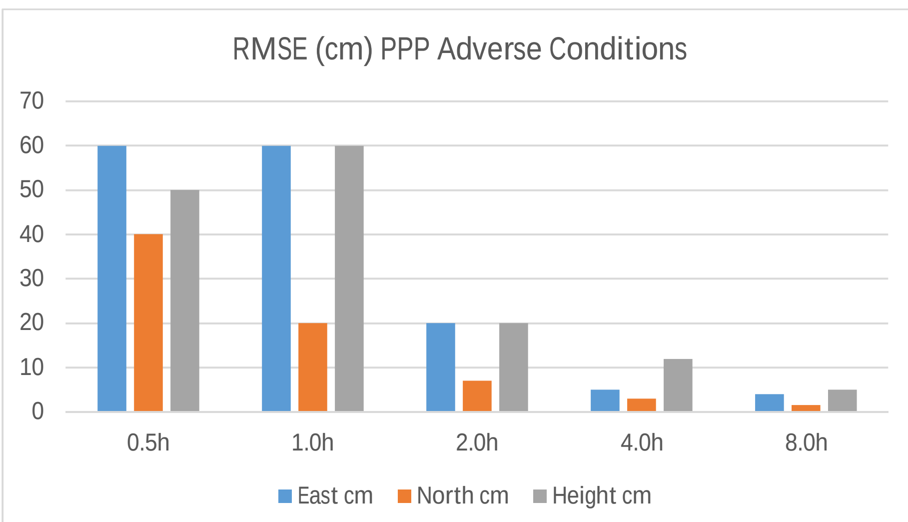

Fig. 5: PPP coordinate errors (RMS values) as a function of session length for the static observations under adverse environmental conditions - Wanninger et al., 2022.

Alkan, et al, 2023 assessed the 3D positioning accuracy performance of the Garmin GPSMAP® 66sr handheld device using the device raw measurements. They established two control points and carried out static GNSS measurements with Trimble R8 geodetic-grade receivers. Finally, all the coordinates obtained from baseline and PPP solutions in the static mode were compared with the known values in terms of 2D horizontal and height components. A summary of results for both Relative static and CSR PPP solutions applied in two fields were given in Table 14.

Table 14. Relative Static (RS) and CSRS PPP Solution Results for Field Test 1 (FT1) and Field Test 2 (FT2), from Alkan, et al, 2023.

Solution	dP (cm)	dH (cm)
RS – FT1	5.3	2.5
RS – FT2	2.6	1.7
RS - Mean	4.0	2.1
PPP – FT1	2.6	4.2
PPP – FT2	0.6	0.6
PPP - Mean	1.6	2.4

Ibrahim Olatunji Raufu, et al, 2025 compared Android GPS applications on three smartphones (Samsung, Tecno, Infinix) and handheld GPS with the existing standard (DGPS). Their study involved determining coordinates in three modes: airplane mode (no network coverage), offline mode (cellular network but no internet access), and online mode (with internet access). Fifteen stations were observed, and the results of the analysis revealed an effect of the observation modes. Standard deviations obtained using handheld GPS as: ±2.598m in airplane, ±2.033m offline mode and ±1.780m in online mode.

Elhassan and Bilani, 2026 suggested a regression formula to improve height accuracy of Etrex Garmin handheld GPS receiver data obtained by Fator and Zomrawi, 2015 referred to above, in this article. Height accuracy was improved from ±7.68m RMSE to ±3.77 and ±4.38m using 4 and 3 control points, respectively.

IV. SUMMARY OF RESULTS & DISCUSSION

Geometric Results obtained for tested handheld GPS by researchers outlined in this article can be summarized as in table 15 below

Table 15 Summary of Research Results

Research	Results (RMSE) – m	
	Horizontal	Vertical
Volker Schwieger, 2003	±1.00	
Elmowafy, 2005 (Max Stand Dev)	±0.14	±0.10
Zupan R. and M. Lapaine, 2007	±7.00	
Halim Setan, et al, 2010.	±3.50	
Zomrawi and Iman Issa, 2012	±3.99	
Fator and Zomrawi, 2015	±3.15	±7.68
Marie-Amélie Forin-Wiart, et al, 2015	±5.87	
Zahraa Ezzaddin Hussein, 2016.	±3.20	±2.40
Lachapelle, et al, 2018a BLK	±1.25	±1.34
Lachapelle, et al, 2018a RED	±1.09	±2.37
Lachapelle, et al, 2018b- GPS EGA	±1.90	±3.80
Lachapelle, et al, 2018b Galileo EGA	±2.50	±4.00
A. Talaat A. and A. Abazeed, 2018	±0.39	±0.27
Wanninger et al. (2022)	±0.01	±0.03
Alkan, et al, 2023 – RS	±0.04	±0.02
Alkan, et al, 2023 – PPP	±0.02	±0.02
Ibrahim Olatunji, et al, 2025 - online	±1.78	
Ibrahim Olatunji, et al, 2025 - offline	±2.03	
Elhassan and Bilani, 2026: 4 control points		±3.77

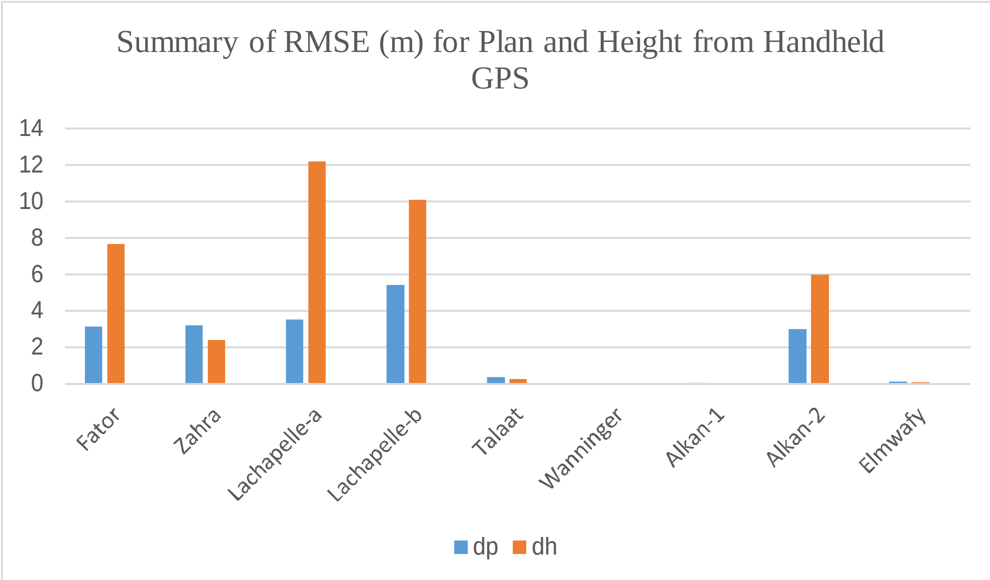

Fig. 6: Handheld GPS 3D Accuracy obtained by Researchers

From the above results it can be noticed that for the studies that took place in the period 1999 to 2016 planimetric accuracy achieved using handheld receivers vary between ±1.00m to ±7.00m, while those carried out in the years 2018 to 2026 planimetric accuracy achieved varies from ±0.01m to ±3.00m. For the first period vertical accuracy ranges from 0.10m to 7.68m, while for the latter one it ranges from 0.02m to 4.00m.

Looking into the standard topographic mapping specifications (Table 16) below that show required horizontal accuracy (RMSE) in meters against topographic map scale (ASPRS, 2024), it can be concluded that recent studies (2018 and after) indicated accuracy of ±2.5m in planimetry which can allow 1:10000 scale mapping.

Table 16. ASPRS Accuracy Standards for Large Scale Mapping Class 1, ASPRS, 2024.

Map Scale	1:100	1:500	1:1000	1:5000
RMSE (m)	0.025	0.125	0.250	1.250
Map Scale	1:10000	1:20000	1:50000	1:00000
RMSE (m)	2.50	5.00	10.00	25.00

Vertical accuracy within ±4.0m, for the recent period, allows contouring with 10m contour interval.

V. CONCLUSIONS

The paper reviewed most of the research published about testing geometric accuracy obtained using handheld GPS.

The literature review shows that different results and conclusions based on methodology and test design were obtained and derived.

The review concludes that planimetric accuracy obtained using handheld GPS receivers can vary between 0.01m to 7.00m. In vertical direction accuracy obtained range from 0.02m to 7.68m. This shows high variation in results for both planimetry and height. It is also concluded that handheld GPS can provide data for planimetric mapping of scale 1:10000 and contour maps with contour interval of 10m. More recent studies, however, show accuracy up to within ±1cm for planimetry and ±2cm in height. More tests should be carried out, however, to confirm these conclusions.

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