XVI Congress of International Society for
Photogrammetry and Remote Sensing
Kyoto 1988

Commission III

ERROR PROPAGATION IN DIGITAL MAPS

Ole Jacobi

Institute of Surveying and Photogrammetry
Technical University of Denmark
DK-2800 Lyngby, DENMARK

Abstract:

In the process of revising and updating digital maps, the difference between old data and new data will introduce errors in the database. These errors will accumulate, and if they are disregarded, the accumulation will sooner or later mean a deterioration of the geometrical quality of the database. In theory, the error propagation can be avoided if observations are stored, and the revised digital map is compilated through an adjustment by least squares method. In the paper, methods for a practical revision of digital maps are discussed .

Introduction

The transition from traditional graphical maps to digital maps stored in Geographical Databases is not an economic transaction for the simple reason that maps produced by digital means are usally more expensive than traditional graphical maps.

The benefits of using digital maps are expected to be a much quicker and easier updating of the maps. In the future, all changes in the field will be incorporated in the database as soon as the changes are measured. When a map of the area is required, an extraction of the database is made, and an up-to-date map with all the new features can be drawn automatically. By producing the maps one at a time when needed, it should be possible always to have updated maps.

The old methods of map production meant large issues of maps printed and sold over a period of many years. Revising a map is a time-consuming and expensive task taking up a great amount of resources if the interval between revisions is to be reasonably short.

The allocation of resources is not the only problem concerned with traditional map revision. If revisions are done frequently, errors will accumulate in the map, and after a certain point, the errors will be so great, that a new map based on new measurements must be made.

In this respect, there will be no change with the new digital maps. The digital map is stored in the database as coordinates to points and not as observations, therefore it is not possible to make a correct updating in accordance with the theory of errors.

To give an example, the value of a digital map can be reduced very quickly when the stations of a geodetic framework are given new coordinates. If the digital map is based on the old coordinates, and all new measurements are based on the new coordinates, the resulting discrepancy in the map can be unacceptable. This is not a theoretical example. In Denmark, the Geodetic Institute is recalculating the whole framework of 30,000 points, and many errors of 30 to 50 centimetres have been found. Alle the digital maps are based on the old coordinates, but from now on all new measurements will be made from the new coordinates.

Map revision can be looked on from a viewpoint of error theory. The prerequisite for a correct theoretical solution is very difficult to achieve in a geographical database. A more practical approach that may work in existing geographical databases will be discussed.

Least Square Adjustment

A digital map is based on observations. The observations are made up of measurements of angles and distances, photogrammetric picture-coordinates or photogrammetric model-coordinates, or, when an existing map is digitized, they may be table-coordinates from a digitizing table.

We give each observation a weight that describes the accuracy of the observation in relation to all other observations.

Observation also includes all editing of the digital map that is carried out at a graphical workstation. If two points are brought together, it may be described as a distance measurement d=0 between the two points, and if this observation is heavily weighted, the two points are brought close together. If a text is put on the map, the placement of the text is given as distance and angle from the object named.

To fall within the theory of errors, all observations must undergo one Least Square Adjustment to compute the coordinates to the points in the digital map. This adjustment must include the aerotriangulation, the absolute orientation of every photogrammetric model, the triangulation and travers framework for the geodetic measurements etc. Only a total adjustment can ensure that all direct and indirect relations between the points in the database are treated correctly.

Whenever new measurements are made, or the system of reference of the geodetic framework is redefined, the whole least square adjustment with all new and old measurements must be repeated.

By this method, the geometrical quality of geograhical databases as a whole will improve, and as redundancy increases, gross errors may be located and removed from the database.

This metod is used by the Geodetic Institute of Denmark to recompute the Danish reference system. It is not possible to compute all 30,000 points in one least square adjustment, and the framework is therefore divided in subunits.

Practical adaption

As an example, we will look at how mesasurements and computation for a geographical database are made by photogrammetry. An aerotriangulation is made based on points in a geodetic reference system, and photogrammetric controlpoints are computed by a least square adjustment. In this adjustment, the geodetic reference points are kept fixed and the computations are based on photogrammetric observations. The next step is the absolute orientation of the photogrammetric models. In the modern analytical plotters, this process is also carried out by a least square adjustment based on the controlpoints. In the analytical plotter points describing all the geographical objects are measured.

The next step is carried out at a graphical workstation. Discrepancy of measurements in different photogrammetric models are removed, names and text are added and geometrical shapes are idealized.

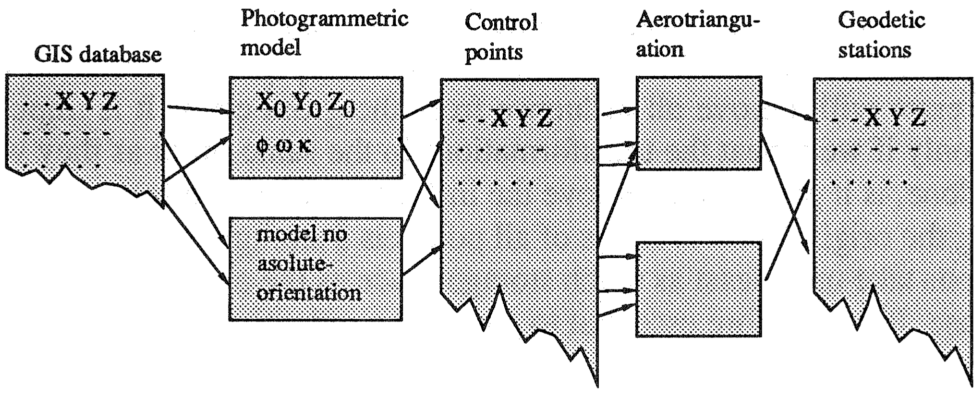
The adjustment processes leading to the digital map can be compared to the methods used before computers were common to adjust geodetic frameworks. The framework was divided into orders, with a primary framework that was measured and adjusted in one step, and a secondary framework based upon the primary points that were measured and adjusted in the next step etc. down to 6th or 7th order.

Taking into consideration the many points in digital mapping and the limited computer power available, it is not a practical solution to include all least square adjustments into one very big adjustment. At this point, we have to abandon the theory and find a solution that can be based on the method of different least square adjustments in orders.

To obtain this, the provenance of each point must be stored in such a way that it is possible to recover:

-how the point was measured (by photogrammetry or by geodesy)
-in which photogrammetric model the point was measured (or from which geodetic station)
- the name and the coordinates of the controlpoints that made up the basis of the least square adjustment providing the absolute orientation of the photogrammetric model
-the aerotriangulation from which the coordinates of the control point were computed
-the coordinates of the geodetic stations that made up the basis of the aerotriangulation.

If this information is stored, we can recompute every point in the database with new observations or altered controlpoints.



Code of origin

A practical solution is to give every point in the database a code of origin. This can be a pointer to the provenance of the point indicating where the necessary information about the transformations that have led to the current coordinates of the point are to be found.

Every time the coordinates to the point are changed, whether as a result of a general map revision or in connection with a local editing of the database, the code of origin must point to a location where the information about the transformation is kept.

Some of this information will be kept by the producer of the map and will only be required if an extensive revision has to take place. This may be so in the case of aerotriangulation. Other kinds of information, as for instance from which photogrammetric model a point was measured, must be kept close to the geographical database as it is necessary whenever new measurements are introduced to the database.

The code of origin can be very helpful in the estimation of errors in the geographical database. The errors are not only a function of the original measurement, they are also a function of the transformations that the point has taken part in. If the transformations are made by least square adjustments, the standard deviation and the residuals from the adjustments are important information that must be accessible to the user of the map at any time.

A special case arises, when a gross error in the geographical database is found, and you want to find the person or the organisation that is responsible for the error. If there is no code of origin recording the provenance of the point, no one can locate where the error may have been made, and no one will take responsibility.

Recalculation

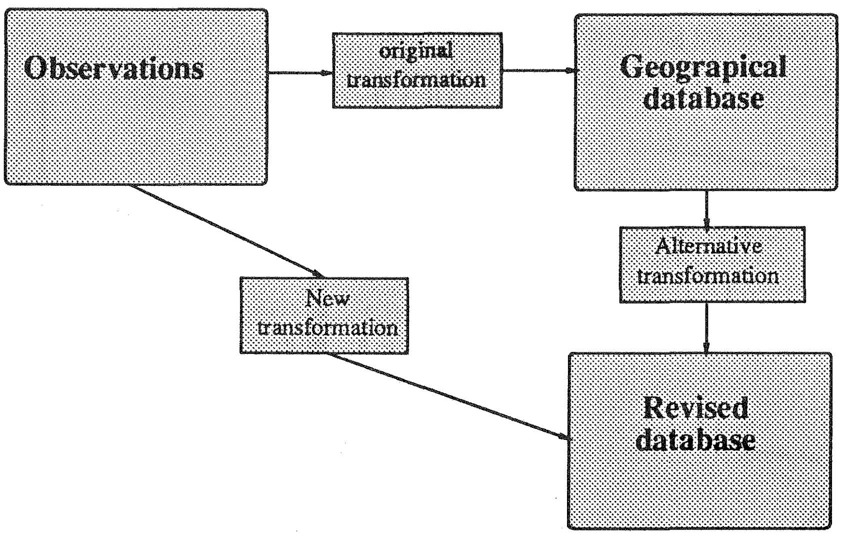
If a satisfactory code of origin is available, pointing to all the data that have been used to produce the geographical database, recalculations based on new reference points or new measurements can be done at any time. If a gross error was incorporated in a former calculation distorting the database, a new calculation without the gross error will remove all influence from the gross error. It is important to note that only if we repeat the transformations in the same order as they were originally done, is it possible to remove the influence of gross errors.

Keeping the original observations of all points is a storage consuming task. The observations take up at least as much storage space as the points in the geographical database. It is therefore essential to consider a reduction of the data that need to be stored.

The observations necessary for the aerotriangulation or for the adjustment of the triangulation or traverse are normally limited in size. The benefits of keeping these observations are great compared to the space they take up, so there is no point in reducing these data.

The bulk of the database are the points describing the terrain and the objects in the digital map. The observations leading to the coordinates of these points are made up of picture coordinates if the measurements are carried out by photogrammetry, angles and distances if the measurements are made by geodetic means.

If we consider the photogrammetric observations as model coordinates in the photogrammetric model, a simplification is possible as the following will show. The transformation from photogrammetric model coordinates to the reference system in which the geographical database is defined is made by a three-dimensional least square adjustment including a scale factor, the so-called Helmert-transformation. With this transformation it is possible to make a correct new least square transformation based upon transformed coordinates. We do not need the original photogrammetric model coordinates for all the points in the model. Only the original model coordinates to the controlpoints that were part of the absolute orientation must be stored. A new absolute orientation based on the transformed coordinates taken from the geographical database will give the same results as the original photogrammetric model coordinates. This will reduce the need for storage capacity.



The same method may be used for measurements made by polar methods in the field. The observations on which the triangulation- or traverse- framework are based must be stored. From these data it is possible to make a new adjustment of the framework and get new coordinates to the stations in which the polar measurements are made. But we need not store the observations to every point if we consider all points measured from one station as a fixed group of points that is transformed by a plane transformation with or without scale factor to the reference system of the geographical database. We only need to know to which polar station each point belongs. If new coordinates to the geodetic reference system are introduced, the triangular framework can be readjusted, and new coordinates for the stations of the polar measurements will be calculated. With these new coordinates the points belonging to one station of the polar measurements can be transformed by a least square plane transformation as a group.

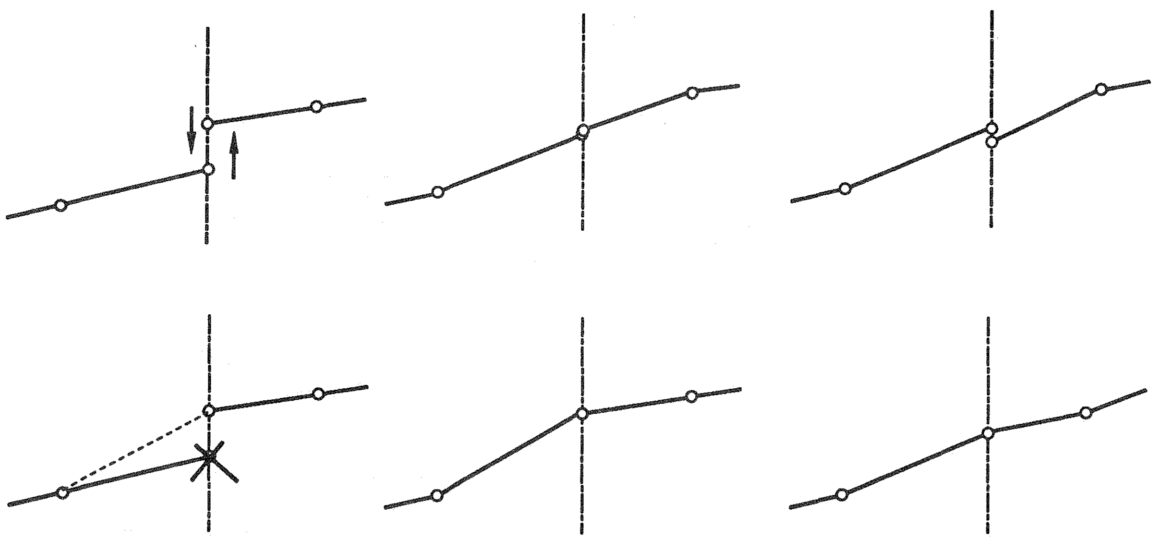
Editing

Photogrammetric and geodetic measurements are not the only sources of data in geographical databases. The measurements are edited in a graphical work station and alphanumerical information is put into the database and connected to graphical objects.

Graphical editing is used to remove small errors in the closure of objects crossing the border between to photogrammetric models. Objects are given a geometrical ideal shape, the squaring of the corners in houses, parallel lines in roads etc.

Quite a lot of manual work is involved in the editing process, and it is unrealistic to think that updating of a database can be followed by a manual reediting.

It is possible to select an editing method that is independent of small movements of the involved points. At this moment, we have not studied alle editing features and it is only possible to give some examples:



Photogrammetric measurement | after editing | after recalculation of models

If a line crosses from one photogrammetric model into another, the lines may not meet, either because of errors in the absolute orientation af the models or because of measuring errors in the points on the line. If this problem is solved by moving the point on the border from one model to fall on top of the point from the other model, a gap will reappear in a revised map, if all the points in one model are moved in relation to the points in the other model. If the editing were to be done by removing the point on the border in one model, and make a line connect the next point in the model with the border point in the other model, a revised map would show no gap when the points are moved.

A solution based on a sounder theoretical basis would be to incorporate points on the boundary between models as tie points in the aerotriangulation.

Another example is the way a text is placed on the map. If a text is given a position on the map by coordinates, the text will not be moved when the lines and points surrounding the text are moved. If the position of a text is described relatively to the object that is connected with the text, the text will move according to the object.

Squaring houses is not necessary if all points of the house belong to the same photogrammetric model, as a plane transformation with a scale adjustment does not change the house. Only when part of the house belongs to one model and part to another model will it be necessary to recompute the squaring algorithms.

It seems to be possible to find editing procedures that will solve most tasks in such a way that there is no need for re-editing. In cases where editing can't be avoided, like the example of the divided house, automatic editing procedures will be needed.

New measurements in an existing database

Photogrammetric measurements from new photographs should be incorporated in the geographical database by a new least square adjustment of a framework consisting of the combined observations in the former and a new aerotriangulation. Tiepoints between the old and the new aerotriangulation would be points from the old database, that can be identified and remeasured in the new photographs. With new coordinates to all controlpoints, absolute orientation of all models can be computed, and a transformation of the existing points in the database can be done so a minimum of discrepancy between new and old measurements will arise.

If the new measurements are carried out by polar measurements with a total station, a framework including aerotriangulation and theodolite measurements should be computed in a combined adjustment.

Experiments must be made to show, whether these solutions are usable or whether shortcuts should be developed.

Conclusion.

The problems of map revision are becoming an important subject in the transition to digital maps. Great resources are spent on this revision, and an assurance that these expensive data will be usable in the future is badly wanted.

As the existing commercial Geographical Information Systems have no features assuring an error propagation free updating, it is important that the necessary data for future map revisions are stored, and that a code of origin can locate these data.

If the information about the photogrammetrical models, the control points, the aerotriangulation and the geodetic stations is lost, there is no way of updating a digital map.

If, on the other hand, the necessary information is stored, a revised database can be established when needed. Even if no programs for the map revision are available, a recalculation with existing software and some manual work is possible.