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THE PROCESS OF MAP CALIBRATION AND ITS IMPACT ON THE QUALITY AND ACCURACY OF CARTOGRAPHIC MATERIALS

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Summary

The calibration process is a procedure that enables adjusting the scanned portion of the map to the current frame of reference, and equipping it with cartometric properties. As a result of the said process, the raster image becomes cartographic material that can be applied, among others, to the context of geodetic work. There are numerous methods of image transformation and ways of selecting the control points, according to which this process can be carried out.
In the paper, the authors present the literature review featuring various problems related to the map calibration process, as well as the methods of transformation, and the ways of selecting the control points. The work was carried out in reference to the example of scanned fragments of cadastral maps, which were then subjected to calibration processes using crosses of map graticule lines and based on situational details. The calibration process was carried out several times using a different number of adaptation points while changing their location and the manner of selection.

Keywords

raster • map calibration • control points • accuracy of analysis • cartographic material

1. Introduction

A map is a graphical model of reality presented in the appropriate scale on the horizontal plane by means of conventional signs. In view of the content, scale and function, many types of maps can be distinguished. Furthermore, in view of the method of data presentation, analogue maps (presented in a graphical version) and numerical maps (in a digital form) are distinguished. Maps are presented as sets of geometric objects: points and lines from which a vector map is created, or in the form of the so-called matrix of pixels forming the image [Medyńska-Gulij 2015].

Numerical maps are created as a result of geodetic works carried out in the field and then, by means of graphic programs, these results are transformed into lines, points and signs, which are the equivalents of real objects. Another way of acquiring cartographic materials is scanning an analogue map and using the obtained graphic image as the basis for creating its digital elaboration. The basic element of processing the scanned map is calibration, which is used to remove distortions, resulting from – among others – scanning errors or any deformations of the map, and to size real objects on the map in relation to the measuring area [Wolski 2012].

2. The process of raster map calibration

As the surveying and cartographic works are conducted, there are situations when the only available cartographic materials of a particular area exist in the analogue version, and what is more, they are kept in the archives. Frequently, such studies date back to the nineteenth century. For the purposes of geodetic works, they are used with a view to examining the scope of ownership rights (during litigation and court cases), as well as in proceedings related to property management, land consolidation and modernisation, or registration update. They can also constitute the basis for research studies consisting in the analysis of spatial changes of buildings and environmental components [Taszakowski 2012]. The vectorization of existing cartographic materials can be also useful in building more complex studies, for instance: to obtain elevation models for spatial planning, either the DEM (Digital Elevation Model) or the DTM (Digital Terrain Model) [Bożek at all 2016].

Archival materials are subjected to a scanning process. However, the raster itself (the scanned fragment of a map), which has not been processed at all, does not enable obtaining reliable information, as no coordinates are set in the adopted reference Coordinate System for Mapping. Such material does not have any geometrical features, which would be necessary for proper application. In addition, the image itself is very often affected by various types of errors, resulting from: faulty field measurement, incorrect mapping of situational details, wear and age of maps, or faulty scanning. The Regulation [Regulation of the Ministry of Interior and Administration of November 9, 2011] *on technical standards for surveying situational and altitude measurements, as well as preparing and transmitting the results of these measurements to the State surveying and cartographic resource* (hereinafter referred to as 'the Regulation') allows the use of this type of cartographic material, albeit subject to certain conditions. Map scanning must be performed by means of a scanner that provides an optical (true) resolution of 400 dpi, while the scan accuracy alone cannot exceed 0.00002 m. In addition, the obtained digital images should be corrected, consisting in the elimination of pixel spots and noise, and the so-called beakers of linear elements or background image splotching, in order to obtain correct readability of the image map content.

The image of a numerical raster map should be assigned points, determining its position in the assumed reference frame, by indicating points in reference to the known coordinates, and their equivalents on the raster. This procedure is referred to as 'georeferencing' [Affek 2012]. The raster must be properly aligned with the specified reference system (i.e. the coordinate system). Information about the location of the graphic file is either added on to the file, or it is determined directly during the calibration process

[Pyka 2015]. The entire process is carried out in two stages. The first step is to calculate the transformations based on the coordinates of the vectors, indicating the specific size and direction of the necessary shift, as well as performing the transformation using the adaptation points. The next step is to interpolate the distorted image to a raster of a specified regular size.

Calibration is the process of transforming the scanned image (a map substrate – usually called a raster) to a numeric form. It is of great use in the process of obtaining cartographic data. During this type of work, calibration methods should be chosen in accordance with the quality and type of data available. It is essential to correctly arrange the appropriate number of control points used during the transformation. Insufficient number of points or their poor arrangement may result in local deformations of the image. It is necessary to control the performance, and to determine the margin of fitting error [Wolski 2012].

There are a number of factors that influence the quality of the work process, as well as the accuracy of the map calibration process performed. The sources of errors tend to lie in the primary materials, which often have the features of inaccurate mapping burdened with inaccurately carried out field measurement. What is more, errors frequently result from inadvertent mistakes, and in some cases, even some neglect on the part of a cartographer. Poor selection of measuring points, faulty representation scale, improper type of map base, low precision of measuring instruments and many other factors undoubtedly affect the accuracy of the map, which is often reflected in the raster quality [Wolski 2012]. Another factor in the process is the need to adapt (transform) the map foundations from the original coordinate system to the given reference one.

The control points used to perform the calibration are reference elements whose spatial location in time has not changed. The most accurate points are the crosses of the geographical grid lines appearing on the maps for which the adopted reference system and the way of mapping are known. Maps, for which the mapping parameters are unknown, are calibrated using the characteristic points found on multiple other maps. To this end, specific objects are selected, i.e. churches, towers, junctions, bridges, etc. The more control points we apply, the more accurately the transformation process will be carried out [Podobnikar 2009]. Control network points are used as check points. However, we need to bear in mind that the control network may contain both measurement and calculation errors. Therefore, control points are likely to be used as the basis for determining transformation formulas. Their selection may consist in direct indication of points in the drawings, by reading the coordinate values from the file, or by using an automatic identification of points [Poniewiera 2005]. Between 15 and 20 control points is recommended for application on a map sheet. Among these points, apart from control points and calibration grids, it is best to use such elements as: terrain details (first accuracy group), intersection of borders, and contours of buildings [Pyka 2015]. There may also be intersections of square grid on the manuscript map, or boundary points that form part of numerical boundary descriptions. The accuracy of the location of the given control point must not exceed 0.10 m in relation to the nearest horizontal control network. In order to obtain some spatial information, the Regulation allows for the possibility of field or photogrammetric measurement of control points, if there is not enough information about their location in the Surveying and Cartographic Resources. The calibration process itself must be performed while respecting the accuracy of the transformation, of which the average error cannot be greater than:

- 0.20 m – for the map in the scale of 1 : 500
- 0.40 m – for the map in the scale of 1 : 1000
- 0.80 m – for the map in the scale of 1 : 2000
- 2.00 m – for the map in the scale of 1 : 5000

Clearly determined points on the maps can also be used as control elements of the performed calibration work.. They tend to constitute situational details of the first accuracy group, i.e.: building contours (corners), boundary points (breakdown of the boundaries of land plots), points of the utilities' network fittings (wells, manholes, grates) [Doskocz 2015].

As to small scale maps, provided that we possess thorough knowledge of the applied coordinate map of the control network points in the map content, as well as its corners, four control points are sufficient for correct calibration. These points should be placed in the corners of a map, following which the transformation, that is displacement, rotation and resizing, should be carried out [Panecki 2014]. The process of automatic image calibration, for cartographic purposes, is very frequently used in photogrammetric surveys provided that we process aerial photographs of the area. In this case, the calibration is based on points with known coordinate values determined using the GPS methods. Applying appropriate methods and algorithms of transformation during the calibration of map primers to the control points in the mosaic process has demonstrated a high level of accuracy of the performed surveys [Cramer and Stallmann 2001].

The accuracy of the process is influenced by the selection of the correct type of image transformation. The basic displacement – shift and rotation – called the isometric transformation, constitutes the simplest method of transformation. This method is used only in cases when the raster is a ready-made map foundation that does not require rescaling, removal of deformations, etc. The Helmert transformation makes it possible to additionally change the scale of the obtained raster. It is a conformal transformation that does not change the shape or deform the image. However, it eliminates, to some extent, the errors caused by the contraction of the map. The minimum number of control points is 2 (with such a number, we do not have redundant observations). Using affine transformation, apart from: displacement, rotation, scale changes, it is also possible to warp the applied raster. The transformation (with a minimum number of control points equal to 3) largely eliminates the effect of map contraction and accidental errors. However, it changes the length and angle values. Transformations using a greater number of control points are called polynomials. The aforementioned methods of transformation are special cases thereof. It is possible to select any degree of polynomial used for transformation by selecting the appropriate number of points.

However, the higher the degree of polynomials, the smaller the resulting deviations obtained at the points, which in turn shall lead to a greater risk of raster deformation. Incorrect identification of a point may cause local deformation of the environment and lowering the level of cartometricity of the underlay in this place. To prevent global deformation of the image, control points need to be located evenly over the entire map sheet [Kadaj 2002; Pyka 2015].

Maps have specific mapping parameters, and are based on the accepted reference system. Geographical grids (the introduced crosses of bars) have precise locations, and are most often described by the values of X, Y coordinates of the adopted reference frame [Affek 2012]. The situation is quite different when the scale of the given study is unknown, and the way of mapping used during cartographic work is also unknown. There are several examples of customising raster maps for a given study:

- The lack of any information on the scale, mapping used, no geographical grid (crosshairs). The map was charted without any use of geodetic surveys.
- The raster has a map graticule; however, there is no information about the reference system used; the map is burdened with deformations. The map is based on geodetic surveys.
- The coordinate system is known, there is a map graticule; the system transformation (change of position) generates the only error.

The first situation includes cases where the historical maps were made without previous detailed geodetic surveys. Distances and angles were estimated, and the only correct procedure performed in the mapping process was the correct representation of objects relative to each other [Affek 2012]. (This works in a similar way to the subsequent field sketches, which are only used to determine and indicate the approximate location of the measured object.) Maps that were not created on the basis of measurements served solely the illustrative and indicative purposes. The image of the map in this case cannot be used to carry out accurate measurements or surveying work. Such studies are not used in the calibration process because they cannot serve as a reliable source of information about the site.

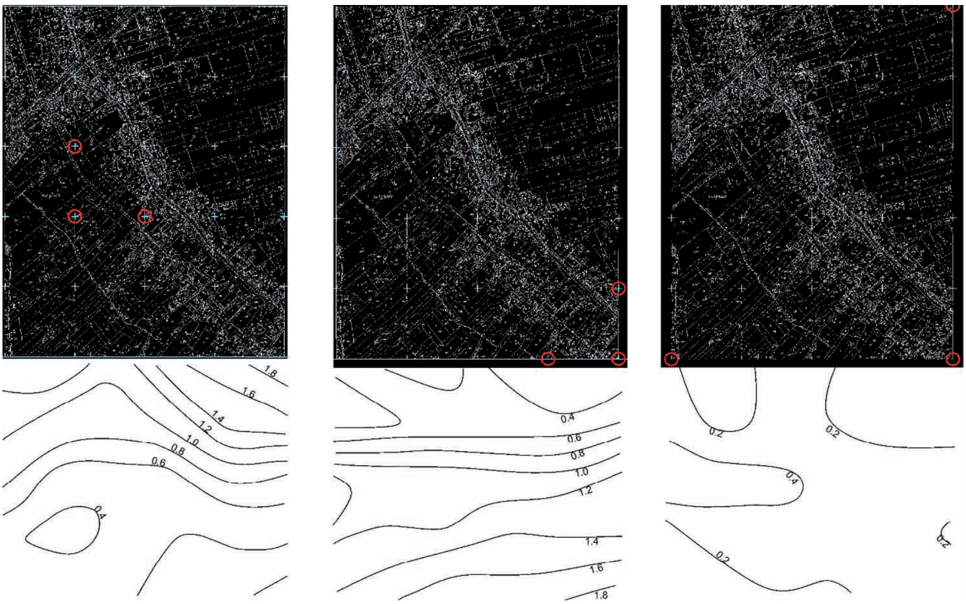
3. Method and methodology of the study

3.1. Map calibration on the crosshairs grid, given their actual location

The study uses a scanned portion of the map, which applied regular crosshairs, used later in the calibration process as control points. The calibration was conducted using the MicroStation V8i programme by means of software options for 3 or more control points (using affine transformation). The following possibilities of placing control points have been used:

1. Control points are located in one place in the central part of the raster.
2. Control points are located in one place in one of the raster corners.
3. Control points are scattered all over the raster corners.

In order to control and test the suitability of the number of control points for the accuracy of the cartographic materials obtained, in the first case only 3 control points were used (that is, the minimum amount) (Figure 1), while in the second case, 4 control points were employed (Figure 2). By means of software tools, a theoretical crosshairs grid was drawn on a scale of 1 : 2000 (scale of the scanned map), which served as control points, while the remaining ones performed the monitoring function. By analysing the distance measures between the theoretical location of the crosshairs grid and the crosses on the raster, the accuracy and fit of the map image was determined. The average map transformation error was determined for each of the possibilities of locating the control points described above. The distribution of points and the map of the distribution of accuracy errors resulting from the location of control points are presented in Figure 1.



Source: author's study

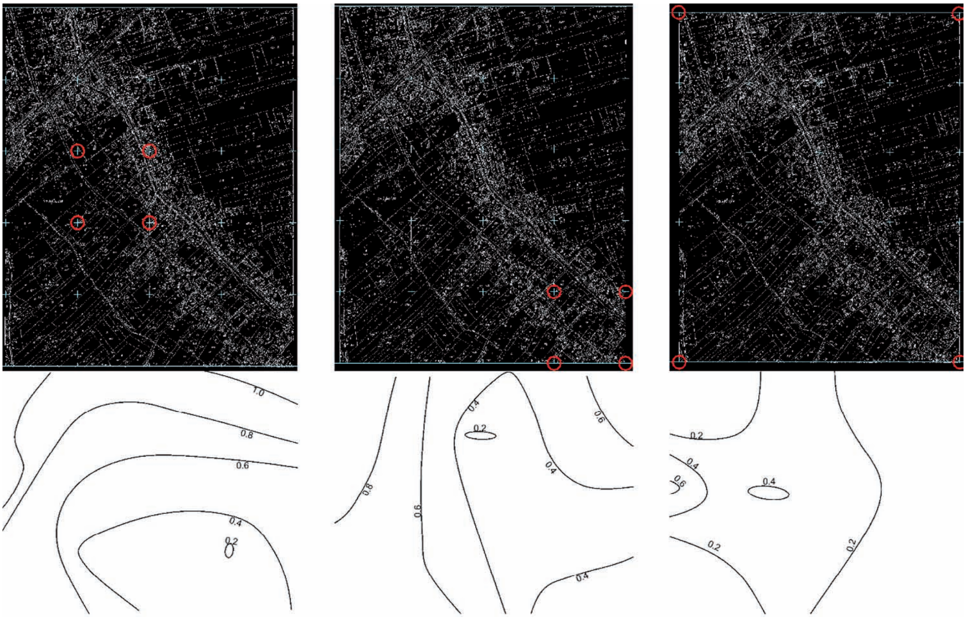
Fig. 1. The location of control points and the accuracy map defining the distribution of errors depending on the placement of points – for 3 control points

Using three control points depending on their placement (Figure 1) the following results were obtained:

- Points arranged in the central part of the raster – the average error of the position of the point on the raster is 0.76 [m]. The distribution of errors in the position of the points increases proportionally with the distance from the points of application.
- Points located in one of the raster corners – point placement resulted in a very low quality of the calibrated map. The error was determined at the average level of 0.95 [m].

- Points arranged in the raster corners – the corner arrangement of the control points results in an increase of the error in the middle part of the raster. Among the three control points, this is the most accurate method of map calibration, with an average error of 0.23 [m].

In subsequent studies, a greater number of control points were used, equal to 4. Their location is identical to that used in the previous example.



Source: author's study

Fig. 2. The location of control points and the accuracy map specifying the distribution of errors depending on the placement of points – for 4 control points

When applying 4 control points, depending on their placement, the following results were obtained:

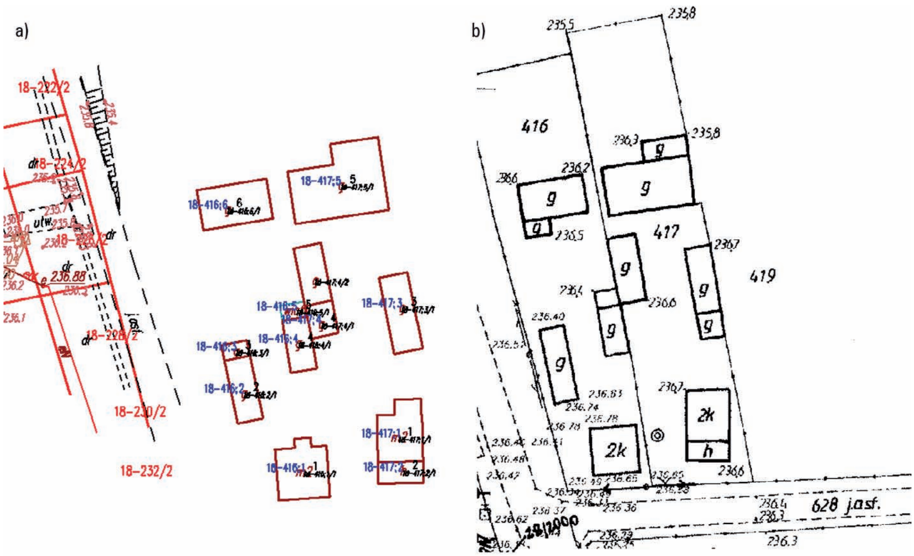
- Points distributed in the central part of the grid – selection of more than 3 control points results in an improved quality of the calibrated map. The average error was determined at the level of 0.60 [m], while the fitting error increases proportionally to the increase in the distance from the cluster of control points.
- Points located in one of the raster corners – the contour distribution of the position error values increases proportionally as you move away from the corner with the adjusted control points. Average accuracy was determined at 0.41 [m].
- Points arranged in the raster corners – the most accurate method of map calibration. Corner and even distribution of points resulted in the correct course of the

map calibration process. The accuracy of the location at an average level of 0.17 [m] results in a uniform distribution of errors throughout the study area.

Comparing the above-mentioned results of the conducted studies, several correlations can be observed. Transformations performed by means of control points mostly meet the requirement (defined by the Regulation, which specifies that the accuracy level of calibrated maps with a scale of 1 : 2000 needs to remain at 0.80 [m]), and only the location of clustered points in the map corner does not meet the accuracy requirements. A good result was achieved when placing the points in various parts of the map. With the use of 4 control points, all transformation processes ensure a sufficient level of the accuracy of map calibration. Among the presented examples, it is necessary to distinguish a high fit with the distribution of control points throughout the raster area.

3.2. Calibrating the map based on situational details

The study uses a scanned fragment of the cadastral map (Figure 3b). In order to calibrate it, a base map obtained from PODGiK (Powiatowy Ośrodek Dokumentacji Geodezyjnej i Kartograficznej – District Centre for Geodetic and Cartographic Documentation) was used (Figure 3a). The map lacks comprehensive information concerning all the thematic layers; therefore, in order to enrich the information contained therein, other supplementary cartographic materials are also required. The analysed fragment covers the area of around 1 hectare.

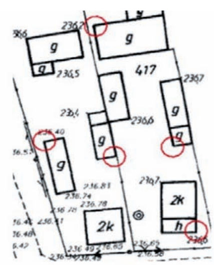
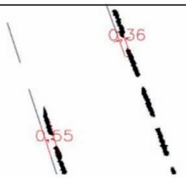
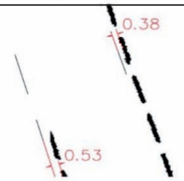
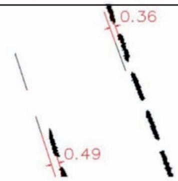
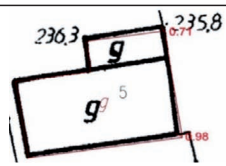
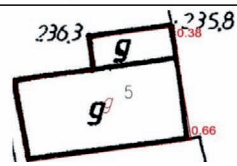
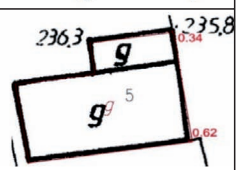


Source: authors' study based on the materials obtained from the PODGiK

Fig. 3. The list of map fragments: a) master map in a numerical version, b) scanned cadastral map

The map contains only the information obtained during field surveys aimed at inventory taking. The corners of buildings were used in order to calibrate the raster fragment. The control elements of the transformation performed were the remaining situational objects, constituting the content of the base map.

Three full transformation operations were performed, using a variable number of control points: 3, 4 and 5, respectively (Figure 4). These were the corners of buildings visible on both maps. Based on the results of the work from the previous sub-point, the control points in this case were evenly spread over the entire study area to effectively increase the calibration results. For the calibration process, the affine transformation method implemented by the MicroStation V8i programme was used. It should be noted that buildings are fixed elements over time; however, there may be some changes in their geometry, resulting from extending or demolishing a part of the structure. The points were located on clearly identifiable objects that had the same geometry on the principal map as on the raster. Such selection has been chosen in order to avoid incorrect location of the control point.

	Case I 3 control points	Case II 4 control points	Case III 5 control points
The location of control points			
The distance between the lines of the road			
The distance between the corners of the building			

Source: author's study

Fig. 4. Selection of the number of control points and control of map calibration in relation to the record map – reference layer

When analysing the summary of situations presented in the table above (Figure 4), we note that there is an increase in the accuracy of the raster calibration based on the increase in the number of indicated situational elements. In respect to the analysed fragment of the map (scale 1 : 2000), the Regulation allows using such material as the basis for further geodetic and cartographic work, unless the accuracy of the individual elements exceeds 0.80 [m]. As control elements, the lines marking the edge of the roadway and the corners of buildings that had not been used in the calibration process were adopted. It should be noted that the points, lines and markings constituting the content of the map have a certain thickness, and this may hinder the unambiguous indication of the location of the control points. Among the analysed cases, only case I (3 control points) contained elements exceeding this limit value. The selection of at least 4 points located on the entire map area produces the desired accuracy. Each additional control point increases the precision level of the work carried out.

4. Conclusions

The map calibration process can be developed using various methods of transformation and control of the raster image. If carried out properly, it provides raster content with reliable spatial information, which can then become cartographic material suitable for the use in various types of geodetic works. The most important role in the process is exercised by the appropriate quantitative and qualitative selection of control points. The placement of these points and their unambiguous traceability also affects the accuracy of fitting a map fragment into a properly adopted reference system. In addition, it should be emphasised that the applicable law imposes accuracy requirements in terms of the use of calibrated material as a reliable source of information about land and facilities.

By means of the conducted literature review and the performed test studies, we can determine that there is a direct correlation resulting from the selection of the quantity and location of the control points and the level of error of fitting the raster within a given reference system. As to small areas (up to 1 hectare), the choice of at least 4 points facilitates a correct performance of the calibration process. Each additional indicated object increases the accuracy of fit. The same could apply to the placement of the points throughout the entire area under investigation. The stratified distribution of errors in such a selection of common elements produces a more even distribution of errors throughout the structure of the object, increasing the accuracy of the map elaboration.

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