

Cartometric Analysis of old maps on example of Vogt's Map

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Abstract:

The article deals with the topic of assessment of the accuracy of Vogt's map of Bohemia. This map belongs among significant cartographic works depicting the Czech Lands in the period 1526 – 1720. The methodology of accuracy assessment is based on cartometric and geometric analyses of sets of identical points in the old map and of a reference map, using the technique of multiquadratic interpolation. The database ZABAGED is used as a reference data set. The database is available via WMS services at the CENIA portal. The results of the analysis including scale isolines, rotation, displacement vectors of identical points were visualised using the MapAnalyst software and the extension software ArcGIS, 3D Analyst.

1 Introduction

Thanks to modern tools cartometric analysis of old or historical maps enables us to verify and assess their accuracy. The results present a valuable source of information about the way of map creation, mathematical-cartographic bases, and technique of processing. They also illustrate the development of map representations of the Czech Lands. They can be used for the study of evolution of landscape and the process of settlement taking into account long-term context. The methodology of cartometric analysis used in this article is based on comparing an old map with the current situation, and subsequent identification, analysis and interpretation of discovered changes. The article deals with the analysis of Vogt's map of the Czech Lands – an important map work which original is deposited in the Map Collection of the Faculty of Science, Charles University in Prague.

2 Characteristics of Vogt's map

Vogt's map is an important cartographic work dated in the first quarter of the 18th century. Because it is not known to the wider public as other maps from this period are, let us characterise it briefly, basing our description on works of prof. Kuchar (Kuchar 1958, 1960, 1961). The map was part of the book "Das jetzt-lebende Königreich Böhmen in seiner historisch und geographischen Beschreibung vorgestellt" published in 1712 whose author was the abbot of the Plasy Monastery Johann Gregor Vogt. The map's size is 853 x 656 cm, its scale along the central meridian is quoted to be 396 800. The map represents the area of Bohemia between the parallels 48° - $51^{\circ} 30'$. The map does not directly include geographic grid, around the map frame there is a scale with the division of $2'$ in the direction of longitude and latitude. The map is not created following a particular map projection. Vogt's map represents altogether 3110 objects; it differentiates walled towns, small towns, villages, churches, castles, ruins, and includes perspective views of some castles (Bezděz). The map

contains geographic names in two languages but it conforms to German custom. The map is richly illustrated, thus being not only an important cartographic, but also a significant artistic work. Vogt's map can be labelled the last independent work created by one cartographer. For the purpose of cartometric analyses we used the original of Vogt's map deposited in the Map Collection of Charles University in Prague.

3 Digitalisation of Vogt's map

Digitalisation of the original of Vogt's map by scanning was our first step. Further progress was influenced by the mechanical characteristics of the original. The material used for manufacturing Vogt's map is paper pasted on canvas. The map had been folded several times; at these places there is mechanical damage of the paper and uneven stretching of the canvas. The map is compiled of 18 map fields, see Figure 1. Digitalisation of the map with subsequent creation of continuous raster image presents a relatively difficult problem because of the above stated reasons.

The original of Vogt's map was scanned using the large-format scanner Contex CRYSTAL XL 42 with the resolution 200 dpi in the format TIFF. Pixel size was 0.127 mm. Then retouching of raster was performed removing impurities with software. This step was performed with the help of the tool Remove Speckles in the program MicroStation Descartes XM.



Figure 1: Illustration of Vogt's map from the Map Collection of the Faculty of Science, Charles University in Prague.

3.1 Creation of continuous map image

Because of repeated folding of Vogt's map and its long-term storage in folded position a slight shift and rotation of individual map fields occurred. Therefore, the creation of

continuous map image of Vogt's map was performed in three stages. The operations were completed using the software MicroStation Descartes XM.

Cutting scanned raster along map fields. The scanned raster was cut by software along the boundaries of map fields into the total of 18 raster images (3 rows, 6 columns). These images were not always rectangle-shaped, in some cases they were shaped like trapezoids. On several places the mechanical wear of the original caused spontaneous removal of small parts of the map drawing, especially along the folds. Therefore, the reconstruction did not result in an entirely continuous image of Vogt's map.

Projective transformation of map fields. Map fields are shifted in relation to each other and partly rotated. Because of using sheet-feed scanner with a material with higher basis weight some map fields were distorted towards a trapezoid shape. These places are unambiguously identifiable on the raster image. For removing this trapezoid distortion we used projective transformation representing the relationship between two planes in central projection. Identical points represented the corners of the reconstructed map fields. The size of the reconstructed field was derived from four adjoining fields.

Linking boundary contacts of adjoining fields. At the contact places of map fields' edges there still were reciprocal shifts in the image, even after projective transformation. For linking boundary contacts of the neighbouring fields, non-residual Jung's transformation was used with the aim of decreasing the extent of image transformation inside the map field to a maximum. Identical points in the local coordinate system were selected at contact places of neighbouring raster images in the areas of linking line elements (waters, roads). The corresponding identical point in the global coordinate system represented middle position of both identical points, its coordinates can be determined as the arithmetic mean of the coordinates of these points.

For each raster we used approx. 20 identical points selected according to the above stated principles. We do not enclose the overview of the coefficients of Jung's transformation because of the extent of this article.

Merging raster images. Individual raster images were then trimmed along vectorized boundaries of neighbouring map fields. In the program Descartes, using the function Merge, all 18 raster images were put together creating a final raster image which represented a continuous variant of Vogt's map. Existing jointing at contacting map sheets were filled with a mask in the colour of the maps background due to aesthetic reasons.

3.2 Transformation of Vogt's map

The next step was the transformation of raster Vogt's map into the JTSK coordinate system. Here, selection of a set of identical points used for the calculation of transformation key played an important role. We will discuss this step in detail because it considerably influences the analysis results. Because of the fact the Vogt's map represents the area of all Bohemia we used the database ZABAGED as our reference map. The database is available thanks to WMS services at the CENIA portal (<http://geoportal.cenia.cz>). However, the map represents also the area of Kladzko which had been part of the Czech Lands in the period of the origin of the map. Because the database ZABAGED does not offer any map materials for this area we did not include it into the cartometric analysis. The positional accuracy of chosen objects in the database ZABAGED characterised by middle position error of approx. 10m ensures a sufficient basis for georeference of the raster image, taking into account

Vogt's map scale.

Selection of identical points. The selection of identical points used for the calculation of a transformation key is a relatively complicated matter. When a map contains a geographical grid it seems best to use nodal points of meridians and parallels supplemented by significant and easy-to-identify points in the map. With such points we suppose that their position does not change significantly with time. Identical points should be distributed around the whole area, ideally in an even manner, so that the resulting transformation key has a global character, i.e. takes into account the geometrical-cartographic characteristics of the whole cartographic work.

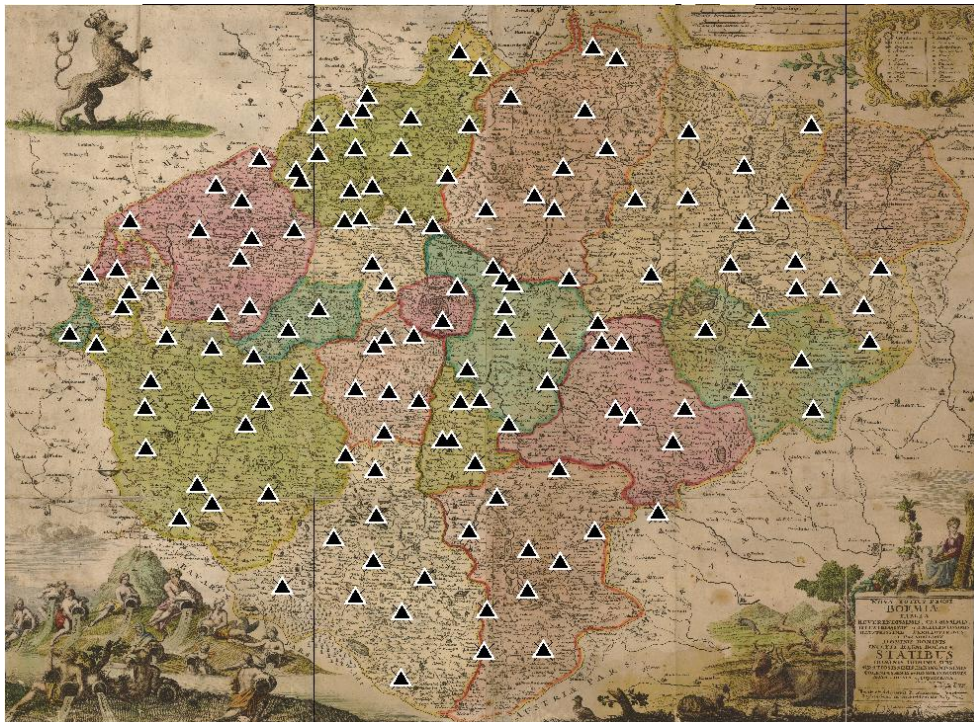


Figure 2: Distribution of 137 identical points for the calculation of a transformation key.

Because the Vogt's map does not contain a geographical grid it is not possible to use nodal points. To calculate the transformation key we selected 137 identical points out of the total of 3110 elements found in the map ($\approx 4.5\%$). This number can seem relatively small at first sight. However, the points were chosen carefully, taking into account the above stated principles, and they apparently constitute a relatively representative sample, see Figure 2. A similar result is presented in Vejrová (2008) using a set of 447 identical points. A complex cartometric analysis of Vogt's map would be possible only after its complete vectorization, which was not done due to time reasons. The set of identical points is "almost" convex, with the exception of the south-east and north-east parts.

Type of identical points. Identical points represented towns, castles and chateaus evenly distributed around the area of the Czech Lands. A number of smaller towns depicted in the area of Sudetenland do not exist anymore these days, and most of the towns expanded considerably due to social or industrial reasons. When looking for corresponding points in the database ZABAGED we respected the historical development of particular towns and

tried to select the position of each identical point in the area of the original centre of the town: square, church, fort, castle, chateau, ruin. In some cases these points are not situated in the centre of the currently built-up area and are noticeably oriented towards the periphery. This is the case in towns whose expansion is influenced by the shape of the surrounding relief, typical for hilly areas or foothills. Among other identical points there could be e.g. river confluences, ponds or other easily identifiable elements. However, it was not possible to perform further work on this topic due to time reasons.

The idea of cartometric analysis in the context of individual map topics could also be interesting, e.g. analyses of the accuracy of depicting municipalities, rivers or ponds. The map was not assessed as a whole but according to particular content elements. This topic could be dealt with in another article.

Transformation. To prevent distortion of the geometrical and positional relationship between the points we used affine transformation of first order. Higher-degree transformations were not used for the analyses because they cause unnatural distortions of the map image. Because of the redundancy of identical points the transformation coefficients were adjusted according to the method of the least squares $\sum v^T v = \min$. The affine transformation equation can be written in a general form

$$X = m_x \cos(\alpha)x - m_y \sin(\alpha)y + \Delta x,$$

$$Y = m_x \sin(\alpha)x + m_y \cos(\alpha)y + \Delta y,$$

where x,y represent the coordinates of the local coordinate system, X,Y the coordinates in the global coordinate system, m_x,m_y the scale coefficients in the direction of the x,y axis, α the rotation angle. The parameters determined from the set of 137 identical points using the program MapAnalyst and supplemented with the characteristics of accuracies of their determination represented by the standard deviation σ are stated in Table 1.

Tab.1 Values of affine transformation coefficients calculated from 137 identical points and standard deviations of the coefficients.

Coefficient	Value	Standard deviation
m_x	53.162318	0.37
m_y	54.841211	0.50
Δx	-65191.91	9.20
Δy	-19082.63	9.20
α	10.4152	0.31

Let us notice the similarity of two scale coefficients which differ by approx. 3%. Vogt's map as a whole is rotated in comparison to reference data set from ZABAGED by approx. 10° .

3.3 Cartometric analyses

The aim of cartometric analyses is to verify cartographic parameters of the map. Because of the fact that cartographic work is a relatively extensive set of point, line and areal

cartographic signs, it is not usually possible to perform an analysis of the map as a whole, due to time reasons. Therefore, it is necessary to choose only a subset of such elements which represent a sample set in which we can suppose a higher degree of positional accuracy.

The basic set of points which was used for cartometric analyses contain 137 identical points. After completing affine transformation we could perform the cartometric analyses of Vogt's map. The results of the analyses serve as an approximate assessment criterion illustrating the accuracy of the map's construction. The results are presented in the form of tables or graphical outputs.

It is necessary to emphasize that the below stated results of cartometric analyses are *dependent* on the choice of the set of identical points serving for the calculation of the transformation key. If the number or distribution of identical points changed the results would be slightly different.

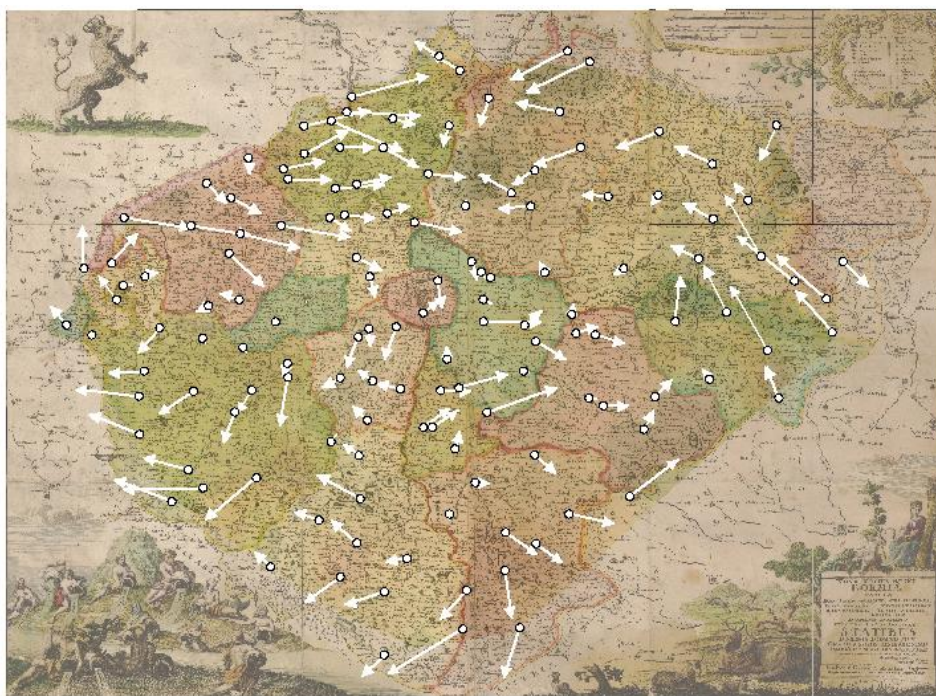


Figure 3: Positional displacement of 137 identical points represented in the scale 2:1.

Corrections on identical points Affine transformation belongs to the group of residual transformations; identical points in both coordinate systems are not fully identified. The values of corrections v_{xy} of identical points can be used to assess the accuracy of depiction of elements on the map, see Figure 3. Table 2 contains a list of 5 most and 5 least accurately depicted towns. It is interesting that using the stated transformation key the depiction of the town of Plasy (West Bohemia) was assessed as the most accurate. The town was the author's birthplace. The ruin of the castle Žampach in East Bohemia (identical point 133) was depicted very inaccurately; here the value of correction is three times bigger than standard deviation.

Tab.2 Five settlements with smallest residual (to left) and greatest residuals (to right).

Settlement	Residuals [m]
Plasy	72
Čelákovice	310
Čistá	329
Nečtiny	806
Rakovník	951

Settlement	Residuals [m]
Žampach	18 630
Hejnice	16 019
Vlašim	15 977
Domažlice	15 134
Frýdlant	14 975

Positional accuracy of Vogt's map. Based on selected identical points, a standard deviation describing positional accuracy of Vogt's map revealed 8256m. This value is rather remarkable considering the fact that Vogt's map was not created on solid geometric and geodetic basis. Moreover, the stated value is highly influenced by errors that originate in the incorrect placing of some objects into the map. After eliminating an identical point no. 133, the standard deviation in position decreases to 8068m.

Calculation of the map's scale When we know the resolution of the scanned raster image defined by the pixel size d and the scale coefficients m_x, m_y of the affine transformation we can determine the scale numbers of the map M_x, M_y in the direction of the x, y axis using the relations

$$M_x = \frac{1000 \cdot m_x}{d}$$

$$M_y = \frac{1000 \cdot m_y}{d}$$

After inserting the values the following results are obtained: $M_x = 418865$, $M_y = 431865$. The calculated data deviate by approx. 6% from the scale number 396 800 stated in available literature and are in accord with the results presented in Vejrová (2008).

3.4 Calculation of scale and rotation

Analyses of scale and rotation are an important factor illustrating the accuracy of the construction of a cartographic work. We used the program MapAnalyst which is specialised for cartometric analyses of old and historical maps (Jenny 2006, Jenny et al. 2007). For this purpose the program contains a complex geometrical-analytical apparatus using multiquadratic interpolation of a set of identical points. Detailed information about the methodology of analyses using multiquadratic interpolation can be found in Beineke (2000, 2007). The process of cartometric analysis is fully automated, with the exception of collection of identical points. This fact contributes to speediness and overall reliability of the analytic process.

Using the set of 137 of identical points and parameters of the affine transformation the program MapAnalyst generated isolines of scale and rotation. Because of the fact the isolines generated by the program were not straight (but curved) and it is not possible to work out their description, the visualisation was performed in the program ArcGIS. For this purpose we used the extensions SpatialAnalyst and 3D Analyst. Data of the old map were gradually exported into the formats DXF and SHP, in attribute table we completed the information

about the coordinate z necessary for the creation of a 3D model. The function TopoToRaster was used to generate a 5m raster model from these data. This process led to the creation of two 3D models showing the dependence of the scale and rotation on the geographical position of the point. Using the extension 3D Analyst isolines of scale and rotation were generated for these two models. Their descriptions were created in the extension Maplex.



Figure 4: Scale isolines of the longitudes of Vogt's map generated with the step 0.05.

Scale isolines, see Figure 4, show that the positional accuracy of Vogt's map changes depending on geographical position. Taking into account this criterion the best results in the map are reached in the area of Central and West Bohemia, the worst ones in the area of North and East Bohemia. This is the consequence of some objects (Žampach, Frýdlant) being incorrectly depicted, in the order of approx. 15km. Distortion values come under interval $\langle 1.4, 1.8 \rangle$. Rotation isolines, see Figure 5, indicate that the biggest rotation appears in the areas of East, South and West Bohemia. On the other hand, the centre of Bohemia demonstrates relatively small rotation values. Rotation values for Vogt's map come under interval $\langle -5^\circ, 50^\circ \rangle$. If we assess Vogt's map taking into account both viewpoints, the following conclusions will be drawn. Vogt's map demonstrates the smallest accuracy in the area of East Bohemia where there are considerable positional and angular distortions. The highest accuracy has been detected in the area of Central and partly West Bohemia where there are minimum positional and angular distortions.

3.5 Result evaluation

The results arising from cartometric analyses are influenced by a number of various factors. The following three important factors can be considered as crucial in our case:

- *The original's quality*: The quality of the scanned original plays an important role in the process of cartometric analysis. In this case only the original was available. It had

to be transformed into a continuous raster map using several heterogeneous geometrical procedures. It is probable that non-linear changes in the reciprocal position of some identical points of both sets appeared, thus influencing the achieved results.

- *Selection of identical points:* It is best to perform cartometric analysis in a completely digitalised cartographic work. If it is not possible due to financial or time reasons, it is possible to perform the analysis only for a subset of the map's content. In such case testing points have to be selected so that they are evenly distributed around the whole surface of the map, and their position has not significantly changed with time. Interpolation techniques based on multiquadratic interpolation are suitable for processing a set with approximately the same density of points. Unevenly distributed clusters of points or places containing no points negatively influence the achieved results. The used set of 137 identical points can be considered as sufficient; however, it was not always possible to maintain the same density of points. In mountain areas, especially in the Krkonoše or Šumava Mountains, the necessary number of identical points was not available. Often these points are situated on the edge of the area; this is the reason we can suppose they will have higher weight when calculating some parameters of the transformation key (rotation).
- *Interpolation technique:* The technique of multiquadratic interpolation also played an important role. It was performed in the program MapAnalyst to reconstruct the continuous surface from discrete data. It is necessary to take into account the fact that the results represent only one of other possible mathematical models constructed for the input data.

Even in spite of the above stated facts the achieved results can be considered valid. None of the factors probably played such a significant role that would considerably influence the results of the cartometric analyses. However, to verify this it would be necessary to perform further tests of statistical character.

4 Conclusion

This article dealt with the process of digitalisation and cartometric analysis of old maps, in particular the analysis of the original of Vogt's map, using the technique of comparing sets of identical points on an old and a modern map. The methodology used during the work enables to analyse inaccuracies in old maps, making use of modern mathematical-geometrical procedures, thus contributing to the speediness and reliability of the analysis. The calculated parameters were visualised using the software MapAnalyst and ArcGIS, giving us interesting information about the accuracy in the construction of Vogt's map depending on the position of points. The results were influenced especially by the selection of identical points which served as a basis for determining a transformation key, and by the method of multiquadratic interpolation which was used.

The Map Collection of the Charles University in Prague currently contains several other cartographic works from the period 1518 -1720. Their cartometric analyses will follow.



Figure 5: Rotation isolines of Vogt's map generated with the step 10° .

5 Acknowledgments

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