METHODS FOR GEOREFERENCING EARLY MAPS

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Abstract
Early maps play an important role in the development of cartography and art. Furthermore, they are an integral part of our heritage and have been attracting the attention of scholars for centuries. The research of early maps reveals the evolution of cartographic methods and skills as well as the remarkable progress in knowledge about the environment. Georeferencing significantly improves the comparison of early maps with those of the present, and there are several methods. This paper concentrates on techniques for the georeferencing of early maps which do not possess geodetic networks or coordinates.

Keywords
Early map, city map, Műller's map, Jűttner's plan of Prague, cartometric analysis, georeferencing, visualization

Introduction

The study of early maps always brings forth new findings, and new technology, such as digitization, offers new methods of cartographic research. One can scan original hand-drawn maps and valuable map prints and then work using the subsequent raster images. The advantages are self-evident: after they have been scanned, valuable prints can be deposited back to the archive; raster images can be processed by various software; digital data can be accessible to many researchers at the same time; raster images of early maps can be easily compared; and early maps – together with the research findings – can be published on the Internet. On the other hand, the researcher loses direct contact with the early map and selecting a suitable method of digitization is crucial to the whole process.

The popularity of publishing early maps on the Internet continues to grow. It makes them accessible to both academia and the general user and makes a valuable contribution to the popularization of cartography, thereby increasing interest in maps. Georeferencing significantly improves the possibilities of comparing early maps with each other or with those of the present. Several projects concerned with early maps, their research and visualization have been undertaken by a team at the Department of Mapping and Cartography of the Czech Technical University in Prague. Maps of the second military mapping of Austria-Hungary, Müller's maps of Bohemia and Moravia, Pinases' and Jüttner's plans of Prague, and other early maps are published through the University's map server at *http://maps.fsv.cvut.cz*.

Method

As mentioned above, georeferencing raster images of early maps has advantages for conducting further research, processing, and visualization. The digital images can be integrated within a GIS, where more operations can be performed. The long path of cartographic evolution has brought forth many different maps and we can distinguish them according to their suitability for georeferencing. The oldest preserved maps are valuable, but they are not accurate enough as the positional errors inherent within such maps would be too large to yield useful results. Also, the deformity caused by transformation tends to decrease the graphic quality of the raster image considerably. The earliest maps which are accurate enough to be used are generally based on geodetic or astronomical measurements; Műller's maps of the Czech lands are a good example (Cajthaml and Krejčí, 2007). However, these maps usually have no coordinates or geographical grid marks, and where they exist, are not

sufficiently accurate to enable straightforward georeferencing. A similar situation occurs with newer small scale maps or city plans (Krejčí and Chodějovská, 2008). A further generation of maps may be distinguished, i.e. when the first national map series began to use a regular coordinate system, trigonometric network, and map layout. These maps can be georeferenced simply by using the known coordinates of the sheet corners. A method of georeferencing based on the identification of a set of control points on early maps is the most effective technique for georeferencing such maps and is addressed in this paper.

The georeferencing technique of using control points within the topographic content of maps is suitable where such points can be readily identified in the source. In tests on medium and large scale maps, its success depends upon gaining a reasonable number of points which correspond to those on an up-to-date map. Regarding scale, it is necessary to use different types of points. For example, symbols representing whole towns and villages on medium scale maps, or the corners of important buildings on large scale maps or city plans. However, a regular pattern of control points, while ideal, is usually unattainable. Furthermore, areas with totally different characteristics are often encountered, e.g., those without any possible points versus those with plenty, but for a good result, it is essential to be as thorough and consistent as possible when choosing points across the map surface. Up-to-date coordinates of a stated positional accuracy can be obtained using a web map server, a desktop GIS or GPS survey, for example.

The complete set of pairs – those on the early map together with their corresponding points at identical positions on a current map – is used for the subsequent transformation. The goal is to choose the most suitable transformation to meet all requirements. A similarity transformation could be employed for a basic georeferencing of an early map. But every map, especially early hand-drawn or printed maps, is influenced by the shrinkage of the original material, e.g. paper. This can be partially eliminated by performing an affine transformation, which does not corrupt the image data too much. A high-order polynomial transformation can be used for more precise transformations, but intensive distortion of drawing can appear. The polynomial transformation of the 2^{nd} or 3^{rd} order is usable, but higher orders have no further advantages. An alternative is the thin plate spline (TPS) transformation, which produces similar effects.

It is necessary to check the positional errors of each point before transformation. Sometimes, choosing and identifying the control points can be a very uncertain process. It is therefore desirable to exclude wrongly determined points from the transformation key. The root mean square (RMS) error of transformation is a possible criterion of map quality and accuracy, although this is highly dependent upon the quality and regularity of the set of control points.

Georeferenced early maps can be added to a map server or integrated within a GIS application. This makes the early map accessible for comparison with other maps or against a current representation and can be very useful for ecological, urban, historical, or purely cartographic studies. An early map that has been accurately georeferenced can reveal dramatic changes in the countryside or in urban areas more easily.

Case Studies

Two case studies of georeferencing early maps will now be described: (1) a medium scale map of Bohemia from the early 18^{th} century; and (2) a large scale plan of Prague produced a hundred years later. Both were georeferenced using pairs of identical points based on the topographical content of the maps. The subsequent visualization of the results on the Internet was an integral stage of both projects.

The first project involves Műller's mapping of the Czech lands; his map of Bohemia dates back to 1720 and consists of 25 sheets. The scale is about 1:132,000 (Kuchař, 1959). The goal was to prepare and publish a seamless georeferenced map and so all 25 sheets were eventually merged into one resultant image. A major problem was the coincident angles of lines between the edges of adjacent map sheets. Local, non-residual transformations were used for making these edges seamless. The seamless map was then ready for georeferencing. Műller's map displays different types of symbols, e.g. representing settlements, rivers, relief, and so on. Two types of points of its topographical content were used: river confluences and large walled towns. Different sets of identical points and transformations were then tested, with the points representing large towns used for the final transformation. The reason was clear: the centres of walled towns are both stable and easily recognizable on a photomap, even if an older town is surrounded by newer suburbs. Walls are rarely preserved, but their outlines are usually visible. The reference point was therefore taken in the centre of a walled town. Its depiction on both Műller's map and on the photomap can be seen in Figure 1.

Figure 1 Depiction of a walled town used as a control point on Műller's map (*left*) and a present-day photomap (*right*)

Affine transformation was chosen, which keeps the spatial relationships across the map reasonably constant (the RMS error of this transformation was 1.21 km, which can be considered a good result with respect to the age and scale of this map). A TPS transformation, which matches any pair of control points within the set, was also applied and showed that the map was widely distorted in some areas.

These georeferenced maps can be easily compared with current maps. A layer of rivers and lakes was chosen for a comparison with the results of the two transformation techniques described above. This is illustrated in Figure 2, where important fish ponds (which have not been preserved) may also be noted.

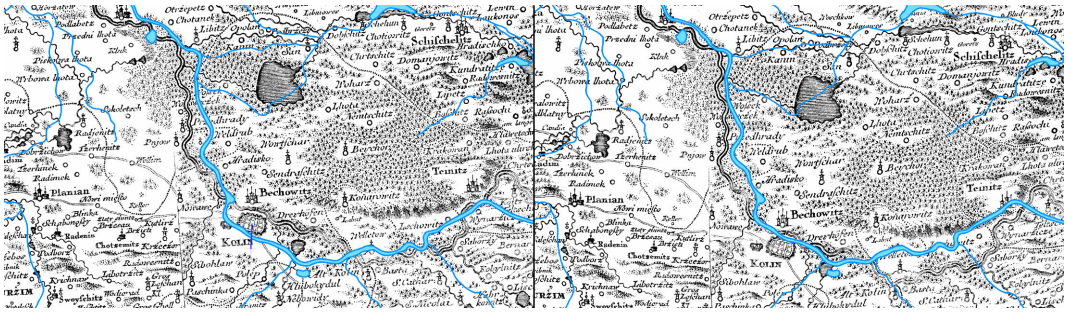

Figure 2 Depiction of Műller's map after the application of affine (*left*) and TPS (*right*) transformations, with hydrological data for reference

The second project involved Jűtner's map of Prague. It was the first plan of Prague to be based on a trigonometric network and geodetic survey (Roubík *et al*., 1972) and at a scale of 1:4,300 is a very detailed depiction of the city from 1816. The plan provides an image of the city a short time before the rapid urban expansion changed its face forever. The plan is complemented by a list of important buildings. The corners of important buildings which remain standing were used to provide the set of control points. Sometimes, a personal knowledge of a city can be very helpful with this process. Some Prague districts have been preserved without large changes and consequently it was not difficult to establish enough points common to the past and present representations of the city. On the other hand, there are some areas, especially beyond the city walls, which have totally changed and it was almost impossible to find any points in these areas. About eighty points were taken (some problematic points were left out) and an affine transformation was applied, yielding an RMS error of 7.21 m. The map was then published on the University's map server and a present-day orthophoto layer was integrated using a web map service (WMS) to allow the historical and present situations to be compared as easily as possible (Figure 3). Such a depiction shows dramatic urban changes beyond the city borders very clearly.

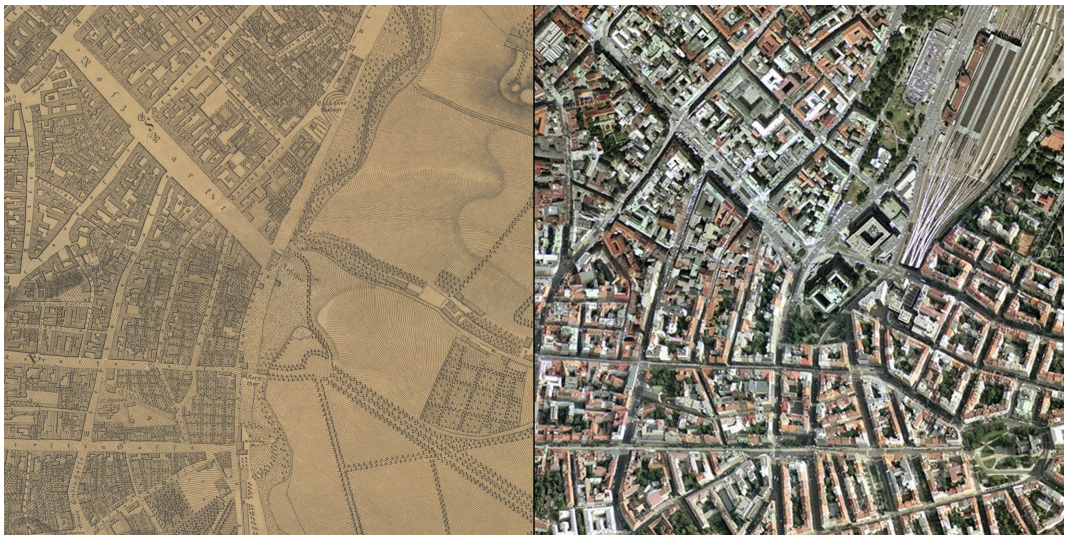

Figure 3 Comparison of Jűtner's map of 1816 with a present-day photomap

Conclusions

Early maps provide new information about our environment and its history, but georeferenced digital images of early maps make the comparison with the present easier. The method of using pairs of identical points from specific topographical features is advisable for those large or medium scale maps without coordinates or a geographical grid. Selecting a good set of control points and choosing the right transformation technique are essential for a successful result, but the method can only be used when a sufficient number of points are easily identifiable on the early map and the up-to-date map. The subsequent visualization of the results on the Internet makes early maps more accessible to academia and the general public, stimulating further interest in cartography.

References

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Biography

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