Measurement-Based Gis Revisited

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1. INTRODUCTION

The first Geographic Information Systems (GIS) developed in the early 1960s (Coppock and Rhind, 1991). Since then large improvements have been achieved, both in designing and in understanding the system. Today GIS has become a widely used tool and often it is so well-hidden that people do not even know they are querying a GIS.

The most expensive part of a GIS is acquisition and maintenance data. As a rough guideline the costs for hardware, software, and data are in the proportion 1:10:100 (Frank, 1995). A common strategy for data capture is, therefore generating data once and later tracking of changes only.

Data are usually based on observations, which are then processed. In most cases the original observations are not stored. Especially when dealing with ground surveys our data sets have been developed over a long time. In some countries surveys for cadastral data sets, for example, started 200 years ago. The quality of the measurement equipment has improved dramatically since then. Therefore, we detect tensions in the geodetic networks if we try to integrate modern measurements. This leads to the problem that adding new measurements to data sets from ground surveys do not improve the quality of the data set if we store the coordinates only. A transformation is necessary to fit the results of the new measurements into the old data set, resulting in a loss of quality. We therefore reduce the quality of the new measurements to the level of the data set.

In the late 1980s several authors started a discussion about systems that store the measurements themselves and not the derived data like coordinates. These ideas led to measurement based systems (Buyong and Frank 1989; Buyong, Kuhn et al. 1991). Goodchild and others are still working on the topic (Hintz, Wahl et al. 1996; Goodchild 1999). Unfortunately we still do not have a working system. One of the problems is suitable software solutions. According to Joffe (2003) the search for software is over and the ArcGIS extension Survey Analyst is exactly what we need:

With ArcGIS Survey Analyst, the quest is over: these tools are now available to surveyors and GIS analysts alike. As a result, a government agency's GIS map base can now be built as a measurement-based multipurpose cadastre, and existing GIS map bases can gradually be transformed into this much desired data model. (Joffe 2003)

The intention of this paper is a brief review of this statement. We took a small conventional (coordinates stored only) data set and computed measurement data for the data set. We then used these measurements to feed our GIS. The question is, if modern computers can handle this amount of data in reasonable speed. Unfortunately the results were not completely as expected.

2. MEASUREMENT-BASED GIS

Data are based on observations. Usually observations are distorted by errors produced by the observation method. These errors cause inconsistencies in our data set. Different observations will yield different coordinates for the same points. Thus a general method to deal with observation errors is necessary. The assumption that the distribution of these errors follows the Gaussian distribution leads to the method of least square errors (Niemeier 2002). The method of least square errors consists of a functional model and a statistical model. The functional model defines the connection between the observations and the unknown parameters. The statistical model describes the errors of the observation. The result of the functional model is adjusted values for the observations and the unknown parameters. The result of the statistical model is a variance-covariance-matrix of the unknown parameters. Usually only the results of the functional model are stored for a data set because the variance-covariance-matrix is too large to be stored for most data sets. Therefore, there are no values available for the errors of coordinates.

A measurement-based GIS suggests storing the original measurements instead of derived data like coordinates. Error estimations for measurements require less space than for coordinates because variance information depends on the equipment used and covariance can be modeled using correlation. Thus quality improves if we add new measurements to a measurement-based system. Measurements of low quality can be checked by measurements of higher quality. The more measurements with high quality are added to the system the higher the overall quality gets.

In some cases coordinates are necessary. Customers may need coordinates or plots must be prepared in a national reference frame. An adjustment of all observations provides a coordinate data set. Additional observations are included by local adjustments (Buyong and Kuhn 1992).

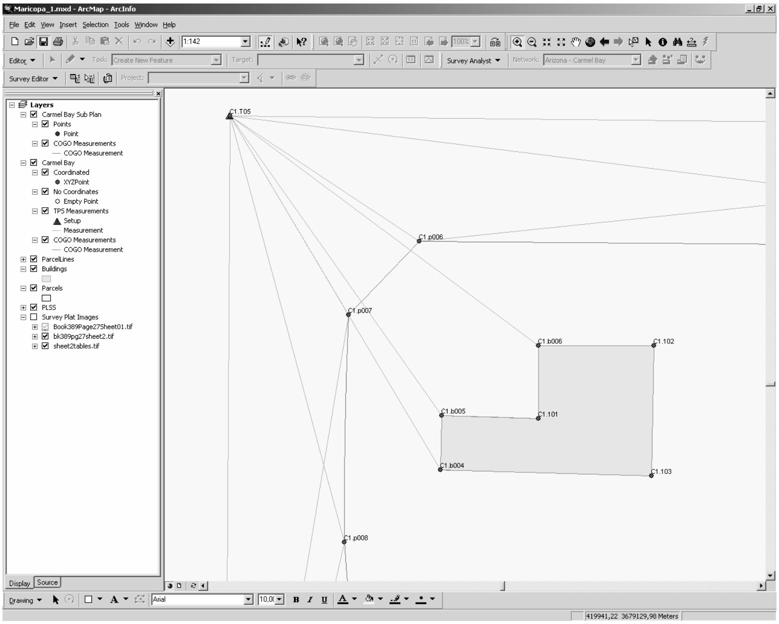

Figure 1: Including measurements in a GIS with ArcGIS Survey Analyst

Recently ESRI released the ArcGIS extension survey analyst, a tool to integrate measurements in a GIS. The extension consists of a set of tools for importing measurements and for defining the functional model between the measurements and the coordinates. Figure 1 shows an example from the tutorial provided with ArcGIS.

3. TEST SCENARIO

The test data set is the administrative unit “Ebergassing” of the Austrian cadastre as shown in Figure 2. The size of the area is approximately 7 km^2. The lines visible are the parcel boundaries.

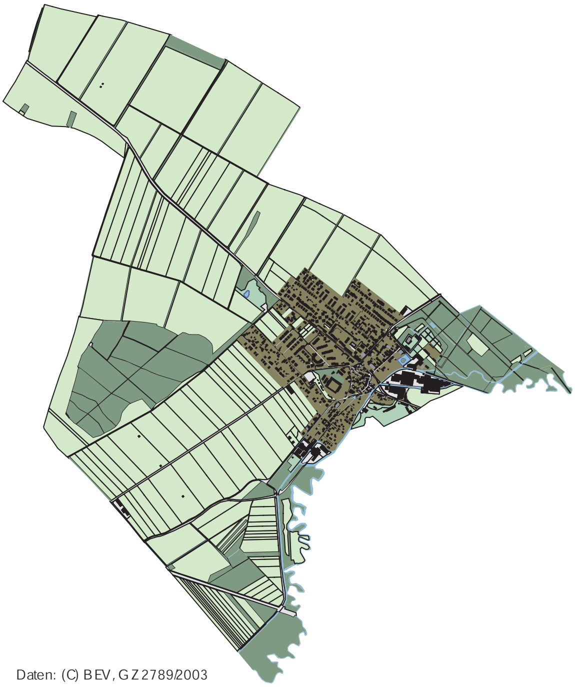

Figure 2: The test data set Ebergassing

Since the Austrian cadastre is coordinate-based there is no set of measurements available. Thus measurements need to be reciprocally derived from the coordinate based data set for testing purposes. This requires knowledge of measurement techniques. Starting with control points surveyors use traverses to define the coordinates of the stations points. From these points they take directions and distances to measure the parcel boundaries. Detailed descriptions can be found in books on surveying (Hartner, Wastler et al. 1910; Jordan, Reinhertz et al. 1931). Since the test data set includes approximately 10.000 bounding points an automatic method for the computation of measurements was necessary. We used a method consisting of three steps:

- digitizing stations (870) by hand,
- computing measurements for each station to the four nearest other stations, and
- computing measurements from each boundary point to the nearest two stations.

This method provides a highly redundant network of measurements defining the boundary points. Unfortunately, it still leaves room for geometries that cannot be solved. Careful revision of the produced data must guarantee that the set of measurement data is error-free. Otherwise the adjustment process will fail because there is no unique solution.

The network of stations consisted of 870 points and approximately 3500 distance observation and the equal number of direction observations. An adjustment of the stations only has 2610 unknown parameters (1740 coordinates and 870 orientations). The adjustment of this network was done with geodetic software Geosi from IDC EDV GmbH in Imst (http://www.geosi.at) and took 36 hours on a 2.4 GHz computer with 1GB main memory and Windows 2000.

We used Microsoft "Access" as a database. Although "Access" can handle the data the response times are slow. However, the main problem of a measurement-based GIS is not the performance of the database. Periodical global adjustments are necessary (Buyong 1992, p. 118 - 119). The test with commercial geodetic software took 36 hours to adjust the measurements for the stations only. A measurement-based GIS must include the measurements to the boundary points raising the number of observations to 47.000 and the number of unknown parameters to 22.000. Current desktop computers cannot handle this amount of data with acceptable speed.

4. RESULTS OF THE TESTS

Importing the measurements into the GIS is simple. Import procedures and formats are well-defined and interoperable. Microsoft "Access" is capable of storing the measurements despite the limitations of the database in speed as well as in amount of data. More sophisticated databases provide faster access but access time is not a problem while testing.

Experiments with small areas showed, that the main functionality is available. It is possible to adjust measurements and to attach boundaries to points. It is also possible to add new measurements and readjust the surrounding points. However, some important functions are missing. Since ArcGIS-functionality is fully accessible for programmers using ArcObjects (Burke 2003) it should be possible to add these functions. The general problem areas were:

- Definition of adjustment: The tools provided do not support adding point ranges to an adjustment.
- Control of adjustment: The user gets no response if the adjustment has no solution.
- Additional measurements require local adjustment. Additional measurements add information to a specified region defined by the geometry of the network. This region must be determined automatically for practical use of a measurement based system. Such a function is not yet implemented.
- Corrections for the observations are the only method available for detection of blunders. Buyong proposes the use of robust estimation for blunder detection. Unfortunately, Survey Analyst does not provide robust estimation methods.

The first three problem areas can be solved by users. The last point presents a more complex problem. Least square adjustment can model robust estimation (Schlossmacher 1973), but this requires iterative adjustments and is not suitable for a measurement-based GIS.

5. CONCLUSIONS AND FUTURE WORK

The test proved that we can build measurement-based systems. The test was performed with ESRI products but it should be possible to add measurements also to products of other companies. Other systems would require programming work to connect the measurements to the data and to provide processing capabilities. The test showed that storing measurement data in a database is simple if the necessary data structures and tools are available. We tested the Survey Analyst using Microsoft "Access" which is a simple database with limited storage capacity. We assume that Survey Analyst will perform equally well or better with other, more sophisticated database systems such as Oracle, Microsoft SQL server, dBase, mySQL, etc.

Adjustments of small parts of the data set proved that the concept of measurement-based GIS is applicable. The tested system allows connecting the boundary points to the measurements. The system stores information on the accuracy of the coordinates with each boundary point and thus allows the computation of accuracy for derived spatial features like areas or distances.

Unfortunately current computer systems cannot deal with the amount of data in a global adjustment. Local adjustments can keep the data consistent for some time but periodically global adjustments are necessary. Current desktop computers cannot deal with the amount of data necessary for a measurement-based GIS. Although the test area is rather small (7 km^2) the computer cannot provide the results of a global adjustment in reasonable time.

In principle, the Survey Analyst is a big step towards the implementation of measurement-based GIS. Unfortunately, computers are still not fast enough to manage large measurement-based systems. For small areas, like constructions sites or archeological excavations, however, the tool can provide valuable support.

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