Calibration of raster image using GIS class software - accuracy analysis

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Abstract. Most of the information related to our environment directly relates to a specific location on the surface of the Earth – spatial data. From the beginning of his existence, the man collected them and made their analysis. Over time, their number increased so that geographic information systems (GIS) were necessary for their storage and processing. The basic GIS functions include collecting, verifying, managing, processing, analyzing and visualizing data. It is the data, next to people, equipment, software and procedures that are the basic element of such systems. Despite the huge technological progress, the basic source of information for this type of systems are still scanned analogue maps. Very often they are the only available material necessary to assess the spatial changes of the environment. However, in order for the information constituting the content of the map to be able to supply the databases of geographical information systems, it is necessary to give them spatial orientation. This can be during the calibration process. The quality of the data and the level of analyzes are largely dependent on the method and error of fitting the spatial map. Significant geo-referencing possibilities are provided by the GIS class software, among others QGIS software.

1. Introduction
Acquisition of data feeding geographic information systems is most often carried out through direct measurements, methods and techniques of photogrammetry and remote sensing, GNSS technology, transfer from other systems or through the use of existing cartographic documentation. Despite the diversity of sources of spatial information, it is often necessary to collect archival cartographic materials to a digital form to collect the necessary information about the real world. In most cases, this process involves three main steps: scanning, calibration and vectorization. As part of the article, the authors focused their attention on the second stage, i.e. calibration, in particular on the accuracy of this stage depending on the transformation method used. There are many definitions of this process in the literature, including georeferencing, spatial fit or registration in a coordinate system [3, 5, 13, 14, 17]. Exact definition of calibration can be found in the Regulation of the Minister of the Interior and Administration on technical standards for surveying situational and altitude measurements as well as the development and transmission of the results of these measurements to the state geodetic and cartographic resources [16]. Pursuant to this regulation, the term "calibration" should be understood as adjustment by means of the mathematical transformation of a digital image of a raster analogue map to a flat rectangular coordinate system [16]. Reading further; calibration of analogue map raster is performed using at least 20 adaptation points located on the map sheet covered with calibration, evenly distributed at the external border and inside the transformed area. The main task of the
calibration is to remove distortions of the paper map and distortions and raster errors caused by scanning.

Unfortunately, it is not possible to carry out these activities faultlessly. The accuracy of this process (expressed in the value of the root mean square error - RMSE) depends on many factors, including: the quality of the raster image (the quality of the analogue map and the accuracy of the scan), the number of adaptation points and their distribution, the type of transformation method used [1, 8, 9]. The GIS class software (QGIS) was used to carry out the calibration.

Geographic Information Systems (GIS) belong to information systems, distinguished primarily by information about the location of objects (so-called spatial information) and topological relations between them.

These systems do not have one specific definition. According to K. Clarke, GIS is an automated system for collecting, storing, searching, analyzing and displaying spatial data [2]. According to the definition given at the 5th Scientific and Technical Conference PTIP GIS is an IT system supporting the collection, analysis and sharing of data about objects uniquely located spatially.

As it results from the above definitions, these are complex space information management systems, which include several basic elements: hardware, software, people, methods and data (figure 1).

A characteristic feature of GIS is the layered structure of spatial data organization (thematic layers - raster and vector) (figure 2).
The great advantage of geographic information systems is the ability to perform various types of spatial analysis, which gives them a universal character and a wide range of applications, as well as the ability to integrate data from various sources but concerning the same object or phenomenon [10].

Acquiring data is most often carried out by direct measurements, methods and techniques of photogrammetry and remote sensing, GNSS technology, transfer from other systems or by using existing documentation in tabular form or in the form of maps [6].

Among the modern technologies of obtaining information on the geographical environment, various maps still play a very large role. Their value definitely grows in a situation where it is possible to give them spatial orientation, thanks to which it is possible to fully analyze changes taking place in the environment (e.g. related to mining enterprises) in a strictly defined time. The GIS class software such as the QGIS program gives invaluable opportunities in this area.

The article presents the results of raster image calibration using the linear method, Helmert’s, I, II, and III polynomial, gluing function and the mapping method. The root mean square error of the calibration was determined for each method.

2. GIS class software - QGIS

Among the modern IT tools used in many areas of our lives, it is listed the GIS class software. Such a program can be defined as any program that allows entering, collecting, analyzing and visualizing data, spatially referenced to the Earth [20]. Undoubtedly, this group includes the QGIS (Quantum GIS).

This is an open, free and multi-platform GIS software (works on GNU / Linux, Unix, Mac OSX and MS Windows platforms) and is an official project of the Open Source Geospatial Foundation (OSGeo)

It was created relatively recently (in 2002) and since then it has been dynamically developing [3, 11, 18]. This program supports both, data in vector and raster. It is used by both, administrative and scientific units, as well as enterprises and private individuals.
The basic functions of the QGIS program include collecting, processing, analyzing and sharing data. It allows to easily manage data and create different types of maps.

The program's functionality extends the so-called plugins, i.e. external modules that can be installed to QGIS from a repository (official or other, including your own), e.g. Georeferencer, OpenLayers, GRASS. This program provides the possibility of integration with other OSGeo projects, including with PostGIS, MapServer, GDAL / OGR.

3. Transformation methods in the QGIS

The term „transformation” refers to the conversion of coordinates of points from one layout on the second. In the case of maps, it is a process of giving a scanned map spatial reference, which is accompanied by removing geometric distortions of the raster. In literature, there are shown many types of transformation [5, 7, 12, 13, 14]. The QGIS also offers several of them. Among them, the following types of transformation can be distinguished: linear, Helmert’s, polynomial I, II and III degrees, spline function and projection.

Linear transformation provides a translation by a given vector and rotation by a given angle of torsion.

The Helmert’s transformation (by similarity) is a 4-parameter flat, linear, conformal transformation that realizes rotation, shift and scale change (uniform in all directions). It requires at least two adaptation points. This is one of the most commonly used transformation methods in geodetic tasks. It is used, among others, for converting rectangular coordinates in small areas and for calibrating raster images of maps [3, 5, 14]. Transformational formulas, according to which the map points are transferred to the new X, Y system, are in the form [13, 14]:

\[
X = t_X + X_p \cdot k \cdot \cos \phi - Y_p \cdot k \cdot \sin \phi \\
Y = t_Y + X_p \cdot k \cdot \sin \phi - Y_p \cdot k \cdot \cos \phi
\]

(1)

where:
\( t_x, t_y \) - offset in the direction of the X and Y axes, respectively,
\( X_p, Y_p \) - coordinates in the original system,
\( k \) - scale change factor,
\( \phi \) - rotation angle.

Polynomial transformations are an example of non-linear transformations. With the increase of the polynomial degree, one can observe a greater flexibility of map adaptation as a result of its transformation [13]. This type of transformation is mainly used for larger areas, with a large number of adjustment points [14]. The most common is the conformal polynomial transformation of the chosen so-called polynomial.
In the case of second degree polynomial, the transformation formulas have the form (3):

\[
X = t_x + a_1 X_p + a_2 Y_p + a_3 X_p Y_p + a_4 X_p^2 + a_5 Y_p^2 \\
Y = t_y + b_1 X_p + b_2 Y_p + b_3 X_p Y_p + b_4 X_p^2 + b_5 Y_p^2
\]

where:
- \( t_x, t_y \) - offset respectively in the X and Y axis direction,
- \( X_p, Y_p \) - coordinates in the original system,
- \( a_n, b_n \) - unknown parameters.

The minimum number of adjustment points in this case is 6.

For transformation of the III-degree dynamate, the transformation formulas have the form (4):

\[
X = t_x + a_1 X_p + a_2 Y_p + a_3 X_p Y_p + a_4 X_p^2 + a_5 Y_p^2 + a_6 X_p^2 Y_p + a_7 X_p Y_p^2 + a_8 X_p^3 + a_9 Y_p^3 \\
Y = t_y + b_1 X_p + b_2 Y_p + b_3 X_p Y_p + b_4 X_p^2 + b_5 Y_p^2 + b_6 X_p^2 Y_p + b_7 X_p Y_p^2 + b_8 X_p^3 + b_9 Y_p^3
\]

where:
- \( t_x, t_y \) - offset respectively in the X and Y axis direction,
- \( X_p, Y_p \) - coordinates in the original layout,
- \( a_n, b_n \) - unknown parameters.

The minimum number of adaptation points in case of transformation with the 3rd order polynomial is 10 [13].

The spline function ensures transformation by matching to control points with simultaneous deformation of the local map (transforms the source control points exactly into the target checkpoints). The implementation of a spline function requires at least 10 adaptation points [4].

Projective transformation defines projection dependencies between the points of the primary and secondary systems. The minimum number of adaptation points is 4 [4].

4. Source material and the analysis of results

As the source material, a 1:5000 map was used, drawn up in 1989, covering the town of Mikołów. It is a mining map of the surface (situational-altitude) and, like most of such maps, it was made in the local coordinate system "Sucha Góra", in the projection of Soldner. This system is characterized by the following:

- the surface of the sphere is tangent to the surface of the ellipsoid at the starting point,
- the radius of the sphere is equal to the radius of curvature on the ellipsoid at the starting point,
- sphere and ellipsoid have a common parallel for the starting point,
- the X axis coincides with the image of the meridian passing through the Sucha Góra point and is directed to the south,
- the Y axis as the image of the geodetic line passing through the Sucha Góra point is directed to the west [7, 15].

The calibration process of the subject map was carried out using QGIS. In this program, georeferencing is possible based on the coordinates of characteristic points or by indicating such points on a previously calibrated map, or on a layer shared in free services such as Google maps, OpenStreetMap, etc.

Due to the fact that QGIS does not allow for the calibration of maps in local systems, the authors calibrated the analyzed raster image based on a map from the OpenStreetMap site. The calibration was carried out with all available methods, based on selected points uniquely identifiable on the raster and the map obtained from the website (twenty adjustment points were used). The adopted number of adjustment points significantly exceeded the minimum number of points necessary to carry out the calibration with the given transformation method (see item 3). The raster image of the map has been
transformed into PL 2000 (in Poland valid coordinate system for large-scale maps). The georeferencer window of the QGIS program on the background of the reference ground with the display of adjustment points is shown in figure 3.

![Image](image.png)

**Figure 3.** QGIS program window against the background of the reference layer from OpenStreetMap [own study].

The transformation parameters for the selected method (Helmert) are shown in table 1.

**Table 1.** Parameters of transformation performed in the QGIS program using the Helmert’s method.

| Offset x       | Offset y       | Scale x | Scale y | Rotation (degrees) | Medium error (m) |
|----------------|----------------|---------|---------|--------------------|------------------|
| 6562100.848    | 5560943.892    | 0.422857| 0.422857| 0.707161           | 2.0542           |

The obtained mean square error values (RMSE) for each method are shown in table 2.

**Table 2.** List of average values of square errors characterizing particular methods of transformation in the QGIS.

| Calibration method | RMS error (m) |
|--------------------|---------------|
| Linear             | 12            |
| Helmert’s          | 2             |
| Polynomial I degree| 2             |
| Polynomial II degree| 6             |
| Polynomial III degree| 4             |
| Spline function    | 0             |
| Projective transformation | 2       |
When analyzing the results in table 2, it can be seen that the largest mean square error is characterized by a linear method. In the case of the Helmert method, the first degree polynomial and the flash transformation, the same values of this error were obtained (2 m). In the case of the spline function, the value of the average square error was 0 m, which is caused by the transformation of points from the raster exactly into points on the layer from the OpenStreetMap site. In the case of the II and III polynomial, this error was 3 and 2 times higher than for the first degree polynomial.

5. Summary and final conclusions

As part of the article, the authors calibrated the situational-altitude map. This map is characterized, like most mining maps, by the local coordinate system (in this case it is the "Sucha Góra" system). The existing regulations allow for such a situation, but it can be transformed into the applicable state system (being part of the state spatial reference system).

There are many programs that allow to calibrate analog maps and give them a spatial orientation consistent with the coordinate system. An example of this can be the programs described in [9].

Based on the activities performed, it can be concluded that the appropriate tools necessary to carry out the calibration process are also offered by the GIS class software. One of such is QGIS.

This program is perfectly suited for this type of work due to the wide range of available transformation methods and due to the possibilities associated with the selection of adjustment points (calibration on points with specific coordinates for a specific coordinate system, points determined on a previously calibrated basis and on the basis of points defined on the layer in free services, eg OpenStreetMap). The latter method seems to be the most effective in the case of transformation of local systems to the applicable state systems and in the situation of significant changes that occurred in the area covered by the map.

The calibration performed with seven different methods of transformation together with the determination of their accuracy allows to conclude that the most appropriate method in this type of task is the Helmert method and the first degree polynomial method. In both of these cases an root mean square error of 2 m was obtained. In the remaining methods, slightly higher error values and slight distortions were observed within the calibrated map.

6. References

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