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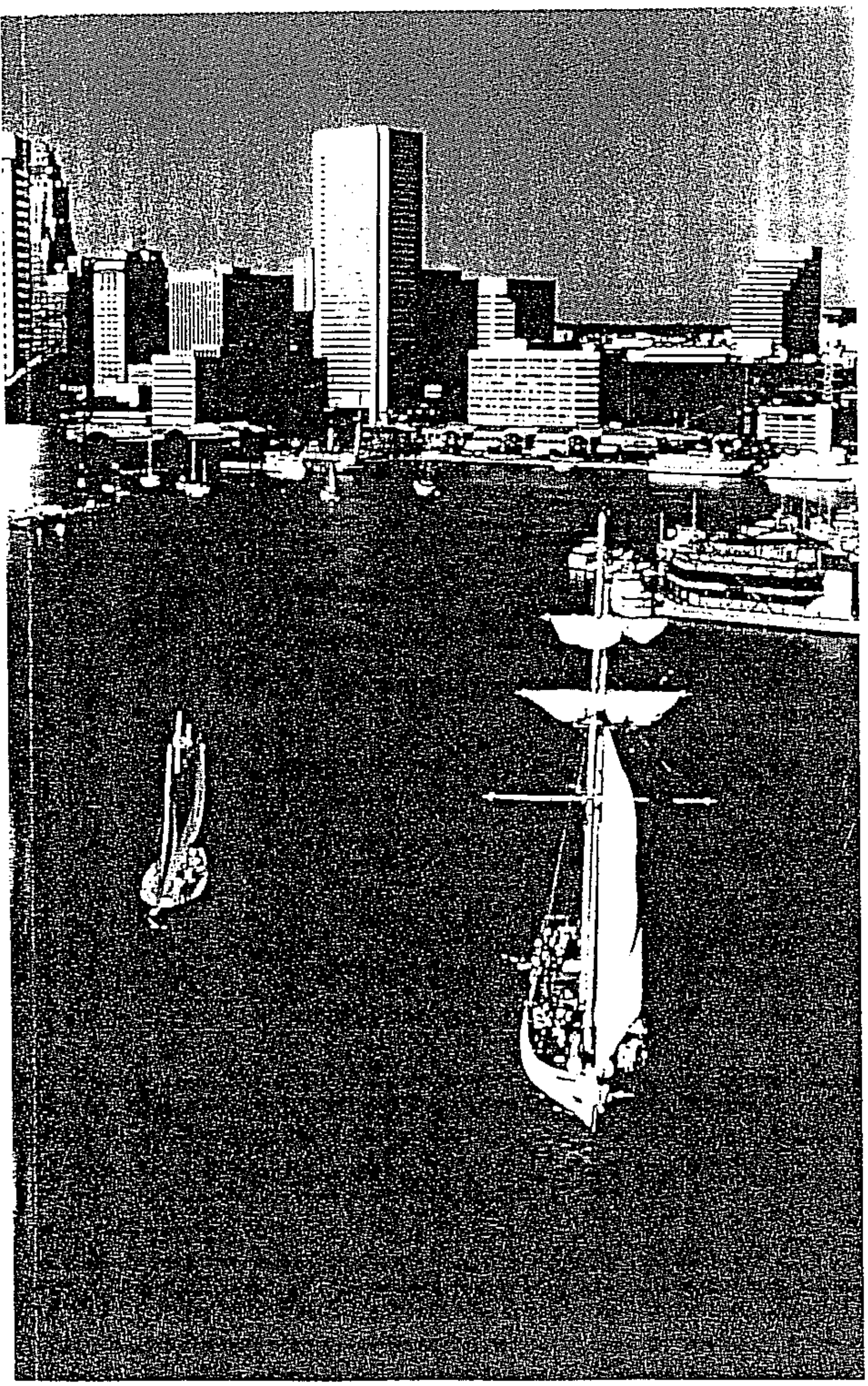

MEASUREMENT-BASED MULTIPURPOSE CADASTRE

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ABSTRACT

Many local level governments have taken significant steps towards implementing a multipurpose cadastre. Most of them follow the National Research Council study which recommends starting a multipurpose cadastral system with a good network of geodetic control points. This approach however, has several major problems. The establishment of geodetic network is very costly and time consuming and often can not be provided by local level governments. We propose a multipurpose cadastral system based on measurements where the implementation does not require the immediate completion of a geodetic control network. The measurement-based system stores measurements instead of computed coordinates and, therefore, it is very easy to update. It can be implemented with a small area and expanded at a later date. This type of multipurpose cadastral system is very suitable for local level governments.

INTRODUCTION

Traditional implementations of a multipurpose cadastral system start with the establishment or improvement of a stable geodetic control network and the preparation of the base maps. All cadastral measurements collected are adjusted to refer to this control network or these base maps. The final adjusted coordinates of cadastral points are then stored in a database to be accessed later for various uses. This is in line with the recommendations of the National Research Council study [National Research Council (1980), (1983)]. Although this approach seems to be the most logical way to implement a multipurpose cadastre, it has several problems that often hinder the realization of the system.

Among the problems that hamper the implementation of the multipurpose cadastral system is the establishment of the network of control points. The creation of a good coverage of control points requires a tremendous amount of effort and capital investment [Bossler (1982), Simpson (1984), Raymond (1986)]. These requirements can not often be easily met, especially by local level governments, the institutions that are really in need of such a system. The elected local level officials, with public demand to minimize taxes and expenditures, find it very hard to put up a large investment where the benefits may not be perceptible to the public even after a number of years [Bauer (1982)]. Hintz et.al. (1988) mentioned several other problems related to the traditional implementation of multipurpose cadastre such as integrating new measurements, datum change and blunder detection.

The measurement-based multipurpose cadastral system does not have those shortcomings. It does not need prior establishment of the geodetic control network, but rather builds it as the multipurpose cadastral system is being built. It therefore does not need the huge up-front capital investment needed to establish the network of control points. The benefits of having the system can be realized much faster because there is no need to wait for the completion of the control network before the system can be fully implemented.

A proof-of-concept implementation has been built at the Department of Surveying Engineering, University of Maine. The system has been tested with the idea of implementing a multipurpose cadastral system without prior completion of the network of control points. Due to unavailability of real data, the implementation was tested using simulated data only.

CONCEPTS OF MEASUREMENT-BASED SYSTEM

The measurement-based multipurpose cadastral system has two important concepts: (1) storage of measurements, and (2) computation of coordinates, as they are used. This is in contrast to the traditional concept for a multipurpose cadastral system where the measurements are used outside of the system to compute the coordinate values for all points of interest and only the coordinates are entered into the system. The measurements are not stored in the system and are not available for use in later computations. The next section will explain some technical aspects of the measurement-based multipurpose cadastral system and a later section will explain the major advantages of such a system.

Storage of Measurements

The measurement-based multipurpose cadastre stores measurements only. Two categories of stored measurements are distinguished: (1) real ground measurements, and (2) derived measurements. The standard deviations of all these measurements are also stored to reflect their degrees of uncertainty.

The real ground measurements consist of all the common terrestrial survey measurements, such as horizontal angles, horizontal distances, directions and azimuths. This category of measurements can either be:

- measurements among the control points
- measurements among the control and cadastral points, or
- measurements among the cadastral points

Ground measurements among the control points (presumably more precise) will have smaller standard deviations than the ground measurements among the the cadastral points. This enables the specification or type of ground measurements to be expressed in terms of their standard deviations. This is an indispensable feature of the system. The measurement-based system does not differentiate, from the adjustment point of view, ground measurements observed among the control points, cadastral points, or among the control points and the cadastral points. Only the user can distinguish them and assign different standard deviations.

The derived measurements consist of values that are not directly measurable. They are obtained from some other systems. Such derived measurements can either be:

- coordinates of control points
- coordinates of cadastral points

and they are primarily necessary to fix the coordinate system in space.

The measured coordinates of the control points are derived from other measuring systems, e.g. astronomy, satellite positioning systems or photogrammetry. Initially however, they can also be scaled from a map or taken from published values, and replaced with better estimates with smaller standard deviations when they become available. This flexibility results from the method of least squares adjustment adopted, treating all points the same and not making differences between the control points and cadastral points. Like the ground measurements, only the user distinguishes between the two types of points and thus assigns different standard deviations to them. This allows the change of specification of a point from a cadastral type to control type (or control point with a low precision to a high precision) merely by changing its standard deviations.

The measured coordinates of the cadastral points can be scaled from a map or generated from the measurements, e.g. using the method described in Vonderohe & Hintz (1986).

It is not important to get accurate estimate of the cadastral point coordinates initially. The measured coordinates of the cadastral points will be improved, i.e. replaced with their adjusted values, when adjustments are performed. This will be discussed in more detail later.

Computation of Coordinates

The measurement-based system does not primarily store adjusted coordinates. Adjusted coordinates of points of any sub-area of the area in which the measurements have been stored are computed using the stored measurements when required. All the measurements, i.e. ground and derived coordinate measurements, that are within the sub-area will be used in the adjustment to determine the coordinates of the points. The computed coordinates of the cadastral points may be stored afterwards.

The computed coordinates of the cadastral points may be stored to take advantage of their better (adjusted) values. Such stored coordinates may be used for quick retrieval and display of maps. Care must be taken however, not to use such computed coordinates with their a posteriori standard deviations in later adjustments as this would constitute a multiple usage of the same measurements (i.e. using measurements with greater precision estimate than warranted) and would over time lead to an apparent increase in precision not based on effective measurement precision.

If later adjustments use coordinate values previously determined, they must use the original (low precision) standard deviations and not the updated ones. The storing of the adjusted coordinates of cadastral points without the newly computed standard deviations is done for various reasons:

- The overall precision of the system should improve only through the addition of measurements, i.e. ground measurements and coordinate measurements. The precision of the system must not be allowed to improve through repeated adjustments using the same measurements.

- Using the improved standard deviations of measured coordinates resulting from the previous adjustment, in re-adjustment, is equivalent to using the same data twice. The standard deviation of the measured coordinates, which are the standard deviations of the adjusted coordinates of the same points from the previous adjustment, are obtained using the data that might also be included in the re-adjustment.

- The re-storing of the adjusted coordinates of the cadastral points is just to solve the problem of high frequency of re-computations for applications that do not need the coordinate standard deviations. Other applications will have to re-adjust the measurements to get the standard deviations.

We propose to limit storage of computed coordinate of cadastral points to adjustments that have included at least two control points. This type of adjustment has the datum, scale, rotation and translation properly defined (by having at least two control points) and, therefore, they yield the optimum adjusted coordinates. The adjusted coordinates of cadastral points from adjustments that include only one or no control point are not stored. This type of adjustment uses the low precision measured coordinates of the cadastral points to define the datum, scale, rotation and translation.

PROOF-OF-CONCEPT IMPLEMENTATION

The two major components of a measurement-based multipurpose cadastral system are the database which allows storage and retrieval of the measurements and the adjustment program to compute the coordinates from the measurements. These components have been built at the Department of Surveying Engineering, University of Maine, and form a proof-of-concept implementation of the system. The two components are discussed below.

Measurement Database

The first requirement of a measurement-based multipurpose cadastral system is the database to store and retrieve the measurements. This proof-of-concept was implemented using the PANDA database. PANDA is an object-oriented database management system [Frank (1986)] which is available for research purposes at the Department of Surveying Engineering, University of Maine. PANDA supports retrieval of spatial data based on their location and has a pascal-programmer's interface. Geometrical objects has been implemented in the application layer in PANDA based on the theory of simplicial complex [Frank (1987) & Jackson (1989)].

Pascal routines were written for the storage of a point with its name, measured coordinates, and the standard deviation of the measured coordinates. Routines were also written to store horizontal distance and azimuth measurements between two stored points, together with their standard deviations. The routines for storing horizontal angles and directions were not yet available for this initial implementation and will be included in the next phase.

To access the stored data (horizontal distance, azimuth and coordinate measurements with their standard deviations), other routines were programmed. Measured coordinates of a point with the standard deviations are accessed by specifying the name of the point. The horizontal distance and the azimuth of a line between two points were accessed by specifying the name of the two bounding points.

Routines were also written to modify the stored measured coordinates of a point in the database. This operation is needed to replace the measured coordinates of cadastral points in the database with the improved (adjusted) values.

These routines were arranged in several modules and incorporated with lower level access modules previously provided in PANDA.

Adjustment Methodology

The second requirement of a measurement-based system is the least squares adjustment program to adjust the measurements to get the adjusted coordinates of the points. Simultaneous adjustment of the measurements with weighted parameters [Vanicek & Krakiwsky (1982) and Steeves & Penton (1985)] was adopted for this implementation.

The technique of weighted parameters in network adjustment allows all the points (control and cadastral points) to be specified as unknown parameters. The role each of the points play in the adjustment depends on the magnitude of the standard deviations attached to the coordinates of the points. From the adjustment computation point of view, the points with small standard deviations are seen as points with small uncertainty and can be taken as control points. This provides a convenient way to change the specification of a point from cadastral to control point (from the user's point of view) without any special procedures.

The technique of weighted parameters also allows the adjustment of a network to be carried out even if the network has no control points. The measured coordinates of the cadastral points and their standard deviations provides a mean for the datum, scale, translation and rotation to be defined, although with some distortion. This will also provide a way to initially start a multipurpose cadastral system even though control points are not yet available and makes possible the computation of coordinates of points of a sub-area that has no control points.

Ground and derived coordinate measurements of an area in which the adjusted coordinates are sought are retrieved from the database using the special spatial access method in PANDA and passed to the adjustment module. The adjustment module will adjust the measurements of that area and return the adjusted coordinates of all the points in that area with their standard deviations. As mentioned before, the adjusted coordinates of the cadastral points, less their standard deviations, are stored back into the database replacing their old values if the adjustment just performed contained at least two control points.

INITIAL RESULTS

Several tests were made on the initial proof-of-concept implementation with the idea of building a multipurpose cadastral system. Only simulated data were used in all the tests done so far. It is hope that real data will be used in the next phase of the project when a relatively more complete prototype system has been built.

The initial proof-of-concept system was tested with the idea of building a multipurpose cadastral network which has no initial control points. An area was first covered with a network of a few cadastral points, with ground measurements of distances and azimuths between them. The cadastral points have measured coordinates with large standard deviations. Since the initial network had no control points, the adjusted coordinates of these points had large standard deviations and, therefore, the overall system was imprecise. As more cadastral points and ground measurements were added to the area, the precision of the system improved. The precision of the system improved even more rapidly if some of the added points were control points (points with small standard deviations).

The system was also tested with the idea that the cadastral points in a network can later be redefined as control points if more precise measured coordinates of those points become available. This is simply done by modifying the measured coordinates and the standard deviations of those points, i.e. replacing them with a better value and smaller standard deviations. Implementing this idea on the above hypothesized network of cadastral points, by redefining a few of its points, produced an improvement in the precision of the system.

The above simple tests on the initial proof-of-concept system, using simulated data, demonstrate the capability of the measurement-based system in building a multipurpose cadastral system without reliance on the prior completion of a network of control points.

ADVANTAGES OF MEASUREMENT-BASED SYSTEM

The above concepts of measurement-based multipurpose cadastre have several practical advantages. These advantages are discussed below.

System Updating

The measurement-based system is very easy to update. New measurements can be added, old measurements replaced or erroneous measurements deleted easily. This is possible because every single measurement is independent of the other. Their inclusion (or deletion) in the database does not affect other data. Furthermore, by storing the measurements instead of the adjusted coordinates, no readjustment of the entire measurements in the system is necessary when updating is done. New measurements among the control points, cadastral points, and among the control points and cadastral points can all be integrated into the system without any difficulty. New measured coordinates of the control points or the upgrading of cadastral points to control points due to the availability of more precise measured coordinates, e.g. from satellite positioning system, can also be incorporated in the system easily.

The ease of updating makes data in the measurement-based multipurpose cadastre always current. Whenever coordinates of points of a sub-area are needed, they are always computed from the latest measurements available.

Incomplete Network Of Control Points

The measurement-based multipurpose cadastre can be started even though no control points are available yet. The measured coordinates of the cadastral points with their standard deviations, in some predefined coordinate system, define the constraint parameters needed for a network adjustment. Control points can later be integrated into the system either by converting some of the cadastral points to control points if more precise measured coordinates for them become available or by establishing new control points and integrating them into the system.

Implementation Can Start With Small Area

The implementation of a measurement-based system can start with a small area. It can be started with or without control points. As more ground measurements become available, (either measurements among cadastral points, among control points or among control points and cadastral points) they can be added to the system easily. The new measurements can be among already existing points or new points. If the new measurement includes new points, this will result in an increase in the area of coverage of the system.

Improvement Of Precision

Even if the system starts without the network of control points and with imprecise measurements, the system can improve its precision over time. As more measurements are added, especially ground measurements among control points and the measured coordinates of the control points, the precision of the system will improve. This is the major advantage compared to the traditional multipurpose cadastral system where new measurements are connected to previously determined points and precision deteriorates over time.

Relative Position Within Neighborhood

The relative position of points within a single neighborhood will not change even if the computed coordinates change [Baarda (1973)]. This is sufficient in a multipurpose cadastral system since decision making for a neighborhood usually depends only on the information within that neighborhood. Since the size of a neighborhood can vary, it can be expanded to cover any area of interest for a decision and may cover the whole area in the database if that is desired. The relative position of points between two neighborhood however, is not meaningful.

Small Start-up Capital

Since the measurement-based system does not need prior completion of the control network, the high cost of setting up of a control network is avoided. The ability to implement the system in a gradual manner, starting with a small area of immediate concern makes a large start-up capital unnecessary.

Quick Return On Investment

Since the measurement-based system can be started with a small area, it can be used soon after it is implemented. This avoids the long wait necessary with the coordinate-based system where the entire intended area has to be densified with control points. The benefits of having the system can be realized much faster.

The quick return on the investment also makes it more likely to gain support from the funding authority. The fact that only a relatively small start-up investment is needed to have a workable system (for a small initial area) makes it financially attractive.

Metes And Bounds Boundary System

The measurement-based multipurpose cadastral system is more in line with the metes and bounds system of boundary description. It is also more in line with the way people generally describe their parcel boundaries, i.e. in terms of measurements of their parcel bounds [Onsrud & Hintz (1989)].

DISADVANTAGE OF THE MEASUREMENT-BASED SYSTEM

The only disadvantage the measurement-based system has is the more frequent computation of coordinate values. In many cases, however, the adjusted coordinates of the cadastral points from certain adjustments are stored as the measured coordinates and high quality coordinates can be obtained by just accessing the stored measured coordinates in the database. The only minor defect is that they do not have their standard deviations, as the computed standard deviations from that adjustment are not stored. For purposes that do not need precision measure, like drawing of maps and plans for decision-making processes, these coordinates are readily available.

If however, the current upward trend of the speed of computing and the downward trend of the cost of computing can be taken as a gauge, frequent computations should be much less of a problem in the very near future.

CONCLUSIONS

It is feasible to set up a measurement-based multipurpose cadastral system based on the described architecture. Its implementation does not require the immediate completion of a control network. Initially it can be implemented within a small area of immediate concern and expanded at a later stage when needed or when budget permits. It, therefore, has a low start-up investment. The return on the investment can be realized much faster since the system can be used almost immediately after being set up. The overall precision of the system also keeps improving with the addition of more measurements. The relative position of the points within a neighborhood is guaranteed and, therefore, should not affect any decision-making processes. Most important of all, this type of multipurpose cadastral system is well suited for use by local governments such as municipalities and counties. These are the bodies that really need it, but which can not afford the high initial investment necessary for current implementations.

FUTURE WORKS

Further work is needed to improve the initial proof-of-concept system. A method for the detection of measurement blunders has to be integrated into the system. Blunder detection preferably done before the computation of coordinates [Vonderohe & Hintz (1987)].

In order to simplify the initial proof-of-concept system, the capability of storing horizontal angle and direction measurements were not included. This facility must be provided in any measurement-based system since they are a common type of cadastral measurement.

When coordinates of points are determine in piece-wise manner, i.e. by sub-network, consideration must also be given to the measurements that are neighboring the sub-network. A method for automatic inclusion of neighboring measurements for a sub-network adjustment is needed. This should be build as a separate module on top of the adjustment module. This module determines all the points and measurements that will be involved whenever an adjustment of a sub-network is requested. The points and measurements are then retrieved from the database and passed to the adjustment module.

The adjustment module needs to have certain geometric constraints built into it. The points that are measured along straight lines should remain in straight lines and points that are at right angles should stay at right angles after the adjustment. An example of points in a straight line is the edge of building, while an example of points at a right angle is the corner of a building.

A method must also be found to verify the identity of a point from one epoch to another. This is very important since measurements are made at different times and possibly over a large time span. This also includes the treatment of point displacement [Grundig et. al. (1985)].

The improved prototype system based on the above recommendations should then be tested with real data. We can only determine how the system would behave with the presence of non-random errors (gross and systematic) using real data.

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