Research Article

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Metrica – an application for collecting and navigating geodetic control network points. Part I: Motivation, assumptions, and issues#

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Abstract: The result of surveys largely depends on the accuracy and measurement technique of the control network. This research work presents the application *Metrica*, dedicated for collection and navigation of geodetic control network points. The main goal of this study is to present the motivation, methodology, and issues with analysis of the database of vertical control points. Such analysis covers south part of Poland territory for the update of the existing set of points of the vertical control network on an ongoing basis. The application has been developed with the use of a test database of points. The status of the points was checked by means of a multi-stage analysis. The prepared database of points was verified taking into account the criteria defined by the authors. In order to optimise the scoring analysis process, two groups of criteria were distinguished: independent of each other and those whose analysis was justified only under the condition of prior verification of other criteria. Based on the analysis of the collected data, the main conclusion was the ongoing need to update the data on the matrix points. It was found that information on points is often incomplete and inaccurate, especially in terms of their horizontal position, which often prevents efficient localisation of points. One of the most significant findings was that only 55.6% of the points available in the database were identified in the field. It should be noted that despite the analysis of the state of the matrix carried out in 2019 on behalf of the GUGiK, there are still many points about which information is not fully up-to-date. It is now possible to extend the application with new attributes and validation rules and conduct updates for several types of geodetic networks. Due to the extensive character of the discussed subject, the study has been divided into two parts. The continuation of this study is the second research work, which presents the development of a mobile application for the update of the geodetic control network. It will present in detail the procedures and IT application development processes.

Keywords: android applications, benchmark, geodetic technologies, geodetic control network, java, vertical control points

Note: This is the first part of the two-set article about the Metrica application. The 2nd one can be found under the title: Metrica – an application for collecting and navigating to geodetic control network points. Part II: practical verification.

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1 Introduction

Currently, universal access to mobile devices and the internet affects the activities performed by every human being. Freely accessible applications for such things as entertainment, everyday life are joined with a source of information applications that can be used for analysis and research. Most applications enable users to collect several types of information that together form a content-rich database. This method should also be used in land surveying, since this is an extremely data-driven field of study, but it also might be applied in other fields, e.g. surface or soil monitoring, cadastre systems, or road traffics (Ilyushina et al. 2018, Sodango et al. 2021, Witkowski et al. 2021, Guzy and Witkowski 2021).

Surveyors, while performing tasks, spend a large part of their time on the appropriate processing of the captured data and verification of their correctness. This is pointed out in their papers (Krzyżek and Przewięźlikowska 2017, Przewięźlikowska 2020, Mrówczyńska et al. 2020). For this reason, any form of assistance that speeds up this process and provides the possibility of preliminary verification of relevant information is an immense help in their work.

Some of the control network points are difficult to access because the procedure of their establishment is based more on the quality of geodetic controls, reliability, geometrical strength, and cost rather than their topographic location which was shown by Bielecka et al. (2014). Their accuracy to a large extent determines the final result of the performed surveys, which was presented in the study by Medved et al. (2019). Therefore, the timeliness of information on the actual status of the control network in the field is a critical issue because, at the planning stage of their work, surveyors have the opportunity to select an undamaged point in the most convenient location.

There are many apps used in the daily work of a surveyor. However, to date, no application has been developed for the ongoing updating of the surveying matrix. It is practically common to access the database of matrix points at the level of national or local geoportals. However, it is necessary to update the data on an ongoing basis, as the state of the network changes over time. Maintaining such a database only by a specific group of people or organisation is inefficient, as can be seen in many outdated warp information.

A similar approach is described in the publication of Yerima et al. (2018), which presents a mobile application for Android that allows us to capture data and participate in surveys using similar devices. A slightly different approach was used by the authors of the ARGeo application (Gazcón et al. 2018), for field data capture. In this particular case, the application is aimed at geologists. It allows us to capture and analyse data using mobile devices. An unusual approach is to enable work even without an internet connection. The authors have rightly noticed that in some hard-to-reach places, an application that requires a permanent connection to the internet can significantly hinder work, especially when the point is located in an area with poor mobile network coverage.

In Poland, there are geographic information portals and applications that enable the presentation of control points on a map. The basic application for publicly available data presentation is geoportal, which is available in the following versions:

- mobile application for Android, iOS, and Windows (Główny Urząd Geodezji i Kartografii, GUGiK 2022a),
- internet application (GUGiK 2022b).

This applies to the first-order and second-order control networks in a manner generally available to any user. This application allows us to search for many important collections and services of spatial data essential for land surveying (GUGiK 2022a). It is important that the geoportal contains a layer with data regarding the basic vertical control network. Files in the .xls format are downloaded together with a folder containing topographic descriptions of points (Figure 1).

However, attention should be paid to the fact that the geoportal does not contain the control network most

numerLinii:	180	nazwaLinii:	MIECHÓW-KRAKÓW						
numerPoligonu1:	0	numerPoligonu2	--	NumPocz:	1631001	NumKoniec:	16330035	klasaOsn:	2
OdcinekCount:	58	Epoka1:	1999-11-0	Epoka2:	2005-04	mKm [m]:	,000304	mPierwszyPunkt [m]:	--
mPrzypKm [m]:	,000284	mSystKm [m]:	,000123	wyrPopr[m	-,0073				
Identyfikator systemu odni		PL-ETRF89-GRS80H							
Układ wysokości:		PL-KRON86-NH							
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Rodzaj wysokości:		normalna							
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L.p	NrPkt	NrGlow	TypZab	KlasaOsn	IdD	WażnyOd	dataOstatniejAk	TypStab	StanPkt	TypPkt	NazwaPkt	rodzajPkt	φ	λ	metFiLa
1.	16310013	AA 4283	brak	2	--	--	2019-08-06	Znak ścienny	dobry	Centr	MIECHÓW,UL.WARSZAWSKA,KOŚC.KAT.	Punkt sieci niwelacyjnej Punkt węzłowy	50°21'27.01"	20°01'37.35"	z przybliżonego pomiaru
2.	16310044	ZW	brak	2	--	--	2019-08-06	Znak ścienny	dobry	Centr	MIECHÓW,UL.J.PIŁSUDSKIEGO 23,BUD.	Punkt sieci niwelacyjnej	50°21'14.69"	20°01'41.83"	z przybliżonego pomiaru
3.	16310045	ZW	brak	2	--	--	2019-08-06	Znak ścienny	dobry	Centr	MIECHÓW,UL.JÓZEFA PIŁSUDSKIEGO 38	Punkt sieci niwelacyjnej	50°20'57.38"	20°01'50.95"	z przybliżonego pomiaru
4.	16310066	zniszczony	brak	2	--	--	2019-08-06	Znak ścienny	zniszczony	Centr	MIECHÓW,UL.J.PIŁSUDSKIEGO 11,BUD.	Punkt sieci niwelacyjnej	50°20'36.54"	20°02'01.19"	z mapy
5.	16310067	zniszczony	brak	2	--	--	2019-08-06	Znak ścienny	zniszczony	Centr	PORADÓW NR 44,BUD	Punkt sieci niwelacyjnej	50°20'10.97"	20°02'01.75"	z mapy
6.	16310068	zniszczony	brak	2	--	--	2019-10-16	Znak ścienny	zniszczony	Centr	JAKSICE NR 84,BUD.MSZK.	Punkt sieci niwelacyjnej	50°19'49.91"	20°01'59.69"	z mapy
7.	16310069	zniszczony	brak	2	--	--	2019-10-16	Znak ścienny	zniszczony	Centr	JAKSICE NR 89,BUD.MSZK.	Punkt sieci niwelacyjnej	50°19'25.91"	20°01'55.16"	z mapy
8.	16310047	AA 7594	brak	2	--	--	2019-10-23	Znak ścienny	dobry	Centr	WIELKI DÓŁ NR 27,BUD.MSZK.	Punkt sieci niwelacyjnej	50°19'00.23"	20°02'13.46"	z przybliżonego pomiaru
9.	16310070	zniszczony	brak	2	--	--	2019-10-16	Znak ścienny	zniszczony	Centr	SZCZEPANOWICE NR 67,BUD.MSZK.	Punkt sieci niwelacyjnej	50°18'01.52"	20°02'06.63"	z mapy
10.	16310049	AU 5054	brak	2	--	--	2019-10-16	Znak ścienny	dobry	Centr	SZCZEPANOWICE NR 65,BUD.MSZK.	Punkt sieci niwelacyjnej	50°17'42.11"	20°02'13.76"	z przybliżonego pomiaru
11.	16310050	AA 7825	brak	2	--	--	2019-10-16	Znak specjalny	dobry	Centr	ORŁÓW,KAM.NIW.PODZ.OBOK BUD.40	Punkt sieci niwelacyjnej	50°17'30.29"	20°02'41.90"	z przybliżonego pomiaru
12.	16310051	zniszczony	brak	2	--	--	2019-10-16	Znak ścienny	zniszczony	Centr	WĘŻERÓW 14,BUD.SZKOŁY	Punkt sieci niwelacyjnej	50°17'02.00"	20°03'23.22"	z mapy
13.	16310071	zniszczony	brak	2	--	--	2019-10-16	Znak ścienny	zniszczony	Centr	WĘŻERÓW NR 3,BUD.MSZK.	Punkt sieci niwelacyjnej	50°16'33.14"	20°03'54.65"	z mapy
14.	16310052	AA 7604	brak	2	--	--	2019-10-23	Znak ścienny	niepelnowartos	Centr	WĘŻERÓW NR 2,BUD.MSZK.	Punkt sieci niwelacyjnej	50°16'32.05"	20°03'53.32"	z przybliżonego pomiaru
15.	16310053	AU 4739	brak	2	--	--	2019-10-16	Znak ścienny	dobry	Centr	PRANDOCIN-IŁY NR 90,BUD.MSZK.	Punkt sieci niwelacyjnej	50°16'08.33"	20°04'20.74"	z przybliżonego pomiaru
16.	16310054	AA 7548	brak	2	--	--	2019-10-21	Znak ścienny	dobry	Centr	JANUSZOWICE NR 90,BUD.MSZK.	Punkt sieci niwelacyjnej	50°15'39.35"	20°04'45.65"	z przybliżonego pomiaru
17.	16310055	zniszczony	brak	2	--	--	2019-10-21	Znak ścienny	zniszczony	Centr	JANUSZOWICE NR 82,BUD.MSZK.	Punkt sieci niwelacyjnej	50°15'08.04"	20°05'14.23"	z mapy
18.	16310056	zniszczony	brak	2	--	--	2019-10-21	Znak ścienny	zniszczony	Centr	SŁOMNIKI,UL.KOSCIUSZKI	Punkt sieci niwelacyjnej	50°14'40.40"	20°04'59.66"	z mapy
19.	16310057	P.N.ZW.	brak	2	--	--	2019-10-16	Znak ścienny	dobry	Centr	SŁOMNIKI,UL.SŁOWACKIEGO,KOŚCIÓŁ	Punkt sieci niwelacyjnej	50°14'24.51"	20°04'45.99"	z przybliżonego pomiaru
20.	16310058	AA 7619	brak	2	--	--	2019-10-16	Znak ścienny	dobry	Centr	SŁOMNIKI,UL.SŁOWACKIEGO,BUD.	Punkt sieci niwelacyjnej	50°14'16.06"	20°04'52.56"	z przybliżonego pomiaru
21.	16310059	zniszczony	brak	2	--	--	2019-10-16	Znak ścienny	zniszczony	Centr	SŁOMNIKI,UL.KRAKOWSKA 62,BUD.MSZK.	Punkt sieci niwelacyjnej	50°14'01.15"	20°04'12.54"	z mapy

Figure 1: File with data on the vertical control network retrieved from Geoportal. Source: GUGiK 2022a.

frequently used by surveyors, namely, the third-order control network. Updating the information about this group of networks and making it accessible are especially important for surveyors. This specific control network is used for all assortments of works, as presented in the study by Krzyżek et al. (2017).

The aim of the work was to develop a mobile application to facilitate the updating of information on geodetic warp points. This will be possible thanks to the ongoing updating of point data, which will be done through public collection of information. The assumption of the application is a simple access to the possibility of updating data on a specific database of matrix points by professional users – surveyors. The access and the appropriate quality of the control network result in accuracy of all the surveys performed, including record-keeping (Hanus et al. 2020). Therefore, this research work proposes a methodology to develop an important and easy-to-use real-time information update application – Metrica (Figure 2).

The second group of information systems are “Surveyor’s portals” used exclusively by surveyors, only after authentication. The most commonly used control, namely, third-order control, can be obtained on various surveyor portals.

The first and second groups include information portals that are used to share centrally or locally collected data to appropriate groups of recipients. At the same time, they are periodically updated in terms of the control network based on procedures related to the modernisation of the control network. The last periodic review of level 1 and level 2 geodetic networks was conducted at the request of the Polish Main Geodetic Office (GUGiK) in 2019. Because of overlapping timing, the article presented in GUGiK (2019) did not yet include the data from the 2019 review.

The third group of applications includes those used to present data after appropriate import, such as Google Earth. In such a system, surveyors can only display what they receive from the ZgiK (Geodetic and Cartographic Documentation Resource). Google Earth is available in the following three versions:
– mobile application for Android or iOS,
– website,
– computer application for PC, Mac, and computers with the Linux system.

This programme also allows import of files with point, xyz, coordinates, which were used in this analysis to display points on the map and compare their actual location in the field with the graphic part of topographic descriptions (Google 2022). However, these applications are not intended to jointly update the data.

The key group should include mobile applications that enable displaying or searching for geodetic points and adding them. Examples of such applications are “*Asystent Geodety*” (BinSoft 2022), MERGDATA survey (Farmerline 2022), GIS Mobile Applications (IGISMAP 2022), Locus GIS – offline geodata collecting, and SHP edits (Locus 2014). For example, the “*Asystent Geodety*” application available in Poland is a mobile application for Android dedicated to users working in the fields of

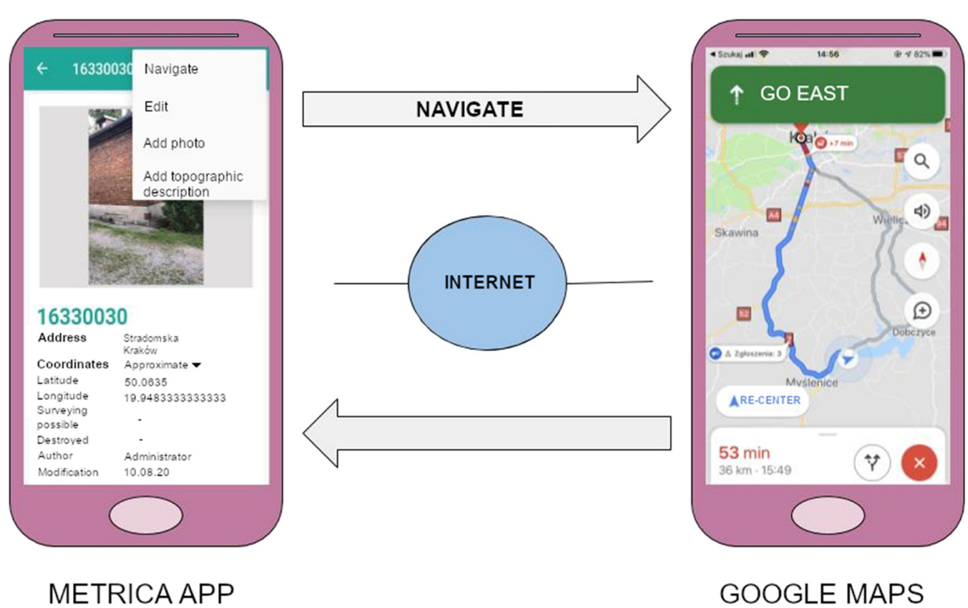

Figure 2: Data presentation in the proprietary METRICA application. Source: Authors’ original contribution.

land surveying, geology, cartography, forestry, and many others in which location plays a significant role. In the free version, it is available with limited options. To have full access to the services offered, it is necessary to purchase a premium package. This programme can be called a mobile position recorder because it quickly determines the location of the client thanks to the built-in GPS module. The accuracy with which calculations are made and the operation of the GPS module are directly dependent on the hardware used to operate the programme and type of the receiver (BinSoft 2022, Chwedczuk et al. 2022). The application collects data in the following coordinate systems: PUWG 2000, PUWG 1965, 1942, PUWG 1992, BL Kras., and BL WGS84. The built-in calculator allows the conversion of coordinates between the supported coordinate systems. Adding new points is possible by importing data from a common .txt file or by manually entering the coordinates. Using the GPS function, there is also an option to add a point at the current location. The programme has a length measurement function for any polygonal chain that passes through the selected points and a measurement of the area of any polygon (BinSoft 2022). Despite the wide scope of application, this application lacks functions that would allow the surveyor to update and collect information about points on an ongoing basis. It is not possible to create a database of points that would be publicly available. Only points with given coordinates are stored there. Database analysis has shown that it contains a lot of outdated information and there are no simple mechanisms on the geodetic market to quickly improve these data. Table 1 shows the planned capabilities of the application. These will be available to those who install the application on their device and work on a specific database.

The main goal of this study is to present the methodology of a detailed analysis of the database of vertical control points in the selected area, which is to be used to develop a mobile application intended for the ongoing update of the existing set of vertical control points, downloaded from the ZgiK. The developed application aims to keep up-to-date information about a given vertical control point and to locate these points faster and in a more precise manner in the field. A very important issue in application architecture is the transfer of data between the application, the server, and the database (Figure 3).

Users of the application are not fully aware of the whole process of communication between the aforementioned tools. However, it is worth noting that all operations performed are complex and many conditions are checked before the input information is positively verified. The example diagram shows the data flow when adding a photo. This gives some idea of how the application works.

A very important element of the application operation setup is the fact that only users with the appropriate permissions can complete the data in it. Therefore, it is crucial that data can be entered only by a client with the appropriate education, i.e. a surveyor. It is unacceptable for information about the matrix points to be edited by someone without the necessary knowledge. It should also be made clear that the geodetic control grid is practically not used for any tasks other than surveying. There are basically no industries that understand the principles of establishing, measuring, and using a geodetic matrix. Hence, this rules out the possibility of using crowdsourcing or Volunteered Geographic Information for updating warp data. In the event of any need to view the points, the application allows the use of the data as a Guest, but with decidedly limited privileges, as illustrated in Table 2.

The conducted research studies on the assessment of the condition and development forecast of the basic vertical, gravimetric, and magnetic control networks (Graszka et al. 2016) revealed that approximately 23% of benchmarks of the basic vertical control network covered by

Table 1: Comparison of the title application with existing tools

Tool	Geoportal	Google Earth	Asystent Geodety	Portal Geodety	Metrica
Downloading a topographic description	+	–	–	+	–
Navigating to a point	–	–	–	–	+
Logging in/registration	–	–	–	+	+
Measurements on the map	+	+	+	+	–
Adding a new point available to all users	–	–	–	–	+
Point database updated and available in real-time	–	–	–	–	+
Display date and author of last modification	–	–	–	–	+
Importing points from a file	–	+	+	–	–
Exporting points to a file	+	+	+	–	–
Coordinate conversion between systems	+	–	+	–	–

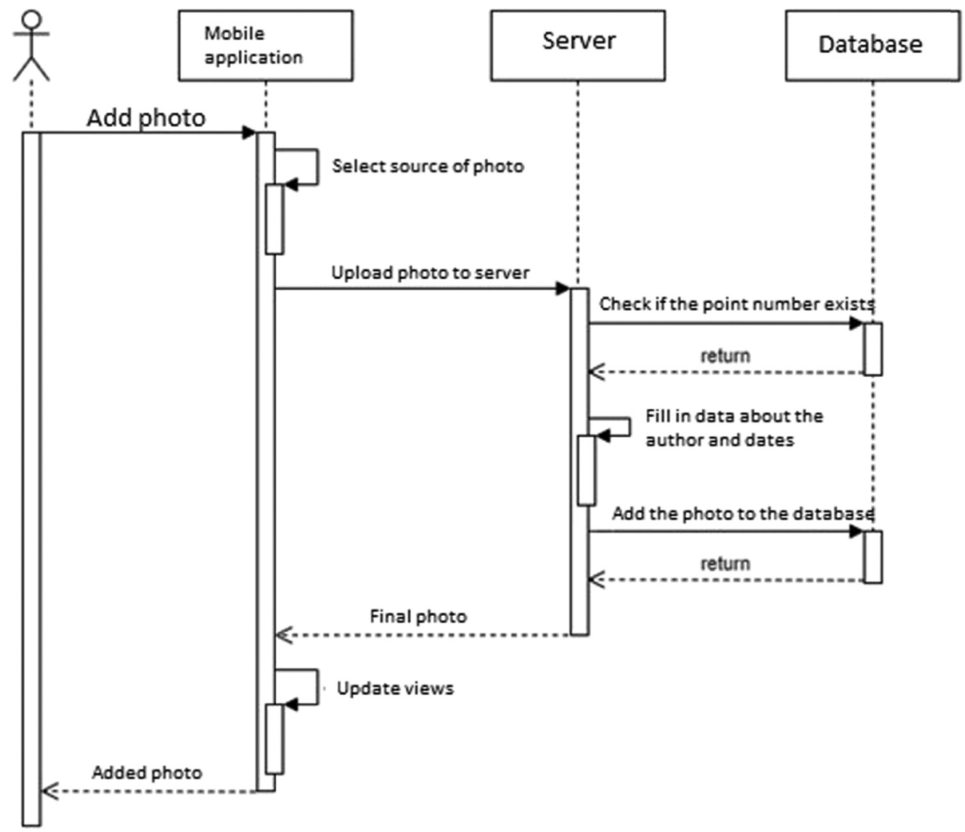

Figure 3: Schema of data flow.

Table 2: Functions available to the user as guest and customer

Function	User type	
	Guest	Customer
Showing a list of points	+	+
View point information	+	+
View photos	+	+
View topographic descriptions	+	+
Display points on the map	+	+
Navigating to a point	+	+
Editing point information	–	+
Adding a new point	–	+
Adding a photo	–	+
Adding a topographic description	–	+
Deleting photo	–	+
Deleting topographic description	–	–

the surveys were destroyed. The condition of the vertical control points may be influenced by external factors. These include environmental impacts that affect the subsidence of vertical control points. Considerations on this subject can be found in the research paper by Borowski et al. (2017), where the earth marks of the vertical control network were selected for the analysis, as well as in the paper on the implementation of the research programme written by Wiśniewski et al. (2014), which concerned the determination of the operational reliability of the vertical control network. An important contribution for the presented subject describing the status of the geodetic network is the publication.

2 Materials and methods

To design the application, a database that stores points for the selected area was retrieved from ZGiK to verify the status of these points in the field and to check the rationale for its development. Collecting the necessary information about the geodetic network had fundamental importance for determining the optimum procedures of information updates with the help of the proposed application. First, an analysis was conducted on how the location of points in different areas influences their actual maintenance status and accuracy. The first factor was the division of the analysed control network with regard to its location. For this purpose, the following point location zones were distinguished:

– CC – City Centre,
– CCO – City Centre Outskirts,
– T – Town,
– RA – Rural Area.

The execution of the work was divided into several stages. The first involved creating an up-to-date database of points by performing an analysis of the status and accuracy of their location in the field. Verification of the location consisted in comparing the coordinates displayed using Google Earth, obtained from the documentation centre, and the graphical part of the topographic descriptions with the actual state in the field. The preparation of the data for the database consisted in an analysis of point data and its verification during field interviews in several selected areas. The result of this part of the work is a point condition analysis. For the point condition analysis, 153 points were considered, of which 85 were found in the field. These were used to create the original database for the author's Metrica application.

2.1 Geodetic network

Pursuant to Article 2.4 of Kancelaria Sejmu (2021), the geodetic control network is understood as *systematic collections of clearly identifiable points that have been marked in the field with survey markers and whose location has been determined in the national spatial reference system in a manner appropriate for a given type of control network, enabling its accuracy to be determined.*

The geodetic network includes points of vertical control, the location of which has been determined in the national spatial reference system, and the height determined in relation to the adopted reference area using surveying techniques (MAiC 2012). Due to the important function of survey markers, they are protected by law. Persons who are owners or holders of real estate on which survey markers are located as well as triangulation structures or facilities protecting them are obliged to:

– avoid actions that could damage, destroy, or displace these markers,
– report information on their damage, destruction, or displacement endangering the life or property of other people to the competent district governor.

Failure to comply with the abovementioned obligations may result in the imposition of a fine (Kancelaria Sejmu 2021).

The numeration of geodetic networks is uniform throughout the country. The numbers of the control points are assigned at the stage when the technical design is prepared, therefore in accordance with the law in force at the time. The current rules for the numeration of geodetic, gravimetric, and magnetic control points have been regulated by the provisions of Chapter 9 (MAiC 2012). However, the numeration of the points of the basic vertical control network analysed in the selected area was prepared at the time of validity of the Technical Guideline G-2 – Vertical Control Network (GUGiK 1986). It should be noted that in the lists from the ZGiK database (Figure 4) concerning control points, two concepts appear simultaneously: point number and point identifier.

The rules for creating a point identifier are defined in detail in GUGiK (2001). The point identifier consists of a string of 13 digits. This system is closely related to the position of the point, determined by the B and L geodetic coordinates.

2.2 Vertical geodetic network database

Pursuant to §16 and 17 (MAiC 2012), information about the points of the national geodetic network (NGN) is collected in two sets:

– in the database of the national register of basic geodetic, gravimetric, and magnetic control networks – GUGiK,
– in the database of the third-order geodetic control networks – district geodetic and cartographic documentation centre.

The state register of NGN collects observations and the results of their elaboration for basic geodetic, gravimetric, and magnetic control networks throughout the country (GUGiK 2022c).

The current statistical data on the number of points in each type of the control network are presented in Figure 5. The chart illustrates the vertical control network analysed in this study.

2.3 Preparation of the database of points used to create the application

To prepare the mobile application for the current update of the network, it was necessary to define detailed procedures for dealing with the point database. First came the

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GEOS PL v.01  Bank danych CODGiK                                                STRONA1
                                        Centralny Ośrodek Dokumentacji Geodezyjnej i Kartograficznej

    Wykaz wysokości.
        Współrzędne B,L w układzie PL-ETRF89-GRS80
        Wysokość normalna   PL-KRON86-NH

   Ilość wybranych punktów: 799

   Id punktu          Nr      Klasa  Kod  Glowica    Stan   B             L              H
   Lokalizacja        1965           Stab.           punktu  ETRF-89       ETRF-89        86
________________________________________________________________________________________________

   Godło
mapy:1731_11_______________________________________________________________________________
26 5019.003523.102      17310102    II   860 AK 3748    D     50° 00' 31,6"    19° 52' 31,3"    250,1704
    SKOTNIKI,UL.SKOTNICKA,KOŚC.KAT.
27 4919.583491.102      17310104    II   880      PKP   D     49° 58' 39,4"    19° 49' 18,4"    215,1833
    SKAWINA,BUD.DWORCA KOLEJOWEGO PKP
28 4919.593510.102      17310105    II   860 AK 3973    D     49° 59' 37,2"    19° 51' 02,3"    215,2341
    KRAKÓW,UL.SKOTNICKA NR 245,BUD.MSZK.JERZEGO KARSKIEGO
29 4919.583513.102      17310109    II   910     B.C.   D     49° 58' 36,0"    19° 51' 34,0"    236,9032
    KORABNIKI,UL.GRANICZNA NR 1,BUD.MSZK.KRYSTYNY CZOPEK
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Figure 4: Fragment of data file retrieved from ZGiK. Source: ZGiK, 2019.

determination of the up-to-date point database, by analysing the status and its accuracy in the field. These procedures initially involved defining the methodology of making an inventory of the existing database and then the determination of the rules for updating the control network using the developed application. To confirm the assumption regarding the timeliness of the data on the control network and to state the validity of creating the application, the database of basic vertical control points was used as a research object, covering a part of the Małopolskie Province in the vicinity of the city of Krakow (Figure 6).

The database consisted of 799 points for which the following information was retrieved:
– B, L coordinates in the PL-ETRF89-GRS80 system,
– normal height PL-KRON86-NH,
– point location address,
– point ID,

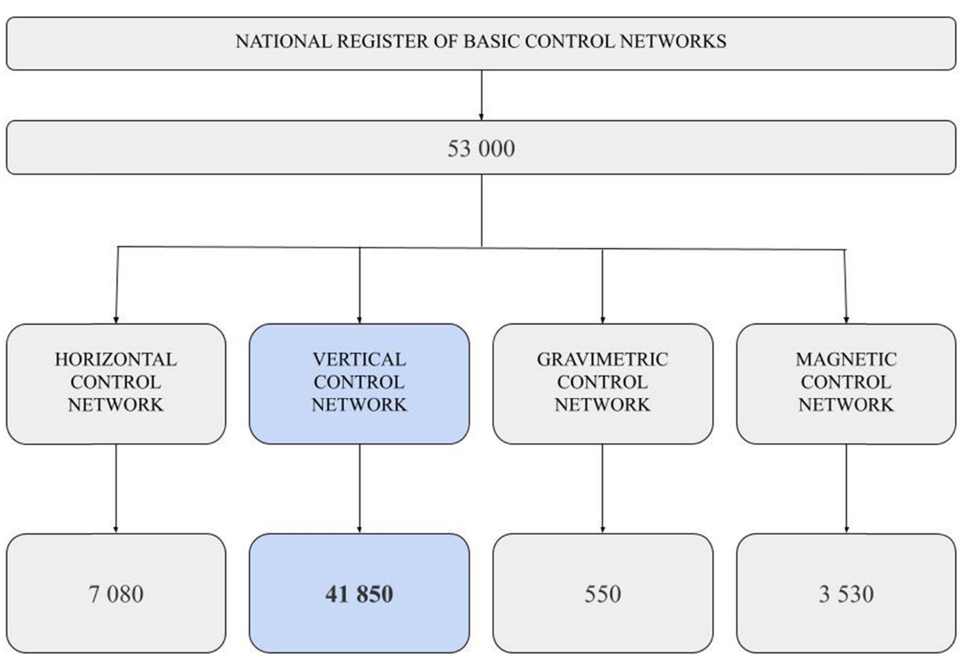

Figure 5: Number of points of geodetic network (GUGiK 2022c).

- point number in the "1965" system,
- control network order,
- monumentation code,
- information about the condition of the point.

A total of 153 points were selected for the analysis from the obtained database. Their choice was based on a selection aimed at distinguishing diverse types of locations (Figure 7):

- CC – City Centre,
- CCO – City Centre Outskirts,
- T – Town,
- RA – Rural Area.

A research hypothesis was formulated that the type of point location affects the quality of information about points and their timeliness. The decisive factors are the degree of urbanisation and the level of human interference with the surroundings (the environment). This assumption was intended to analyse to what extent these factors affect the control network to be maintained in an appropriate condition and timeliness. The designed types of locations were intended to indicate to what extent location factors determine:

- point database completeness (the number of points actually existing),
- accessibility of measurement points,
- timeliness of information about points,
- examination of the technical condition of the points.

2.4 Characteristics of location types

As the CC and CCO, the authors chose Krakow which is the capital of Małopolskie Province and the largest city in the province (Figure 7). The city's infrastructure is advanced, with dominant dense development.

The control points selected for the analysis, located in the strict city centre, are within the limits of the CC and CCO point location zones, which have been determined by circles with a given diameter:

- CC – 3 km (marked in red),
- CCO – 5 km (marked in yellow),

whose starting point is in the centre of the Main Square.

For the CC zone, 44 points were analysed, i.e. all occur in this area, the distribution of which is illustrated in Figure 7. All points were within a predetermined circle with a radius of 3 km.

The area encompassing CCO contained 53 points of the basic second-order control network, and all of them were analysed. The points were evenly distributed within the CC zone in a strip formed by circles with radii of 3–5 km (Figure 6).

Another point location zone created for the analysis is Towns (T, Figure 6). Two towns located south of Krakow were selected: Myślenice and Skawina. Myślenice is an urban–rural commune, which is the largest commune in terms of the area in Małopolska. The topography of the area is diversified, and most of it remains undeveloped. There is only dense development in the very centre of the town (Urząd Miasta i Gminy Myślenice 2016). Considering the area and population, Myślenice is one of the smaller towns in Poland. The database in Myślenice consists of 14 points of the basic second-order vertical control network, all of which were analysed. Most of the points are located near main roads and in heavily urbanised places.

The second of the selected towns is Skawina. It is located in Krakow County in the urban–rural commune

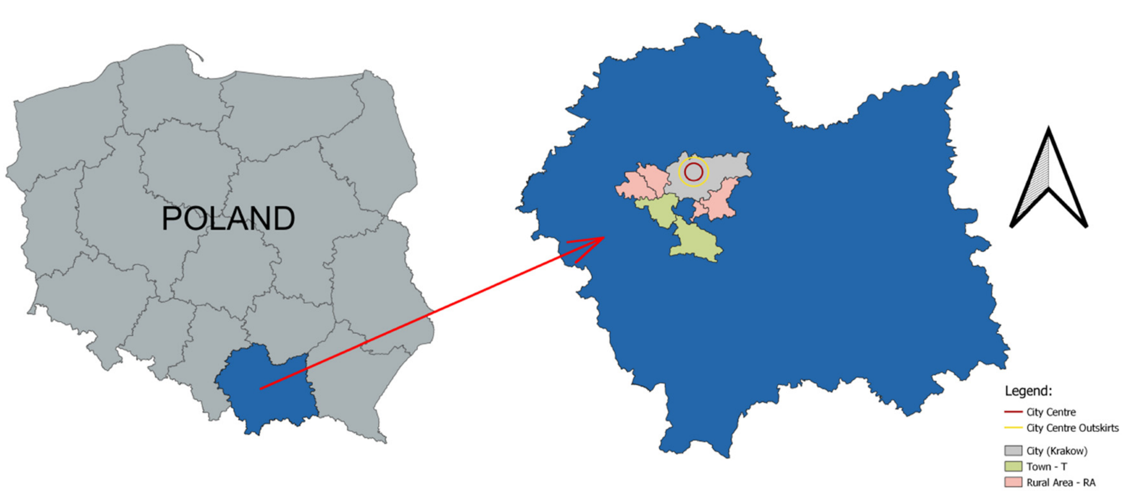

Figure 6: Selected locations in Małopolskie Province.

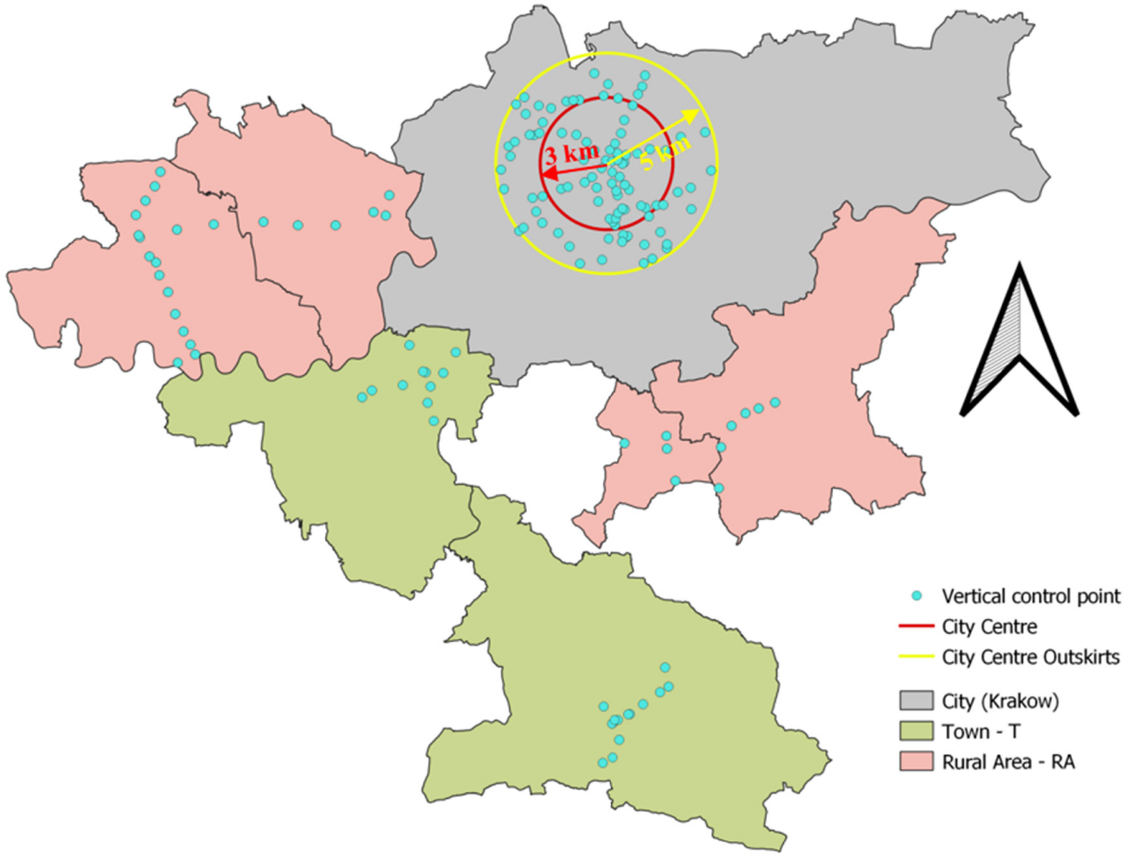

Figure 7: Presentation of selected control points in selected types of locations.

of Skawina (Gmina Skawina 2022). The direction of the town's development in recent years has created favourable conditions for the growth of new investments. The rapid expansion of the town is favoured by:
- its convenient location (Krakow is approximately 17 km away),
- a lot of unused land,
- developed industrial zones,
- extensive communication network,
- diverse labour market providing employment for many people.

In Skawina, nine out of ten existing points, which form the database of the basic second-order vertical control network, were selected for the analysis.

In addition to urban areas, four representative urban–rural communes located in RA were selected (Table 3):
- Czernichów,
- Liszki,
- Świątniki Górne,
- Wieliczka.

The selection was aimed at checking points in areas with lower investment development, where control points are less used. Out of 83 points from the database, 33 points of the basic second-order vertical control network located in RA in villages near a large city were selected for the analysis (Figure 7).

The points were selected with a view to various degrees of the influence of external factors such as the immediate vicinity of a busy road, location on private properties, etc. Figure 7 illustrates the control points selected for the analysis in all types of areas presented. Table 3 demonstrates the most important data characterising the individual communes selected for the analysis in terms of topography and geodesy.

2.5 Analysis of the condition of points in selected research areas

The condition of the points was checked in several stages based on a field inspection. The prepared database of

Table 3: General information on selected communes, source (Polska w liczbach 2021; Polska w liczbach 2022a; Polska w liczbach 2022b; Polska w liczbach 2022c)

	KRAKOW	MYŚLENICE	SKAWINA	COMMUNE OF CZERNICHÓW	COMMUNE OF LISZKI	COMMUNE OF ŚWIĄTNIKI GÓRNE	COMMUNE OF WIELICZKA
	City	Town				RA	
Area (km^2)	327	30	21	84	72	20	100
Population	774,389	18,415	24,325	14,712	17,447	10,195	60,481
Altitude above sea level (m)	188–300	315–648	218	220–365	212–246	230–400	222–362
Basic vertical control points (no.)	279	14	10	17	7	10	49
Point density (points/km^2)	0.85	0.47	0.47	0.20	0.10	0.50	0.49

points was verified considering various criteria defined by the authors. The adopted criteria of the analysis were related to the specificity of the available data on points. The sequence of the analysis of individual criteria was determined in detail.

1. Existence of the control point in the ZGiK database – B, L coordinates data, point address, and the points are also accessible in GUGiK (2022d).
2. Accessibility of the point for inspection – an inaccessible point is the one located on the property inaccessible to entry – no further verification.
3. Occurrence of the point in the field – the point physically exists in the field.
4. Existence of topographic description of the point.
5. Consistency of the point location with the graphic part of the topographic description.
6. Consistency of the B, L coordinates with the actual location of the point in the field – with the presentation in Google Earth – concerns the consistency of the point location as indicated based on the coordinates retrieved from ZGiK, displayed using Google Earth with the actual location in the field. A significant deviation in the location of a given point, which could result in selecting an incorrect point or considering the point as non-existent, was considered an irregularity.
7. Possibility of performing surveys on the point – when it is possible to place the staff correctly on the point.
8. The point has been built-up – consequently, the survey is impossible.
9. The point has been destroyed.

To optimise the point analysis process, criteria were distinguished that could be analysed independent of each other, e.g. 6 and 7, as well as those whose analysis was justified only subject to prior verification of other criteria, e.g. criterion 3 depending on 7. Therefore, the above numeration of the criteria was given by topological sorting of the graph according to the order of their verification presented in the diagram (Figure 8).

During the field inspection, various situations were encountered when the condition of the control points changed over time. One of the cases was when the point was built-up, which hindered the performance of surveys on that point. Such activities are the result of human ignorance about the way the control network is used. The direct analysis of the control network conducted in the field demonstrated to what extent the information on the points may be outdated. The comparison of the existing status with the information retrieved from ZGiK revealed that the main users of the network, i.e. surveyors, can be frequently misled. Due to the numerous

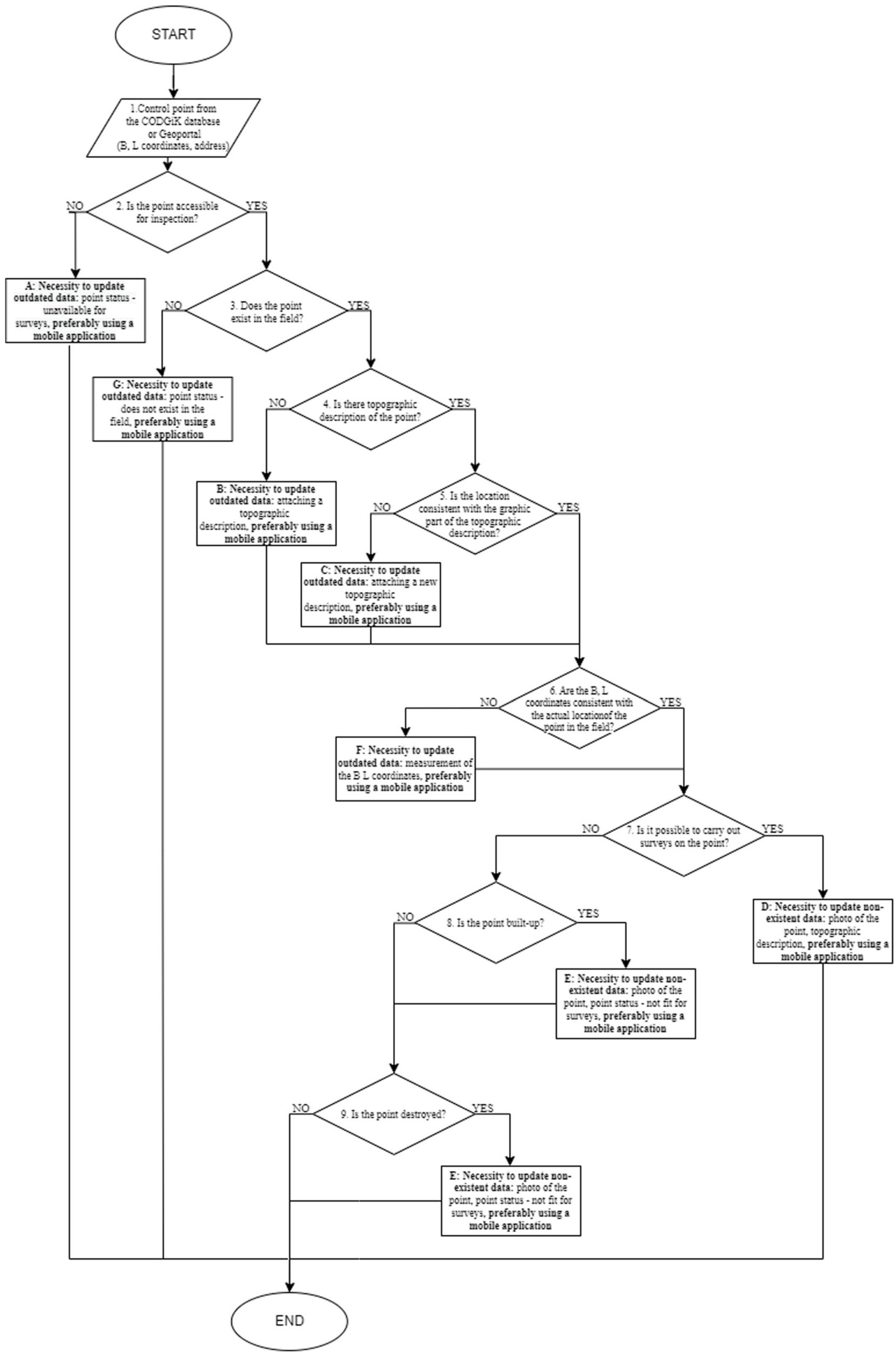

Figure 8: Diagram of control network analysis according to the adopted criteria. Source: Authors' original contribution.

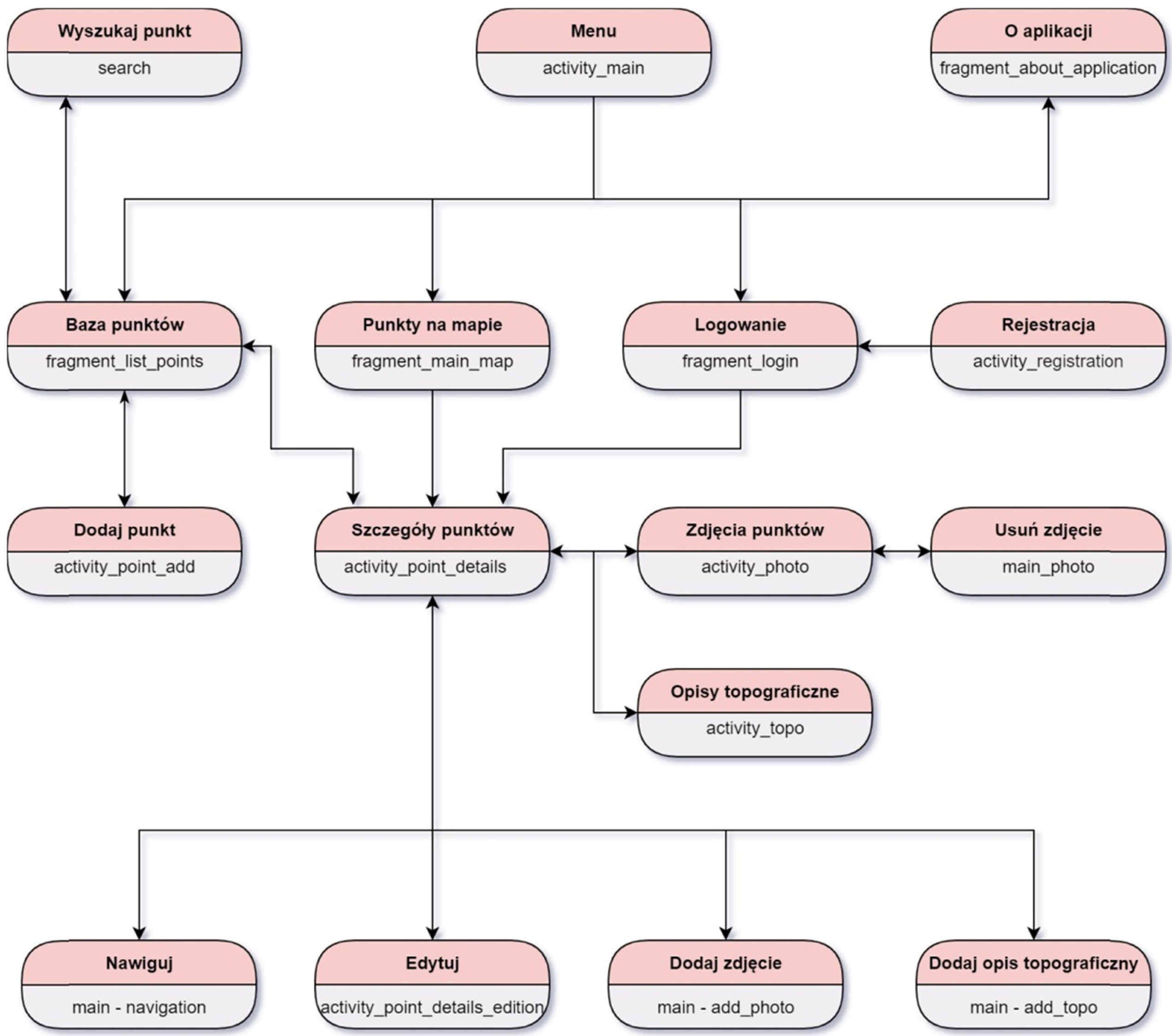

Figure 9: Schematic of the transitions between the different views in the application.

irregularities identified in the status of information about the control network, it was decided to create a tool that would make it possible to update the information about control points on an ongoing basis. It seems that the best solution for such work is a mobile application, which

- would allow for the correct determination of the point location in the field,
- would enable real-time updating of the point information.

The diagram presented in Figure 8 demonstrates the scope of the information on the control network that needs to be updated depending on the identified discrepancies in the existing information on the point. They can be divided into two main groups:

- update of outdated data – procedures A, B, C, F, G,
- update of non-existent data – procedures D, E.

In each of the groups of the necessary updates, the scope of the data that need to be completed is adapted to a specific case.

Figure 9 shows the transitions between the various views of the application.

There are many elements of this type, representing the stages of application construction. They will be presented in the following parts of the articles, as it is not possible to cover them all in one publication.

3 Conclusion

Maintaining up-to-date information about the points' heights is a challenging task due to the wide range of their distribution and lack of control over some changes occurring in the points due to their location, e.g. on private property. Therefore, the idea was to design a mobile application that would allow surveyors to easily access the information about the state of the matrix points.

In the first part of the work, it was necessary to prepare a test database, which was used to design the application. The article presents a methodology for direct verification of the database during a field inspection conducted by the authors of the study. Based on collected data analysis, the main conclusion was that it is necessary to update the matrix data. One of the most essential elements was the fact that only 55.6% of the points were identified in the field. It should be emphasised that the analyses were performed shortly before the outbreak of the pandemic. Since then, much of the matrix data in Poland have been released and can now be downloaded directly from the State Geoportal, which was not possible in 2019. To perform the analyses, data were obtained by indirect methods, from the Central Centre for Geodetic and Cartographic Documentation. The quality of the data meant that information on points was often incomplete and inaccurate, especially regarding their horizontal location, which often made it impossible to localise points. Hence, it was necessary to plan a methodology for analysing the data available at that time, which is discussed in the article. By releasing data via Geoportal, one can observe successive changes in the matrix information. At the same time, despite the performed analysis of the state of the matrix conducted in 2019 on behalf of GUGiK, there are still a lot of points that are not fully up to date. Therefore, a real-time update process is highly advisable, hence the need for a tool to update the matrix network on an ongoing basis.

The developed application has possibilities for further development depending on the type of matrix the recipient will have to work with. An important addition will be, from a localisation point of view, the search for a point by address and the selection of an address from a list. For users wishing to start working with the application in a new area, the option to impose a specific structure for adding point numbers and importing/exporting points from/to a file will be of interest. As the application will be used primarily on mobile devices, it is possible to download photos and topographic descriptions to such devices. Another important element to be developed is the possibility to convert coordinates between systems.

The result of the work is a mobile application Metrica, which can be successfully implemented for updating geodetic control network points. The application was developed using a test database of points, in accordance with the original concept of the authors. It is now possible to extend the application with new attributes and validation rules and to perform updates for different types of geodetic networks. Due to the extensive nature of the subject matter, the study has been divided into parts. This study is continued in a second research paper, which presents the development of a mobile application for updating the geodetic grid. In that, the IT procedures and processes of application development will be presented in detail.

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Conflict of interest: Authors state no conflict of interest.

Data availability statement: Data from the Polish vertical control network are currently available from the repository of the Polish Geoportal: http://www.gugik.gov.pl/pzgik/zamow-dane/osnowy-geodezyjne,-grawimetryczne-i-magnetyczne. Other datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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