Application of Membrane Homogenization Method for Slovenian Cadastral Index Map

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Key words: cadastral map, homogenization, membrane method, proximity fitting, Slovenia.

SUMMARY

A digital land cadastral index map is a composition of digitized various analogue land cadastral maps and measurement data sets with different positional accuracy, depending on the scale of the map and on the methodology (quality) of data acquisition. In Slovenia the problem of heterogeneity of graphical land cadastral data is the issue of importance when the quality of data and use of those data in the framework of GIS is in question. In the article, the application of membrane method is presented as one of the approaches for the improvement of land cadastral index map's geometrical quality. The application is based on additional surveying measurements, where the basic principles of geodetic profession are to be firmly respected (methods of the coordinate geometry, topology, adjustments, error propagation law etc.). The case study was implemented in the rural area near the capital Ljubljana where geometrical quality of few cadastral index maps was tested and improved based on field measurements of cadastral (identical) points, field book data and additional conditions (rectangularity of buildings, straight lines and others). The membrane method has been applied to analyze how heterogeneous parts of cadastral index map get fitted to the "real" positions by use of positions of identical points, relative measurements and geometrical constraints. Results show the possibility of incremental improvements of homogeneity of the cadastral index maps in Slovenia with additional measurements introduced into the adjustment process.

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1. INTRODUCTION

In Slovenia, as well as in the comparable traditional cadastral societies, a digital land cadastral index map is a composition of digitized various analogue land cadastral maps and measurement data sets with different positional accuracy, depending on the scale of the map and on the methodology (quality) of data acquisition. The first bigger and encompassing cadastral survey of the Slovenian part of the Habsburg Monarchy was carried out under Joseph II, starting in 1785. The so called *Josephine cadastre* was completed in four years, but the cadastre never came into the force. The oldest official cadastral maps based on cadastral surveying in the territory of today's Slovenia are maps of the *Franciscan cadastre* from the first half of the 19th century (1818–1828). The main scales used were 1:2880, for mountainous area 1:5760 and for cities 1:1440 or 1:720. For the Slovenian territory, the majority of cadastral maps from that period were produced in Krim (near Ljubljana) or Schöckelberg (near Graz) coordinate system (in Vienna fathoms or later in meters) as the origins of cadastral measurements, or better mapping. During the two centuries, this maps have been revised (the complex revision for the whole Slovenian territory was implemented only once during the period 1869-1882), and maintained using different methods in different periods. In 1924, the Gauss-Krueger cartographic projection of meridian zones based on the Bessel ellipsoid was introduced, but in Slovenia only some areas have been newly surveyed. In the last decade of the 20th century all cadastral maps were digitized (Kosmatin Fras et al., 2012). These digital maps, covering the whole Slovenia, are called cadastral index map, which practically became only conditional applicable for the professional use due to measurement techniques, mathematical foundations of old cadastral surveying, poor maintenance of analogue maps through the centuries and consequently the heterogeneity of the those maps. Therefore, reasonable attention has been focused to the improvement of positional and geometrical accuracy of digitized content of cadastral maps.

The aim of this paper is to present methodology for the homogenization of cadastral index maps. The method, suggested here, follows homogenization applying adjustment techniques, which use simulated and real measurements. The method has been applied to analyze how heterogeneous parts of cadastral index maps get fitted to the real positions by the use of the "real" positions of identical points, relative measurements and geometrical constraints. The study area is the cadastral municipality of Žažar which is a typical rural community with the prevailing old cadastral maps based on the graphical survey of parcel borders from the beginning of the 19th century. One of the purposes of our research (see Čeh et al., 2011b; Švab, 2012) has been to evaluate the use of different identical (tie) points, to determine their optimal arrangement for the purpose of improving the relative positional accuracy of land cadastral index maps.

2. DATA SOURCES AND METHODOLOGY

2.1 The problem domain

The problem of measurement based spatial data is a considerable problem in the field of GIS and spatial data infrastructure, also for the newer measurements and data sets of high quality (see Navratil et al., 2004). GIS is in general designed to consider geometrical parameters (coordinates) as deterministic values. This leads to the misunderstanding of the nature of spatial data in GIS. Coordinates are namely always calculated from the observations, which are redundant aleatory values. Consequently, coordinates are also aleatory values as well as correlated ones. The accuracy of relative geometry is higher than the absolute accuracy. Coordinates and relative measures are therefore not equivalent (Gieldsorf et al., 2004). Without any consideration of neighborhood relationships to other points at all, the relative geometry between updated and unchanged points in GIS would be highly violated.

Focusing on the land cadastre in Slovenia it has to be pointed out, that land cadastral positional data are predominantly based on observations for in the field mapping techniques and the original measurements data are most often not preserved. In Slovenia, as a part of former Habsburg monarchy, surveys of cadastral datasets started around 200 years ago. The quality of measurement equipment as well as the methodology (based on tachometry, global navigation satellite systems GNSS, remote sensing etc.) has improved dramatically since then. Adding new measurements to the old datasets, by storing point coordinates only, does not improve the quality of datasets. Here, the problem of integrating new measurements in the existing datasets appears (Čeh et al., 2011a).

2.2 Methodology

Our starting point is that the integration of new, more accurate cadastral data into the existing data sets (cadastral maps) should result in more accurate point coordinates and should improve and homogenize relative geometrical accuracy of neighboring cadastral (spatial) data. The geometrical quality of the cadastral index map can be improved by integration of precise geodetic measurements, existing field book measurements as well as other sources of data (photogrammetric measurements etc.). Wider areas (not only the measured land parcel) should benefit from this accuracy improvement without loosing its internal geometrical quality. By positional accuracy improvement localized pockets of higher accuracy data (contemporary measurements of higher positional accuracy) are used to improve the positional accuracy of surrounding (neighborhood) low level positional accuracy datasets, in our case the land cadastral vector index map. The methodology determines the best fit of positioning solutions using positional information from several dataset. The method is based on the surveying adjustment theory and is also able to preserve geometric properties such as straight or parallel lines. The same methodology has been already applied in some federal German state (see Gielsdorf et al., 2004; Gruending et al., 2007; Hope and Kealy, 2008).

The proximity fitting methods are applied to keep neighborhood relationships. They substitute usually applied single system transformation. The result of ordinary transformation can be seen as the first step of proximity fitting. Spatial heterogeneity implies that each location has intrinsic uniqueness, but conditions vary from place to place. The lengths of the edges in network may be equal, but they have different relative interpretations within the clusters and are based on their absolute distances. It is clear that relative proximity is more important than absolute proximity in geo-referenced settings and thus geospatial clustering (Ickjai, 2005).

3. APPLICATION - MEMBRANE HOMOGENIZATION FOR SLOVENIAN CADASTRAL INDEX MAPS

The method was applied for cadastral data in the cadastral municipality of Žažar. This rural community is covered by digitized cadastral maps with the origin from the 19th century, which is a typical situation also for more than three quarters of the Slovenian territory. The research project was organized in four phases:

- field inspection to identify identical (tie) points
- filed measurements,
- office computation of measurements and adjustment of existing data (calculation of approximate values, adjustment and homogenization),
- analyses and interpretation of results.

3.1 Identification of identical (tie) points

The main reason for the selection of the cadastral municipality of Žažar for the study case was the fact that in this area had relatively few developments and consequently only some changes in the cadastral maps have been applied. The second reason was that rough relief is not very appropriate for modern (machine supported) land cultivation, which preserved a lot of historic parcel boundary monuments in the field. Ad hoc accuracy of cadastral index map of the study area is 2–5 m (assessed by the Geodetic Institute of Slovenia). The field inspection and identification of identical (tie) points was performed by support of field computer displaying relief in the background, cadastral map boundaries labeled with the azimuth and horizontal distances between the boundary points (source: cadastral index map). The boundary monuments were recorded in the field computer and grouped by age, type of monument and type of boundary:

- Cadastral municipality boundary monuments, crafted on larger stones usually located at the natural relief break-lines outside of the area of intensive agricultural cultivation (Fig.1). At the time of initial cadastral measurements they served as the frame (skeleton) points. For identification of these points we used historic written description (from the 19thcentury) of the boundary polygon.
- Boundary marks of initial cadastral survey (from the 19th century), marked in the field with natural stones, but no marks have been engraved, and no written description is available.
- Boundary marks of cadastral points (from the 20th century) marked by concrete blocks 10x10 cm with engraved cross which might be also cut in natural rock or built object. These points are described in the field books of that time.
- Topographic features of old roads and paths, presumably persistent from the age of initial survey as well as selected relief break lines limiting the land use patterns.

Figure 1: Old cadastral community boundary monuments, crafted on larger stones.

3.2 Field measurements

After field inspection and identification of identical points (Fig.2) the geodetic survey was performed, following the plan of measurements (GNSS measurements combined by classical measurements using total stations). With the respect to the surveying rules for cadastral measurements in Slovenia we have performed the measurements with the horizontal accuracy of 4 cm (major axis of the standard error ellipse). Fast static GNSS method (10 min + 1 min/km) was used for determination of surveying framework points with the achieved accuracy of 1,4 cm. Survey of detail points was performed partially by RTK GNSS method (horizontal accuracy 1–3 cm). Tachometric survey was used for cadastral survey of boundary points where conditions were not appropriate for any GNSS method (forest sites, inside the village etc.).

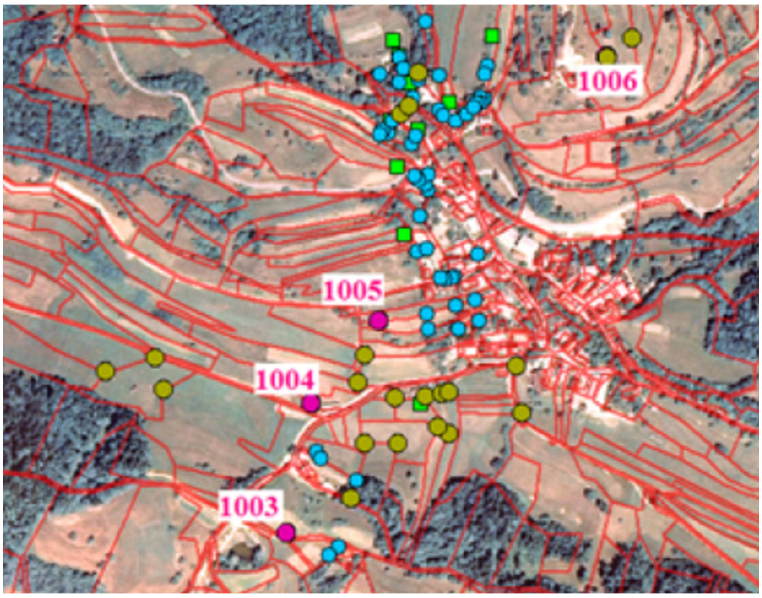

Figure 2: Cadastral index map (red lines) on ortophoto with the identical points: boundary marks of cadastral survey for the 19th century (green points), boundary marks of survey in the 20th and 21st century (blue points), and geodetic points (violet points).

3.3 Adjustment and homogenization

In the transformation phase an artificial coordinate differences between identical (tie) points, the connection points and the new points are introduced into the adjustment. These pseudo observations are weighted depending on the distances. There are no direct neighborhood relationships between the interpolated points. Additionally, the result depends on the number of identical points which create residuals. The method is not suitable to model direct neighborhood relationships. The resulting displacements of new points are dependent on the density and distribution of identical points. In the second step the mapping approach is extended by the introduction of relative geometry information. Advanced methods use the Delaunay triangulation to model the neighborhood relationships directly. Here, topological neighborhood information is applied by the Delaunay triangulation process over all GIS points (identical points and other points) of the original system (Fig.3). The triangle sides are used as carriers of neighborhood information. Along the triangle sides, artificial coordinate difference of observations are generated which are subsequently introduced in the adjustment calculation according to the least squares method. The observation values are derived from the coordinates in the original system. The triangular net is acting like a homogeneous membrane. Its elasticity is given by the weights based on the accuracy of cadastral points (see Gielsdorf et al., 2004; Čeh et al., 2011a).

Figure 3: All vertexes of cadastral index map (including identical points, red dots) are included in Delaunay triangulation (dashed lines). The geometrical constraints (rectangularity, straight lines) are also considered.

The resulting displacements are independent of the density and distribution of identity points. The so called membrane method uses as functional model of coordinate differences along the triangle sites, and leads to linear residual equations with a very stable convergence behavior. The stochastic model is derived from the finite element methods, and it simulates the behavior of a rubber membrane. The proximity fitting is run as an adjustment calculation method (see Gielsdorf et al., 2004; Gielsdorf, 2010).

The point accuracy improvement can be noticed by the integration of already existing GIS coordinates, additional field measurements, field book measurements and geometrical constraints. Fig.4 shows the integration of measurements from the field book.

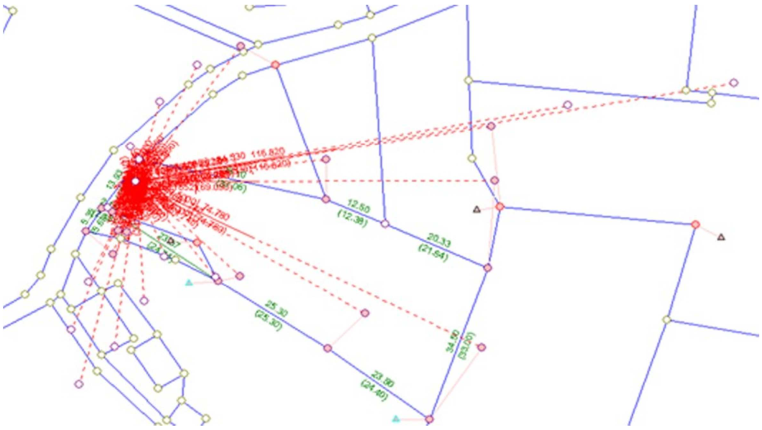

Figure 4: Integration of field book data (polar measurements).

The next example shows a cadastral index map transformation with the integration of field measurements of identical points, measurements from the field books and additional relative constraints (rectangularity and straight lines) using the proximity fitting approach. Wider areas (not only the measured land parcel) profit from this accuracy improvement without loosing its internal geometrical quality. By relative positional accuracy improvement local pockets of more accurate data (contemporary measurements of higher positional accuracy) are used to improve the positional accuracy of surrounding (neighborhood) low level positional accuracy datasets, in our case the land cadastral vector index map. Methodology determines the best fit positioning solutions using positional information of several dataset.

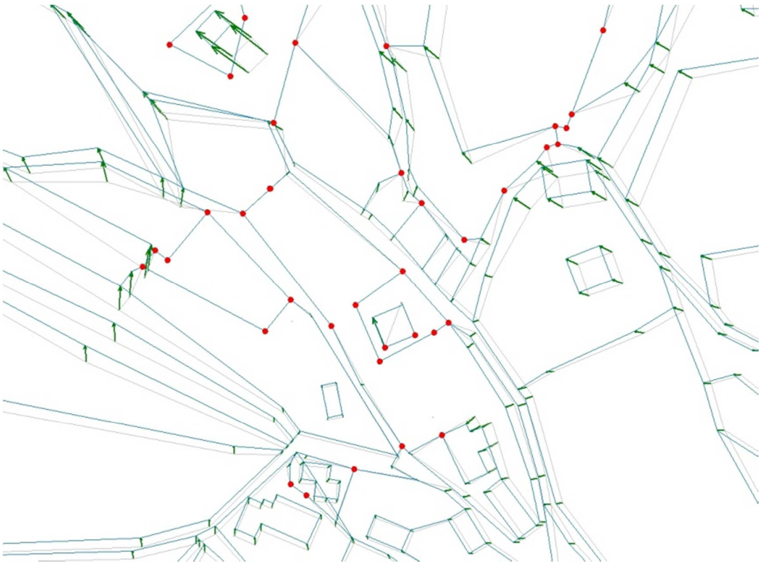

Figure 5: Improvement of geometrical and positional accuracy of land cadastral index map in the cadastral community of Žažar – red points are identical points.

4. CONCLUSIONS

Problems concerning effective land administration supporting the suitable use of land resources, improved land management and, in general, and suitable spatial decision making are becoming more and more important all over the world. With the greater need for environmental controls and market impact on the investments policy for real estates and pressure on land rights, these issues need considerable attention. The modern land administration systems are filled with large volumes of digital data on land and real property, and are organized in the framework of multipurpose geographical (land) information systems.

The problem of geometrical improvement of graphical land cadastral index map is common for the traditional cadastral societies - not only for Slovenia, but also for Austria, Germany etc. Coordinates of land parcel border vertexes are mainly derived from positional heterogeneous analogue maps that were digitized and geo-referenced. The analogue maps, which in Slovenia originate from the beginning of the 19th century, had been maintained throughout the centuries with manual technique of graphical adjustment. Improvement of geometrical accuracy of land cadastre index map has become a challenging issue in Slovenia.

This pilot study of positional and geometrical improvement of land cadastral index map in the cadastral municipality of Žažar shows that presented approach (already applied in certain German federal states) would be reasonable in Slovenia too, in particular for the prevailing areas with old cadastral datasets from the 19th century. The methodology is able to preserve geometric properties such as straight or parallel lines in addition to the improvement of the land cadastral index maps' positional accuracy which is of great importance.

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BIOGRAPHICAL NOTES

Dr. Marjan Čeh is a researcher and assistant at the University of Ljubljana, Faculty of Civil and Geodetic Engineering (UL FGG), Slovenia. His research interests are focused on GIS technology, spatial data interoperability, ontology and semantic enrichment of spatial data.

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Blaž Švab has graduated at the University of Ljubljana, Faculty of Civil and Geodetic Engineering in 2012 under the supervision of Anka Lisec. The topic of his thesis was the positional accuracy improvement of land cadastre index maps, based on the membrane method.

Dr. Miran Ferlan is a higher lecturer at the University of Ljubljana, Faculty of Civil and Geodetic Engineering (UL FGG), Slovenia. His research work is focused on the copyright protection, land management, land administration, spatial planning and programming.

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