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MEASUREMENT AND VERIFICATION OF SELECTED PEAKS IN THE "NEW CROWN OF POLISH MOUNTAINS" FOR INVESTIGATING THE ACCURACY OF LIDAR POINT CLOUDS

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Abstract

The Crown of Polish Mountains is a list of mountain peaks that has long attracted significant interest, with all included summits being considered worthy conquering. The proposal to expand this list with additional peaks, termed the "New Crown of Polish Mountains" by historian Krzysztof Bzowski, served as the impetus for a study of examining the accuracy of LiDAR (Light Detection and Ranging) point clouds in the areas of the newly proposed peaks. The primary data source analyzed in this study is the LiDAR point cloud with a density of 4 points per square meter, obtained from the ISOK project. As a secondary LiDAR data source, a self-generated point cloud was utilized, created by using the integrated LiDAR sensor in the iPhone 13 Pro and the free 3dScannerApp mobile application within terrestrial scanning. These datasets were compared against RTK GNSS measurements obtained with a Leica GS16 receiver and mobile measurements conducted using Android smartphones. In addition to analyzing the raw point clouds, the study also involved the visualization of the analyzed areas by the creation of Digital Terrain Models in two software programs: ArcGIS Pro and QGIS Desktop. The research confirmed the known accuracy of ALS point clouds and revealed that the integrated LiDAR sensor in the iPhone 13 Pro demonstrates surprising accuracy. The potential for laser scanning with a smartphone, combined with the capability of conducting mobile GNSS measurements, could revolutionize geodetic surveying and simplify the acquisition of point cloud data.

Keywords: LiDAR, RTK, GNSS, accuracy

POMIAR I WERYFIKACJA WYBRANYCH SZCZYTÓW „NOWEJ KORONY POLSKICH GÓR" W CELU BADANIA DOKŁADNOŚCI CHMUR PUNKTÓW LIDAR

Abstrakt

Korona Gór Polski jest listą szczytów górskich, która od lat reprezentuje wysoki wskaźnik zainteresowania. Wszystkie objęte nią szczyty są warte zdobycia. Propozycja rozszerzenia tej listy o kilka szczytów nazwana została „Nową Koroną Polskich Gór" przez historyka Krzysztofa Bzowskiego i stała się inspiracją do wykonania badania dokładności chmury punktów LIDAR

(Light Detection and Ranging) na terenach nowo zaproponowanych szczytów Korony Gór Polski. Chmura punktów LIDAR o gęstości 4 punktów na metr kwadratowy pozyskana w ramach projektu ISOK jest głównym źródłem danych objętych analizą. Jako drugie źródło danych LiDARowych wykorzystano samodzielnie wykonaną chmurę punktów za pomocą wbudowanego sensora LIDAR w iPhone 13 Pro oraz darmowej aplikacji mobilnej 3dScannerApp w ramach naziemnego skaningu. Takie dane porównano do wyników pomiarów RTK GNSS wykonanych odbiornikiem Leica GS16 i pomiaru mobilnego wykonanego za pomocą smartfonów z systemem Android. Oprócz badania surowej chmury punktów podjęto się wizualizacji terenów objętych analizą, za pomocą wykonanych Numerycznych Modeli Terenu w dwóch programach: ArcGIS Pro oraz QGIS Desktop. Badania potwierdziły znaną dokładność chmury punktów ALS i odkryły, iż wbudowany sensor LIDAR w iPhone 13 Pro reprezentuje zaskakującą dokładność. Możliwość skaningu laserowego za pomocą smartfona wraz z możliwością wykonania pomiaru mobilnego GNSS może zrewolucjonizować pomiary geodezyjne oraz ułatwić pozyskiwanie danych chmurowych.

Słowa kluczowe: LiDAR, RTK, GNSS, dokładność

1. INTRODUCTION

In 1997, Marek Więckowski and Wojciech Lewandowski introduced their vision of the Crown of Polish Mountains (CoPM) in the journal "Poznaj swój kraj" initially encompassing 27 peaks. The primary goal of the CoPM initiative was to popularize and promote the names of mountain ranges and peaks that were previously less known and less frequently visited. The project also aimed to increase interest in the natural environment, geology, culture, and history of these regions. Currently, the Crown of Polish Mountains includes 28 peaks [1]. In 2023, Krzysztof Bzowski published the book "Nowa Korona Polskich Gór" in which he proposed an updated list of CoPM peaks, based on the new regionalization of the Carpathians and Sudetes [2]. The new list is set to include 38 peaks [3].

This study focuses on analyzing the new proposed peaks, examining the accuracy of Light Detection and Ranging (LiDAR) point clouds obtained from various sources. The primary LiDAR data source utilized was the publicly available point cloud created within the Informatyczny System Osłony Kraju (ISOK) project using the Airborne Laser Scanning (ALS) in 2014 [4]. The secondary data source was a point cloud generated using the built-in LiDAR sensor of the iPhone 13 Pro, along with the free 3dScannerApp. This modern approach to laser scanning may significantly simplify the acquisition of point clouds for various objects. Research using this device has been conducted for several years in numerous science fields [5–8]. Results are clear, that the built-in sensor can be used as a measurement support tool or even as a standalone scanning tool for f.e. capturing 3D data of crime scenes, crash sites etc.

To verify the accuracy of the LiDAR data, it was compared with more precise data obtained from the RTK GNSS technique, which provides centimetre-level accuracy. Technical information about the GNSS measurements was sourced from the "GPS w praktyce geodezyjnej" [9] and the "Systemy satelitarne GPS, Galileo i inne" books [10]. To validate the RTK GNSS measurements, the raw GNSS observations can be performed using a smartphone, which in terms of accuracy and measurement method is comparable to rapid static GNSS receiver techniques [11]. Such features enable a comprehensive assessment of the capabilities of LiDAR point clouds. Before commencing fieldwork, similar studies described in scientific articles were reviewed (including those authored by AGH staff) [12–16], in which we can find the information about the elevation differences for various mountain peaks relative to different data sources, as well as GNSS measurement results and their comparison with elevations derived from LiDAR point clouds. A valuable finding is also the fact that elevations between sources may differ due to the use of different coordinate systems or frames.

In the analysis of LiDAR point clouds it is often not feasible to rely solely on derived products such as Digital Terrain Models (DTMs), especially when dealing with low point density, as observed in the areas under study. This sentence can be supported by findings from a review in Vaclav Petras et al. [17], which discusses the effects of point density variations on the precision of airborne LiDAR-generated DTMs, reaffirming that denser point clouds contribute to higher model accuracy. Given the low vertical accuracy (15 centimetres) and low point density (4 pts/m^2) of the LiDAR point cloud retrieved from geoportal.gov.pl, we do not consider the DTM as the primary source of elevation data but rather as a supplemental tool for visualizing the study area.

The mail goal of this study is the examination of the accuracy of LiDAR point clouds and examination iPhone 13 Pro built-in LiDAR sensor possibilities in geodetic field, based on RTK GNSS measurements of the highest terrain points on the newly proposed mountain peaks in the book “Nowa Korona Polskich Gór”.

2. STUDY AREA

The subject of the research were 7 peaks located in Southern Poland named: Eliaszówka, Gęsia Szyja, Dudasowski Wierch, Magura Witowska, Kiełek, Baków, and Ochodzita presented in Figure 1. All of them are in the new list of the Crown of Polish Mountains.

Eliaszówka is located on the border between Poland and Slovakia, within the ridge extending eastward from the Gromadzka Pass towards Piwniczna-Zdrój, on the southern side of the Czercz stream valley. This section of the mountain range is characterized by significant relative elevations and a diverse landscape featuring picturesque side ridges, steep slopes, and scattered hamlets nestled among the mountains, with a distinctive mosaic of meadows and forests.

Gęsia Szyja owes its name to the narrow and undulating section of the ridge above Rusinowa Polana. The summit is crowned with hard dolomitic rock formations, offering a stunning view of the northern part of the High Tatras. The mountain can be ascended via the green trail from Wierch Poroniec to Hala Gąsienicowa or from Palenica Białczańska through Rusinowa Polana. The ascent to the summit involves climbing 1,235 steps.

Dudasowski Wierch is located in the Spiš Magura range, which is characterized by treeless slopes, with the Polish section being significantly lower than the Slovak side. Although the landscape, particularly in the Polish part, resembles a foothill region, both the absolute and relative elevations classify this area as mountainous.

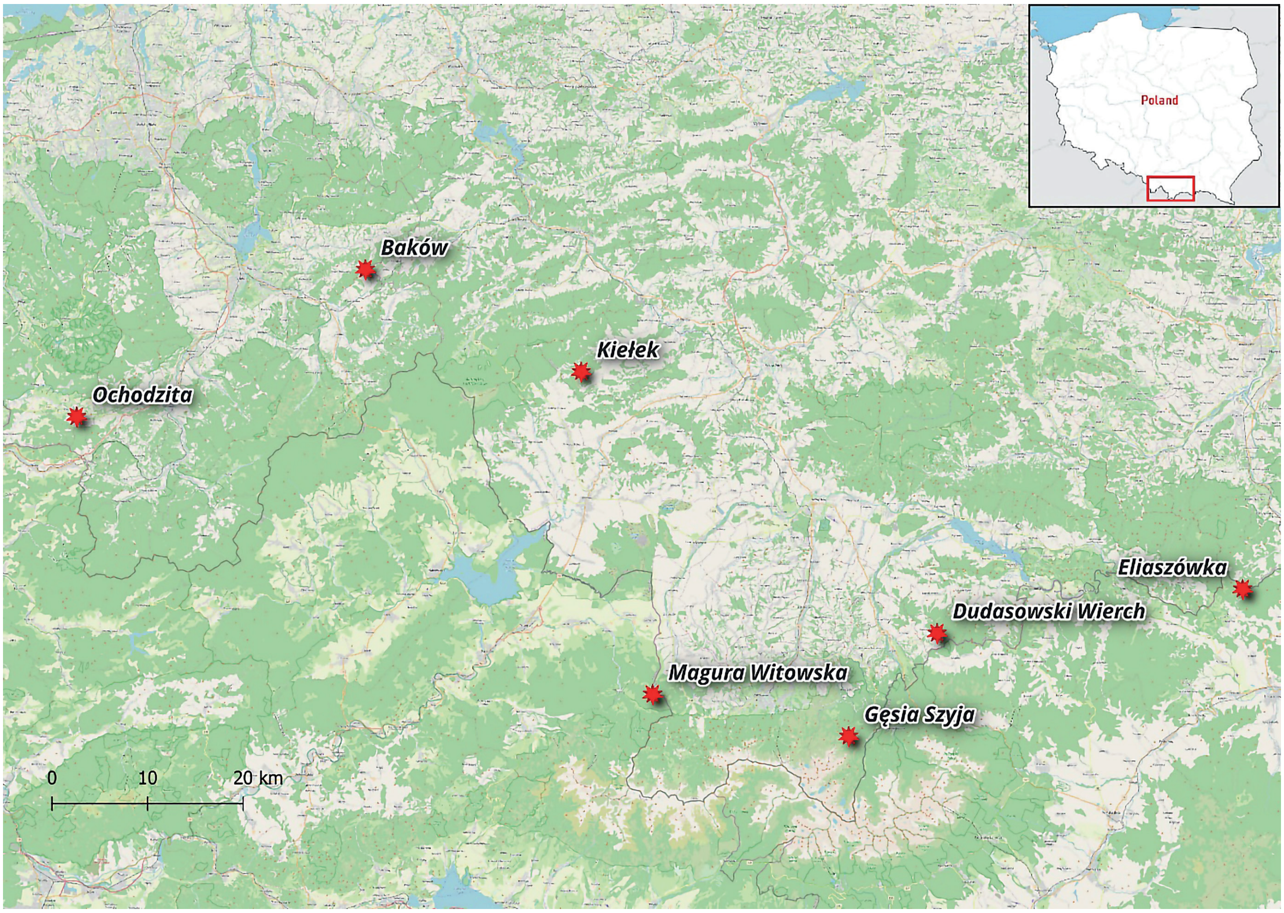


Fig. 1. The map of the distribution of measured peaks (QGIS Desktop generated on OpenStreetMap background)
Ryc. 1. Mapa rozmieszczenia pomierzonych szczytów (wygenerowana w QGIS Desktop na tle OpenStreetMap)

Magura Witowska rises along the Polish-Slovak border, situated between the valleys of Czarny Dunajec to the east and Orawica to the west. Due to its exposed summit, it serves as a fantastic vantage point, offering exceptional views, particularly of the Western Tatras.

Kiełek is the highest peak of a small ridge that branches off from the southeastern arm of Czyrniec in the Polica Range. Although this rarely visited elevation is not difficult to locate, there is no marked tourist trail leading to it.

Baków is located in the Pewelskie Range. The yellow trail passes through it, connecting the summit of Gachowizna with Jeleśnia. The summit of Baków is not particularly impressive, and it can be easily reached by an asphalt road from Hucisko. The sub-peak meadows offer good views, especially towards the east and south, although there are no views from the summit itself.

Ochodzita is situated along a long ridge that, through the Koniakowska Pass, directly neighbors the Silesian Beskids. The mountain owes its prominence above the surrounding ridges to the harder rocks that form it, specifically coarse-grained sandstones. Ochodzita is easily accessible and serves as an excellent vantage point for observing the surrounding higher mountain ranges.

3. MATERIALS AND METHODS

3.1. Data Acquisition

Before the expedition, point clouds were obtained from the ISOK project, featuring a density of 4 pts/m^2, available at the geoportal.gov.pl [18]. The data was provided in the PL-KRON86-NH vertical reference frame, which is outdated (no longer in service) [19]. For relatively small (mountain peaks) this has a negligible impact on results. The downloaded point clouds were imported into the free QGIS Desktop software, where they were clipped to the study areas using the Lastools plugin. The resulting products were point clouds with dimensions of 100 × 100 meters, with their geometric centre corresponding to the investigated peak. Subsequently, a classification accuracy check was conducted using the "lasview" option, where any potential deviations from classification that could be considered data errors were examined. None of the point clouds contained such errors, so they were used for further analyses, including the creation of a Digital Terrain Model (DTM) and height studies, which constitute the primary focus of this work.

3.2. Methodology

The methodology of this work was based on several stages. Majority of data were obtained from personal measurements including RTK GNSS measurements, mobile surveying, and laser scanning (performed with a smartphone). Firstly, the utility of the LiDAR sensor in the iPhone 13 Pro was assessed concerning the study's objective, which is to evaluate the accuracy of LiDAR point clouds. Subsequent stages involved: analysing LiDAR point clouds collected as part of the ISOK project, acquiring and cleaning LiDAR point clouds obtained from the iPhone, creating a Digital Terrain Model (DTM) for each measured peak, and analysing these models. The highest point from each DTM and point cloud was identified using a Matlab script, and the obtained values were verified using the "lasview" option in QGIS Desktop along with the Lastools plugin.

To identify the highest ground point in the area of each peak, an optical level (Leica Sprinter) was used. Subsequently, coordinates were determined by RTK GNSS measurements (Leica GS16 receiver, PL-ETRF2000 and PL-KRON86-NH frames) at locations which potentially are the highest ones. To ensure the low level of uncertainty, measurements were taken over a period of 180 epochs at each location. We achieved height accuracy of 1–5 cm. Mobile measurements using smartphones were conducted at the peaks of Eliaszówka, Gęsia Szyja, Dudasowski Wierch, and Magura Witowska. The measurements were performed using the RinexOn application, with each measurement session lasting approximately one hour. The accuracy of the raw GNSS data measurement was unsatisfactory. Peaks like Kiełek, Baków oraz Ochodzita were not included in the this measurement due to conclusions drawn after the first observation session (low accuracy).

The LiDAR data source for this study includes point clouds obtained with the built-in LiDAR sensor in the iPhone 13 Pro. The free app used for this purpose was 3dScanningApp, which offers various scanning modes. For this study, the "LiDAR" mode was selected. Before applying the device to the primary study objects, its utility was tested on a sledding hill in Jordan Park, Kraków. Four reference targets were placed at the summit, which were surveyed with a Leica GS16 receiver in 30 epochs using the PL-2000 coordinate system, zone 7, and the PL-KRON86-NH height frame. Scanning with the iPhone 13 Pro was initiated by launching the 3dScannerApp and selecting the "LiDAR" measurement option. It doesn't require any stabilization – the scanning itself reminds of making a film on a smartphone. The app captures photos during the scan, which are used for colouring the point cloud and creating the model. Results were satisfactory – the generated point cloud was highly detailed and faithfully reflected the measured terrain.

The first method for determining the highest points in the point cloud involves using the "Lastools" plugin for QGIS Desktop. The "lasinfo" option within this plugin will generate a report for the entire point cloud – both the ALS data from the ISOK project and the data obtained from the iPhone 13 Pro. It is important to note that the point cloud from ISOK contains points from all classes, so to identify the highest terrain point, points classified as "2" (ground) must first be exported. The second method involves using Matlab. First, we used QGIS Desktop with the "Lastools" plugin and the "las2txt" option to export all points in the cloud along with their classifications. Next, in Matlab, a script was written to load the previously exported text file, select the points (rows) classified as class "2" which denotes "ground", open a new text file to save the selected rows, and identify the highest elevation from the selected rows. This script is applicable only to point clouds obtained from ISOK, as point clouds from the iPhone 13 Pro are not classified. The smartphone clouds are representing the ground class as the scanning object was the ground itself.

Last, but not least we generated the DTM for each peak using two software: ArcGIS Pro and QGIS Desktop to visualize the terrain and check, if studied point clouds are good sources for creating the terrain models. In QGIS Desktop we used the Lastools plugin and grid method of creating the DTM. On the other hand, in ArcGIS Pro we used an option, which allows you to generate the DTM with using the triangulation method. Both ways included the 25 cm × 25 cm cell size of exported raster.

4. RESULTS

4.1. Test Object – Sledding Hill in Jordan Park, Kraków

Based on the conducted test of the iPhone 13 Pro, the suitability and utility of the obtained point cloud were evaluated. To achieve this we imported earlier exported point cloud into the CloudCompare (opensource software). Next, the local coordinate system of the point cloud was transformed to the PL-2000 (zone 7) coordinate system by identifying the reference markers and inputting the previously measured RTK GNSS coordinates. The transformation error measured by RMSE (Root Mean Square Error) was 0.01139 m, which was considered a good result.

Locating the centre of the target markers was relatively straightforward. During the initial attempt to scan the test object, red-painted wooden stakes were used. Unfortunately, they were difficult to locate in the scan. This led to the decision to use target markers that feature high contrast and cover a larger scanning area.

After manually cleaning the point cloud, it was easily exported in the appropriate coordinate system to a *.las file for further analysis in other software programmes. The exported point cloud was imported into QGIS Desktop, where the Lastools plugin and the "lasinfo" option were used to obtain the minimum and maximum elevation values for the test area. The results were very close to those measured in the field. That led us to the decision of using iPhone 13 Pro as a surveying instrument in further analysis.

Fig. 2. The point cloud of the test object with four target markers in CloudCompare

Ryc. 2. Chmura punktów obiektu testowego z czterema tabliczkami celowniczymi w CloudCompare

Table 1. Heights provided from various sources and height differences between RTK measurement and point clouds (PL-KRON86-NH height frame)
Tabela 1. Wysokości z różnych źródeł wraz z różnicami wysokości między pomiarem RTK a chmurami punktów (układ wysokościowy PL-KRON86-NH)

Peak	Eliaszówka	Gęsia Szyja	Dudasowski Wierch	Magura Witowska	Kiełek	Baków	Ochodzita
RTK measurement [m]	1023,90	1490,00	1037,60	1232,07	959,87	765,54	895,14
ISOK cloud point [m]	1024,12	1489,14	1038,30	1231,56	960,18	765,78	894,71
iPhone cloud point [m]	–	–	–	–	960,18	765,70	895,36
|dH RTK-ISOK| [m]	0,22	0,86	0,70	0,51	0,31	0,24	0,43
|dH RTK-iPhone| [m]	–	–	–	–	0,31	0,16	0,22

Table 2. Heights provided from generated DTMs with their differences (PL-KRON86-NH height frame)
Tabela 2. Wysokości pozyskane z wygenerowanych NMT z ich różnicami (układ wysokościowy PL-KRON86-NH)

	DTM ArcGIS Pro		DTM QGIS Desktop			
Peak	ISOK H [m]	iPhone 13 Pro H [m]	ISOK H [m]	iPhone 13 Pro H [m]	|dH ISOK| [m]	|dH iPhone| [m]
Eliaszówka	1024,08	–	1024,11	–	-0,03	–
Gęsia Szyja	1489,01	–	1489,12	–	-0,11	–
Dudasowski Wierch	1038,26	–	1038,28	–	-0,02	–
Magura Witowska	1231,56	–	1231,55	–	0,01	–
Kiełek	960,15	960,18	960,16	960,18	-0,01	0,00
Baków	765,77	765,71	765,76	765,71	0,01	0,00
Ochodzita	894,70	895,36	894,70	895,36	0,00	0,00

4.2. Research Subjects – New Proposals for Peaks in the Crown of Polish Mountains

All peaks were measured with RTK GNSS method. The peaks Eliaszówka, Gęsia Szyja, Dudasowski Wierch, and Magura Witowska were under the raw GNSS data measurement. The peaks Kiełek, Baków, and Ochodzita were additionally scanned with an iPhone 13 Pro. The highest elevation from the point clouds was determined using a script in Matlab.

4.3. Digital Terrain Model – Elevation Analysis and Visualization

The Digital Elevation Model (DEM) was created using ArcGIS Pro and QGIS Desktop programmes. For the LiDAR point cloud obtained from the ISOK project, a raster pixel size of 0.25 meters was chosen, reflecting the cloud's measurement accuracy of approximately 15 cm. For the point cloud acquired with the iPhone 13 Pro, which was aligned and transformed based on RTK GNSS measurements with an accuracy of 3–5 cm, a raster pixel size of 0.05 meters was selected. The iPhone point clouds were captured from a height of approximately 140 cm with average density of 15000 pts/m^2.

The DTM created from the point cloud obtained using the iPhone 13 Pro is significantly more accurate than the Digital Terrain Model made from a LiDAR point cloud from ISOK project. Raster cell size was chosen according to the accuracy represented by the source point cloud. The difference in values between the DTM from the ISOK point cloud using ArcGIS Pro and the DTM from QGIS Desktop ranges from 1 to 11 centimeters. The DTMs from iPhone 13 Pro don't differ between the sources of their creation.

Table 3. Digital Terrain Models for Baków peak localization
Tabela 3. Numeryczne Modele Terenu dla lokalizacji szczytu Baków

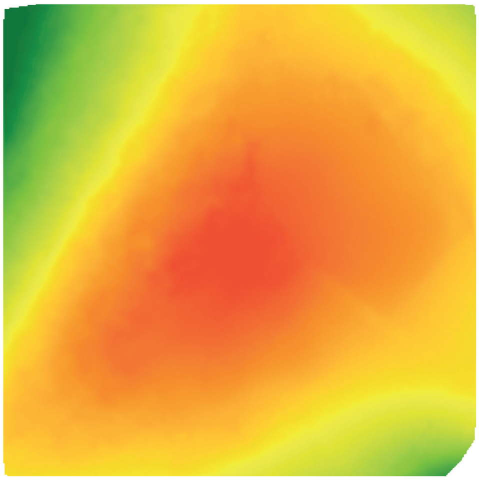
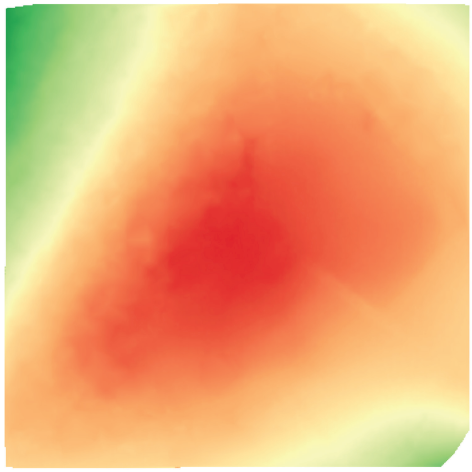
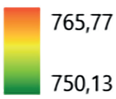
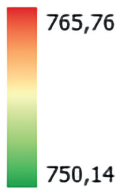
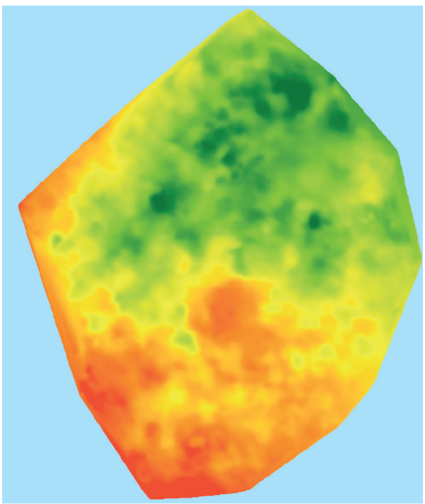
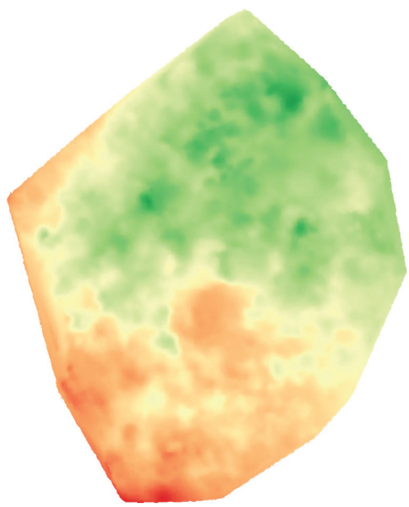
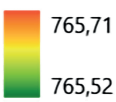
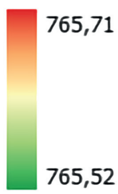
DTM ArcGIS Pro ISOK	DTM QGIS Desktop ISOK
	
	
DTM ArcGIS Pro iPhone	DTM QGIS Desktop iPhone
	
	

Table 4. Digital Terrain Models for Kiełek peak localization
Tabela 4. Numeryczne Modele Terenu dla lokalizacji szczytu Kiełek

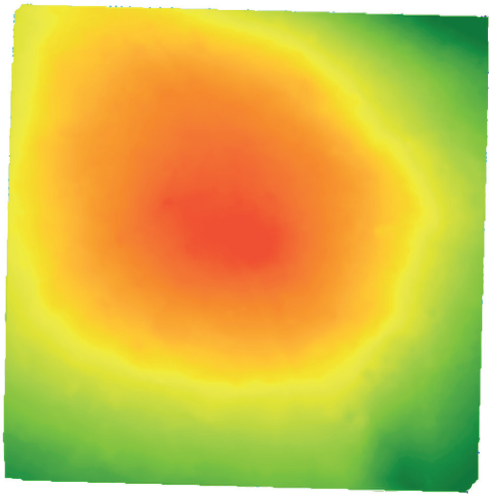
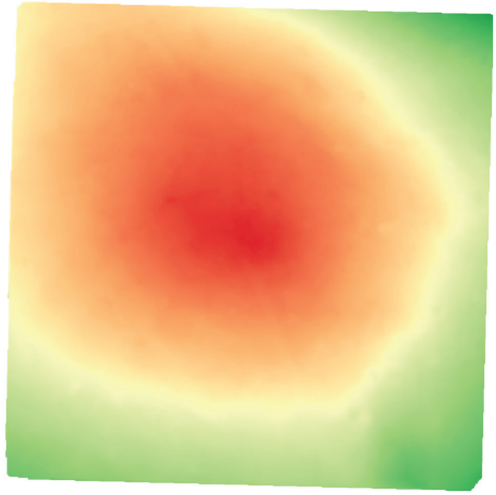
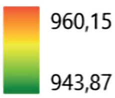
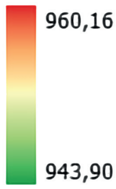
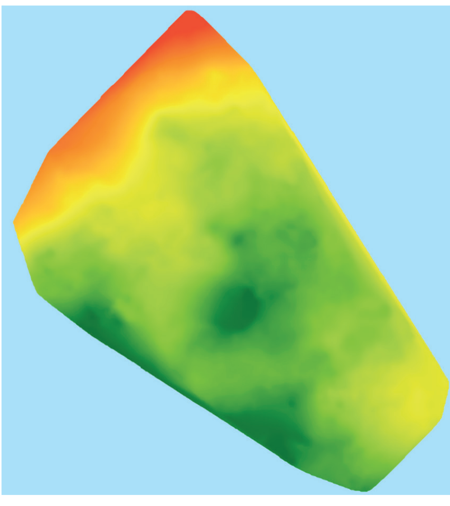
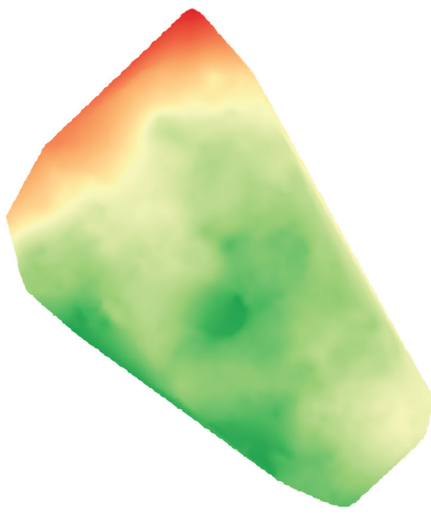
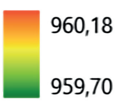
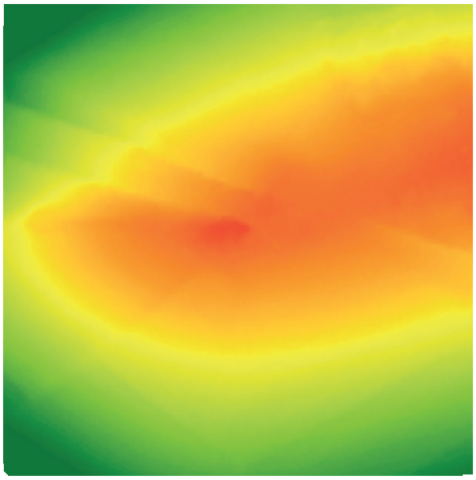
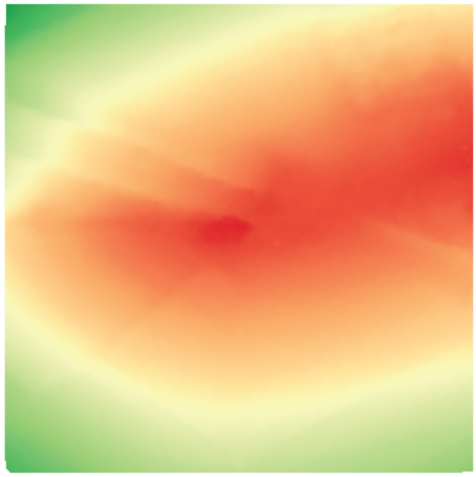
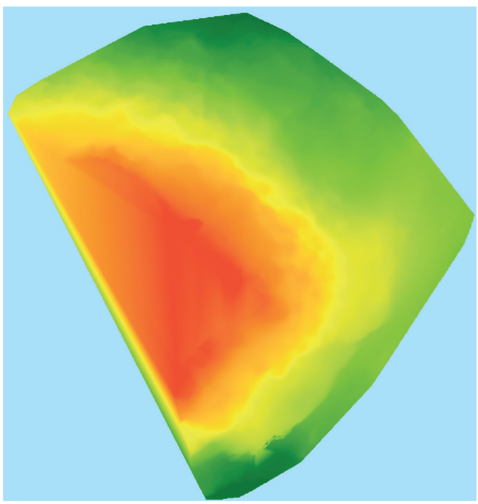
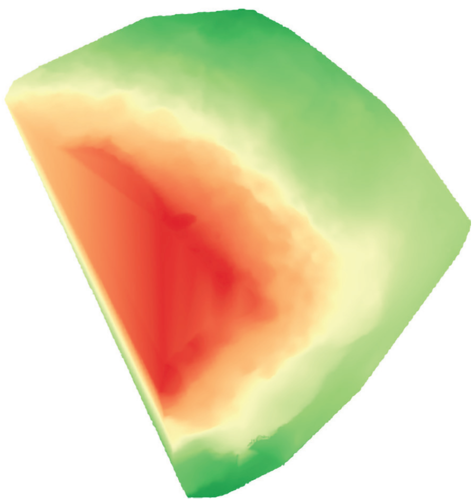
<table>
<tr><td>DTM ArcGIS Pro ISOK</td><td>DTM QGIS Desktop ISOK</td></tr>
<tr><td></td><td></td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>DTM ArcGIS Pro iPhone</td><td>DTM QGIS Desktop iPhone</td></tr>
<tr><td></td><td></td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Table 5. Digital Terrain Models for Ochodzita peak localization
Tabela 5. Numeryczne Modele Terenu dla lokalizacji szczytu Ochodzita

DTM ArcGIS Pro ISOK	DTM QGIS Desktop ISOK
	
894,70 880,23	894,70 880,23
DTM ArcGIS Pro iPhone	DTM QGIS Desktop iPhone
	
895,36 894,12	895,36 894,12

4.4. Raw GNSS Data Smartphone Measurement

After processing the measurement data we could use only the observations which were obtained at Gęsia Szyja and Dudasowski Wierch summits. This limitation may be due to the fact that these peaks had relatively good satellite visibility, whereas the other peaks, Eliaszówka and Magura Witowska, were heavily forested. The smartphones were receiving only code observations unlike the Leica GS16 receiver, which was receiving also phase observations. The RTK GNSS measurement was conducted without any obstacles in these locations.

Observations at Gęsia Szyja and Dudasowski Wierch, however, proved insufficiently long to achieve geodetic accuracy, despite an hour of measurement. Only brief observations from the hour-long session were recorded. The results from the mobile measurements were unsatisfactory and did not provide the high level of accuracy anticipated during the measurement process. The data needed to be transformed from ITRF to ETRF2000 coordinate system. Subsequently, the ellipsoidal heights calculated in the ETRF2000 system were converted to normal heights in the PL-KRON86-NH system using the quasigeoid model available on the website of the Head Office of Geodesy and Cartography [http://www.gugik.gov.pl/bip/prawo/modele-danych].

5. DISCUSSION AND CONCLUSIONS

Based on the field measurements and the analysis of point cloud data, several conclusions can be drawn regarding the accuracy of the LiDAR point cloud obtained from airborne laser scanning and the built-in sensor in the iPhone 13 Pro.

Comparing RTK GNSS elevation measurements to the heights obtained from both point clouds analyses reveals minimal discrepancies. The Leica GS16 receiver measurements are considered the most accurate source of data, representing up to single centimeter-level precision.

The accuracy of the LiDAR point cloud obtained from geoportal.gov.pl, part of the ISOK project, is approximately 15 cm. The point cloud from the iPhone 13 Pro is estimated to have an accuracy of around 5–10 cm, given its high point density and alignment with RTK GNSS measurements. This method also accounts for the impact of manual cleaning of the point cloud in CloudCompare. The point cloud from the iPhone 13 Pro lacked classification, and the removal of extraneous points not belonging to the "ground" layer depended on the data analyst.

The most closely matching results to RTK GNSS measurements were observed at the peaks of Kiełek, Baków, and Ochodzita. For Eliaszówka, similar results were also noted, with a maximum difference of 22 cm. The maximum difference for Baków was 24 cm, for Kiełek was 31 cm, and for Ochodzita was 44 cm. The point cloud LiDAR data obtained from the iPhone 13 Pro was closest to the RTK GNSS elevations.

The Digital Terrain Model created from the iPhone 13 Pro point cloud with a 5 cm × 5 cm grid cell size is significantly more accurate than the DTM created from the LiDAR point cloud with a 25 cm × 25 cm grid cell size. The grid cell size was chosen to match the accuracy of the source point cloud. The difference in values between the DTM from the ISOK point cloud in ArcGIS Pro and the DTM in QGIS Desktop ranges from 1 to 11 centimetres. This difference may result from the fact that the DTM in ArcGIS Pro was generated using a TIN (Triangulated Irregular Network) model, while the DTM in QGIS was based on a GRID raster model.

Research indicates that the iPhone 13 Pro, combined with an RTK GNSS receiver, can create an excellent setup for generating small-scale 3D models. Based on

Table 6. Data obtained from the smartphone raw GNSS data measurement with RTK measurement results
Tabela 6. Dane pozyskane z pomiaru mobilnego surowych danych GNSS wraz z wynikami pomiaru RTK

Peak	RINEX file	X [m] ETRF2000	Y [m] ETRF2000	Z [m] ETRF2000	Ellipsoidal height [m]	Height anomaly [m]	Normal height [m]	RTK height [m]
Gęsia Szyja	GEOP254E.23o	3918131,76	1432050,83	4810584,53	1531,925	42,447	1489,348	1490,00
Dudasowski Wierch	GEOP254O.23o	3906966,62	1437684,66	4817336,65	1081,832	41,343	1040,359	1037,60

both the test object and the studied objects, the optimal scanned area size is 10 m × 10 m, while the ISOK point clouds from ALS cover much larger areas with lower point density. When scanning with the iPhone 13 Pro, it is crucial that reference points are placed on a hard, level surface and marked with a contrasting marker of at least 10 cm × 10 cm.

The ideal measurement setup would involve using only a phone, which can also perform mobile GNSS raw data measurements. However, based on our research and results, we cannot recommend the phone as a precise source for coordinate measurements. Discrepancies of 39 cm on the peak of Gęsia Szyja and 2.56 m on Dudasowski Wierch were observed between mobile raw GNSS data measurements and RTK measurements. External and environmental conditions at the peaks hindered accurate measurement with such imperfect devices. The results significantly deviate from the other obtained measurements. Nonetheless, this measurement method represents a potential revolution, allowing to reduce equipment costs.

In summary, LiDAR point cloud accuracy is continually improving, and the technology is becoming increasingly widespread in everyday objects, including not only smartphones but also vacuum robots. The accuracy of the publicly available point cloud on geoportal.gov.pl is insufficient for creating high-precision (1–5 cm) products solely from its data. The point cloud from the iPhone 13 Pro demonstrates higher accuracy and can be an excellent source of data for elevation work, as well as an additional data source that enhances the efficiency and cost-effectiveness of various surveying tasks.

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APPENDIX

Table 7. Updated summary of measured peaks in the AGH project "Setka w Koronie"
Tabela 7. Zaktualizowane zestawienie pomierzonych szczytów w ramach projektu AGH "Setka w Koronie"

Summit	Mountain range	Mountain massif	H GPS	H LiDAR	GPS – LiDAR
Lubomir	Beskid Makowski	Beskidy	903,60	902,50	1,10
Czupel	Beskid Mały	Beskidy	930,70	931,10	–0,40
Lackowa	Beskid Niski	Beskidy	997,90	996,80	1,10
Eliaszówka	Pogórze Poprawskie	Beskidy	1023,90	1024,12	–0,22
Radziejowa	Beskid Sądecki	Beskidy	1262,10	1261,90	0,20
Ochodzita	Międzygórze Jabłonkowsko- -Koniakowskie	Beskidy	895,14	894,71	0,43
Skrzyczne	Beskid Śląski	Beskidy	1258,10	1256,80	1,30
Mogielica	Beskid Wyspowy	Beskidy	1171,90	1170,40	1,50
Kiełek	Pogórze Orawsko-Jordanowskie	Beskidy	959,87	960,18	–0,31
Babia Góra	Beskid Żywiecko-Orawski	Beskidy	1723,60	1723,60	0,00
Baków	Pasma Pewelsko-Krzeczowskie	Beskidy	765,54	765,78	–0,24
Turbacz	Gorce	Beskidy	1309,90	1309,80	0,10
Wysoka	Pieniny	Beskidy	1049,30	1049,30	0,00
Rysy	Tatry Wysokie	Beskidy	2499,00	2499,40	–0,40
Starorobociański Wierch	Tatry Zachodnie	Beskidy	2175,70	2175,80	–0,10
Tarnica	Bieszczady Zachodnie	Bieszczady	1346,10	1345,70	0,40
Jaworniki	Góry Sanocko-Turczańskie	Bieszczady	909,20	908,30	0,90
Skała Agaty	Góry Świętokrzyskie	Góry Świętokrzyskie	614,00	613,40	0,60
Łysica	Góry Świętokrzyskie	Góry Świętokrzyskie	613,60	613,10	0,50
Gęsia Szyja	Tatry Reglowe	Karpaty	1490,00	1489,14	0,86
Dudasowski Wierch	Magura Spiska	Karpaty	1037,60	1038,30	–0,70
Magura Witowska	Pogórza Przedtatrzańskie	Karpaty	1232,07	1231,56	0,51
Szeroka Góra	Góry Bardzkie	Sudety	766,30	766,00	0,30
Kłodzka Góra	Góry Bardzkie	Sudety	757,20	757,00	0,20
Postawna	GóryZłote	Sudety	1115,50	1115,90	–0,40
Brusek	Góry Bialskie	Sudety	1115,20	1115,50	–0,30
Rudawiec	Góry Bialskie	Sudety	1106,20	1106,90	–0,70

Jagodna Północna	Góry Bystrzyckie	Sudety	984,50	985,10	–0,60
Jagodna	Góry Bystrzyckie	Sudety	977,20	977,90	–0,70
Wysoka Kopa	Góry Izerskie	Sudety	1127,60	1127,30	0,30
Okole	Góry Kaczawskie	Sudety	725,30	722,90	2,40
Folwarczna	Góry Kaczawskie	Sudety	724,70	722,90	1,80
Skopiec	Góry Kaczawskie	Sudety	720,70	720,40	0,30
Baraniec	Góry Kaczawskie	Sudety	720,10	719,80	0,30
Waligóra	Góry Kamienne	Sudety	934,30	934,30	0,00
Biskupia Kopa	Góry Opawskie	Sudety	889,80	889,80	0,00
Orlica	Góry Orlickie	Sudety	1084,50	1084,30	0,20
Wielka Sowa	Góry Sowie	Sudety	1015,70	1015,60	0,10
Szczeliniec Wielki	Góry Stołowe	Sudety	921,70	921,60	0,10
Borowa	Góry Wałbrzyskie	Sudety	853,40	853,40	0,00
Chełmiec	Góry Wałbrzyskie	Sudety	850,00	850,00	0,00
Kowadło	Góry Złote	Sudety	988,00	989,70	–1,70
Śnieżka	Karkonosze	Sudety	1603,20	1603,20	0,00
Ślęża	Masyw Ślęży	Sudety	717,80	717,30	0,50
Śnieżnik	Masyw Śnieżnika	Sudety	1423,00	1427,20	–4,20
Ostra Mała	Rudawy Janowickie	Sudety	944,80	944,40	0,40
Skalnik	Rudawy Janowickie	Sudety	944,50	944,20	0,30