Geo-Referencing of Analogue Maps with Special Emphasis on Positional Accuracy Improvement Updates

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Key words: Geo-Referencing, GIS, Positional Update.

SUMMARY

In order to create GIS thousands of analogue maps were digitized, respectively this process is going on. The achieved geometrical quality reflects the quality of the underlying maps. However, digitized coordinates show a characteristic difference between their relative and absolute accuracy. Therefore in many cases it is necessary to perform a stepwise point accuracy improvement (PAI). But many GIS data models have no provisions for the option of PAI. This leads to inconsistencies in data which have an inherent geometrical relationship. As a typical example, facility line geometry might be falsified if referenced to points which are affected by PAI.

The paper shows how the effectiveness of geo-referencing and boundary fitting can be maximized using adjustment techniques. A data maintaining strategy is presented which regards point coordinates just as a view on redundant primary data. PAI updates can then be seen as the generation of a new view applying adjustment techniques.

ZUSAMMENFASSUNG

Für den Aufbau von GIS wurden bzw. werden noch viele Karten digitalisiert. Die so erreichte geometrische Qualität widerspiegelt die der zugrunde liegenden Karten. Doch die relative Genauigkeit der digitalisierten Koordinaten unterscheidet sich stark von deren absoluter Reproduzierbarkeit vor Ort. Aus diesem Grund ist es notwendig, die absolute Punktgenauigkeit schrittweise zu verbessern. Doch von den meisten GIS Datenmodellen wird ein solches Vorgehen nicht unterstützt. Dies kann dort zu Inkonsistenzen führen wo das Prinzip der Nachbarschaft nicht beachtet wird.

Das Paper zeigt wie die Effizienz von Geo-Referenzierung und Randanpassung durch die Nutzung von Ausgleichungsalgorithmen entscheidend gesteigert werden kann. Weiterhin wird eine Strategie der Datenverwaltung vorgestellt, welche die absoluten Punktkoordinaten als Sicht auf redundante Primärdaten betrachtet. Die Verbesserung der absoluten Punktgenauigkeit ist in diesem Fall gleichbedeutend mit der Generierung einer neuen Sicht durch Anwendung von Ausgleichungsalgorithmen.

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1. INTRODUCTION

In society today, there is a need to convert accumulated analogue maps into digital format. In most cases, many individual maps exist at various scales and levels of detail and it is either impossible or too expensive to physically re-survey the features for the creation of a new digital map. The initial step of digitisation involves converting an image from analogue to digital format. Once digitised, images have to be geo-referenced. Geo-referencing takes an image from its local coordinate system and defines it in a global coordinate system. It is performed through the determination of transformation parameters. Every transformation results in an adjustment problem if more fixed points than required are available. In other words a transformation is considered an adjustment when redundancies exist.

The classic transformation technique, for each map that is to be transformed, requires 4-6 fixed points to be determined. Only the transformation parameters of the local coordinate system are calculated as unknowns. Disadvantages of this technique are that every map has to be transformed individually and that no reference is made to boundary information. Thus, the problem still exists of joining individual maps together. It is extremely common that this technique results in dramatic boundary fitting problems (discrepancies and overlap). The reasons for this are extrapolation effects.

Similar to the classical transformation, the interconnected transformation technique also calculates the transformation parameters of the local coordinate system as unknowns. However, it also includes the coordinates of the interconnection points as unknowns. By utilising maps boundary points as interconnection points, it must be stressed that significantly fewer fixed points are required for connection between neighbouring maps. In fact, it is not even necessary for fixed points to be present in all maps. This is a major advantage of the technique. Because the interconnected transformation technique introduces boundary data directly into the adjustment in the first step, it eliminates the associated boundary connection/fitting problems that occur when using the classical technique. This aspect makes results of this technique cheaper as it is less time consuming to process the adjustment result. And also better because the adjustment technique has the ability to detect and eliminate blunders. For example, misidentification of identical points can be detected easily through the use of normalised residuals. Therefore, it can be eliminated or corrected to improve the adjustment result.

It must be heeded that the result of the interconnected transformation and the following detail digitisation is not ultimate. The accuracy of the resulting coordinates reflects just the accuracy of the processed maps. In many cases it will be necessary to improve the accuracy by introduction of new coordinates or observations.

But it has to take care that at the introduction of new, more accurate information, the geometrical neighbourhood relationships will not violated. A neighbourhood fitting procedure can preserve the geometrical neighbourhood relationships. For such procedure exist several approaches, but in any case it will be necessary, to map this process in the data model of the applied GIS. Prerequisite for that is a strict separation of topological and geometrical information in the data model of the GIS.

2. SITUATION IN THE FEDERAL COUNTRY BRANDENBURG

The surveying departments of the federal countries of Germany are responsible for the establishment and maintenance of the automated cadastral map (German abbreviation: ALK). The ALK constitutes the information system of geographical basic data in Germany.

In the federal country Brandenburg it is the intention of the surveying administration to establish the ALK all over the country by the year 2006. To reach this target it is necessary, to digitise about 11700 cadastral maps. These maps are in the most cases isolated maps without fixed frame. The scale factors of the maps cover a range from 1:500 to 1:7000. Accuracy and actuality are very heterogeneous.

A special problem of the digitisation in Brandenburg is the geo-referencing of the maps. The problem results from the collectivization of agriculture in the 1960'es. In that time many of the existing landmarks were removed to be able to machine wide fields. Therefore the legal situation, documented in the cadastral maps, is irreproducible on site. That effects in massive problems at the location and measuring of fixed-points for the geo-referencing.

The Working Committee of the Surveying Authorities of the States of the Federal Republic of Germany (AdV) recommend in its guidelines for the ALK establishment to geo-reference maps by a 6-parameter-transformation using at least 6 fixed-points for each map. To realise this technology would mean to locate and measure at least 70200 fixed-points. The coast estimation of the Brandenburg surveying administration assume costs of 300…500 DM per fixed-point. The cumulative costs would be 21…35 million DM only for locating and measuring of fixed-points, a serious argument to look for alternative technologies.

3. PRINCIPLE OF INTERCONNECTED TRANSFORMATION

An alternative to the classical method is the interconnected transformation. This approach uses the information about point identities at the map boundaries. It assembles the maps like a puzzle and needs just some points to reference a whole block of maps in the global reference frame. According to the cost estimation, by using the interconnected transformation approach, the costs for the location of fixed-points could be reduced to 7 million DM.
Table 1 shows the comparison between the classical and the interconnected transformation approach. The difference consists in extension of the set of unknowns. In addition to the

transformation parameters X_0, Y_0, a, o, the coordinates of the interconnection points will be introduced as unknowns. This approach leads to a non-linear adjustment problem.

Table 1: Comparison between the approaches

	Classic	Interconnected
Observations	x_i, y_i	x_i, y_i
Target Function	$\sum_{i=1}^{n_p} v_{x_i}^2 + v_{y_i}^2 \overset{!}{=} \min$	$\sum_{i=1}^{n_p} v_{x_i}^2 + v_{y_i}^2 \overset{!}{=} \min$
Unknowns	X_0, Y_0, a, o	X_0, Y_0, a, o, X_i, Y_i

One question was if a 4-, 5- or 6-parameter-transformation should be applied. In earlier diploma thesis (Beckert 1996) this problem were inquired, with the outcome, that a 5-parameter-approach delivers the best results. The set of unknowns contains in this case the values $X_0, Y_0, a, o, \Delta m, X_i, Y_i$.

4. IMPLEMENTATION

The Workflow of geo-referencing consists in the following steps:

- Digitisation of map boundaries
- Detecting of point identities
- Free adjustment for analyse
- Stepwise blunder detection
- Introduction of a minimum number of fixed-points
- Densification of fixed-points

The result contains not only the transformation parameters of each map but also adjusted coordinates of the map boundary points with their standard deviations. That means that the interconnected transformation unifies the work steps transformation and boundary fitting, which are separate in the classic approach, to a single one. The fact, that all map boundaries are fixed allows a division of work with respect to the digitisation of the map contents and the object generation. Each map can be digitised isolated and it is guaranteed, that it fits to its neighbours.

4.1 Modelling of Identity Information

A special problem is the modelling of identity information. In principle two options exist to do this. The first and common one is the logical modelling. The identity between two digitised points will be mapped by giving them the same point identifier. But this method leads then to problems if identity errors occur. In such a case it is necessary, to decouple the points and to give them unique identifiers again.

A better solution is the functional modelling of identity information. At this approach both digitised points keep their identifiers but they will be connected by an identity observation. Such identity observation can be realised by two coordinate difference observations.

$$v_{\Delta X} = X_k - X_i$$
$$v_{\Delta Y} = Y_k - Y_i$$

(1)

The standard deviations can be calculated by error propagation.

$$\sigma^2_{\Delta X} = \sigma^2_{X_i} + \sigma^2_{X_k}$$
$$\sigma^2_{\Delta Y} = \sigma^2_{Y_i} + \sigma^2_{Y_k}$$
$$\sigma_{X_i} ... \sigma_{Y_k} \approx 0$$

(2)

Another benefit is the much easier detection of identity errors.

4.2 Naming Convention for Boundary Points

Before starting the digitisation of map boundaries it was necessary to define a naming convention for the digitised points. The convention should follow general rules of data management as there are:

- Each object has a unique identifier
- The identifier is independent of the object attributes
- Already existing naming conventions should be used

That means, that the point identifier had to be unique all over the country. It should especially be independent of the point coordinates (no kilometre squares as prefix).

In Germany each parcel has a country wide unique identifier. It consist of identifiers of the administrative organisation structures “Bundesland” (federal country), “Kreis” (district), “Gemarkung”, “Flur” and “Flurstück” (parcel). A cadastral map contains always the area of one organisation structure of the type “Flur”, so that it is possible, to identify each map by the “Flur”-identifier.

The point identifier consist furthermore the number of the drawing at the map, because a map can consist, next to the primary drawing, several secondary drawings and an ongoing point number.

Example of a point identifier:

3160 007 00 023

- ongoing point number
- number of secondary drawing
- “Flur”-identifier
- “Gemarkung”-identifier

5. POSITIONAL ACCURACY IMPROVEMENT

One of the core problems of GIS is the question of how the geometrical information will be mapped. Considering geometrical information in general, two main classes should be considered. The first class contains the absolute geometry. Absolute means, that the position of an object is referenced to a global reference frame, in the case of a GIS to an official coordinate system. The second class contains the relative geometrical information like local coordinates, distances or angles.

Most GIS store only the first class, the absolute geometrical information. This class of information is unique and non-redundant. Relative geometrical information is only considered as a view of the absolute geometrical information. This is the classical view of the software engineer.

The view of the surveying engineer is different, however. In practical applications absolute geometrical information can not be observed directly, it is rather derived from relative observations. These observations are in general redundant and will contain contradictions. The contradictions in the observations are an expression of their stochastic properties. The task of the surveying engineer is to derive non-redundant and compatible absolute geometrical information from the observations. The tools used to achieve this are geodetic adjustment techniques. The result from the operation *adjustment calculation* is unique but not reversible. From a geodetic point of view absolute geometrical information is just a view at the relative geometrical information, the observations.

The difference between the classical software engineering view and the geodetic view with respect to geometrical information is fundamental. It is the task of geodetic science to overcome this shortcoming of the software engineering view. A prerequisite for the solving of this task is the integration of geodetic adjustment techniques into databases as operators to create views on the original observation data.

In the sense of this paradigm, each positional accuracy improvement (PAI) update is nothing else than the generation of a new view of the original observation data. The view generation is done by a long transaction - the adjustment calculation. Because of the fact that the adjustment calculation is too complex to be done "on the fly", it is necessary to keep its result

- the new view - persistent in the database. In the initial stage, observations are mainly local digitized coordinates, point identities and global coordinates of control points. The list of observations can, however, be arbitrarily extended by new observations such as GPS based coordinates or total station measurements. During the adjustment calculation all relative geometrical relationships will be updated, so that the resulting absolute geometry is consistent again.

A prerequisite for the realization of this strategy is the existence of a topological layer with unique point identifiers in the data model of the related GIS. Furthermore long transactions have to be supported by the database system. Figure 1 shows the principle.

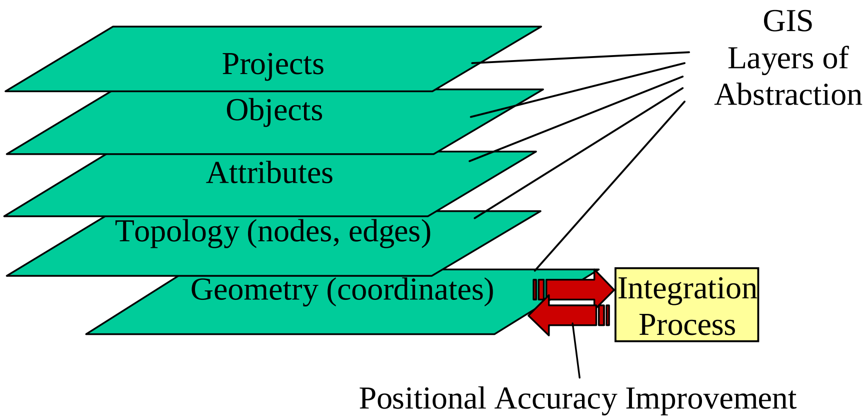

Figure 1: Long database transaction whiles the neighbourhood fitting process.

6. CONCLUSION

It was shown that the interconnected transformation is an efficient approach to geo-reference a large number of maps simultaneously. The problems having to be solved are less of a mathematical type. Much more deciding is the mapping of the whole workflow as a long transaction in a GIS-database. Necessary are system comprehensive unique object identifiers, a clear separation between the topological and the geometrical abstraction layer in the data model and the opportunity to maintain geometrical neighbourhood information in the database.

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BIOGRAPHICAL NOTES

Dr. Frank Gielsdorf, born 1960. Graduated in 1987 as Dipl.-Ing. in Surveying from Technical University of Dresden. Obtaining doctorate degree in 1997 from Technical University of Berlin. Since 1995 Assistant Professor at the Department of Geodesy and Geomatics, Technical University of Berlin.

Prof. Dr. Lothar Gruendig, born in 1944. Graduated in 1970 as Dipl.-Ing. in Surveying and obtaining doctorate degree in 1975, both from University of Stuttgart. From 1970 to 1977, work as Assistant Professor and until 1987 senior research assistant at University of Stuttgart. Scientist at Scientific Center of IBM in Heidelberg on data bases 1984-1982 and guest scientist at Calgary University for 4 months in 1983. Since 1988 Professor of Geodesy and Adjustment Techniques at the Department of Geodesy and Geomatics, Technical University of Berlin.

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