Positional Accuracy Assessment of a Cadastral Dataset based on the Knowledge of the Process Steps used

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ABSTRACT

An approach to estimate the positional accuracy of a cadastral dataset derived from uncontrolled and unrectified aerial photography is presented. The approach is based on the knowledge of the process steps used to develop the dataset together with the related errors, with the error due to relief displacement considered the most important. A simple example of the approach using constant width buffer is shown. Further work involves investigating the generation of variable buffers and their effectiveness in geometric feature matching.

INTRODUCTION

The identification of land parcel boundaries using photogrammetric methods is considered as an alternative to ground based surveys and has been adopted in different ways by various countries at different periods of time. However, the application of photogrammetric techniques to cadastral surveys was pioneered in Switzerland (Weissmann, 1971; Gavish, 1987). The main motivation was to increase the speed of mapping and to reduce costs, particularly where a large number of boundaries had to be registered. Photogrammetric and remote sensing techniques are also used in updating of existing cadastral maps.

The minimal use of photogrammetric techniques in parcel boundary mapping is attributed to the traditional opposition of public access to aerial photographs for supposed security reasons; the fact that it is difficult to distinguish boundary features on aerial photographs and the apparent difficult to meet high precision specifications of cadastral surveying and mapping. Further, more fieldwork is required to supplement the information interpreted from aerial photographs.

The determination of positional accuracy of a dataset based on photogrammetric restitution is possible if the knowledge of the restitution process is available. But when the dataset is based on unrectified aerial photography, the determination is not straight forward. Moreover, when such a dataset is intended for integration with other datasets, the distance between common objects will be required if the geometric criteria of distance (Song, et. al., 2006) is to be used in the matching process. Usually, the distance is based on the root mean square of point features or the epsilon band for linear features. In this paper an approach to estimate the positional accuracy of a cadastral dataset based on uncontrolled and unrectified aerial photographs is presented. This is preceded by a general discussion on cadastral boundary mapping with regard to positional accuracy specifications as well as photogrammetric techniques in cadastral mapping.

LAND PARCEL BOUNDARY MAPPING AND ACCURACY SPECIFICATIONS

Cadastral maps generally show the land parcel boundaries and due to historical, cultural and social differences, cadastral maps not only do they have different contents, but also play very different roles in different jurisdictions, for example, taxation and registration (legal) purposes. Cadastral maps are not an end in themselves, but together with the cadastral register, they support land tenure systems and are valuable geo basis data, particularly if buildings are included. The identification and delineation of land parcel boundaries by either artificial or natural marks is mainly influenced by the value of land and the information needs of the cadastral system users. On the other hand, this also determines the technical requirements of the demarcation and delineation (FIG, 1995), the information of which is usually represented on maps.

The common scales for cadastral maps range from 1:500 to 1:10,000. The large scale maps usually for urban areas show more precise parcel dimensions and are often prepared by cadastral surveys for each parcel based on ground surveys or aerial photography, while the smaller scale maps for rural areas contain neither the measured nor the dimensions of the parcel boundaries but serve only as a graphical presentation of the parcel layout. In many countries, the high costs associated with large scale cadastral mapping have prohibited the mapping of all land parcels at a common large scale, resulting in the use of different scales. Although the positional accuracy depends on the scale in the case of graphical cadastral maps (i.e., the coordinates of the boundary points only represent the boundary in the graphic map but not on the ground), for numerical cadastral maps, the accuracy depends on the accuracy of the measurement made on the ground before mapping. It is therefore important that the choice of a given mapping scale is guided by accuracy specifications.

For traditional reasons, accuracy specifications for cadastral surveying have been expressed in terms of precision ratios by establishing limits of traverse linear or angular misclosure (for example, a linear misclosure of 1/20,000); in terms of error ellipses (or root mean square), in which every point position as determined on the ground from any of the control points should be within a given tolerance (for example, in Zone 1 – 0.03m, Zone 2 – 0.07m), resulting in different orders of survey. The rationale of the accuracy specification is to ensure that surveys meet the standard of accuracy.

In different countries, the standards of accuracy documented in manuals of survey instruction provide for varying “classes of surveys” or zones. The class of survey addresses issues such as the difficulty of terrain and the value of the land being surveyed and influences the expected standard of accuracy. In general mapping, the common accuracy specification for published maps as defined by (ASPRS, 1990) states that for maps on publication scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error (horizontal) by more than 0.847mm, measured on the publication scale; and 0.508mm for maps on publication scales of 1:20,000 or smaller. For vertical accuracy, for 90 percent of well defined points that are tested, the maximum allowable vertical tolerance should be one-half the contour interval. It is therefore expected that if photogrammetric techniques are used in cadastral mapping, at least these accuracy specifications are considered.

PHOTOGRAMMETRIC TECHNIQUES IN CADASTRAL MAPPING

Although initially not given much attention, for example in Gavish (1987), there is now renewed interest in the application of photogrammetric techniques not only for cadastral mapping, but also for updating of the existing cadastral maps. This is due to the development of automated photogrammetric techniques and the increase in spatial resolution of satellite imagery. Projects have been conducted to determine and exploit that potential, for example, (Vassilopoulo, 2002).

The consideration of aerial photography for particular mapping applications depends on the scale of photography. Traditionally, the positional and elevation accuracies achievable using photogrammetric methods and the scale of the final map were determined based on mapping requirements and practice. The accuracy and photo-map scale relationships mainly depend on the scale and resolution of aerial photography, the flying height, the base-height ratio and the accuracy of the stereoplotting. The choice of the photographic scales based on the mapping scale and contour interval as practiced (as a rough yardstick) by the British air survey companies is given in (Petrie, 1990).

Although scale is a concept which relates to the level of generalization of digital geographic data, it is mainly used with regard to analogue presentation of spatial information. In digital representations precision or resolution is used instead. Therefore, when capturing digital data from a scanned aerial photograph or satellite imagery, the desired ground resolution (geometric accuracy) of the details, which is independent of image and map scale, should be considered.

If photogrammetric techniques are to be used for parcel boundary mapping, the technical (accuracy) requirements of the final map should be considered. But this depends on how to best eliminate the geometric displacements and distortions. On the basis of achievable accuracy and manner of use, five approaches for photogrammetric mapping are identified by (Dale, 1979) and are illustrated in Figure 1).

The first approach entails the production of numerical coordinate data for points on the air photographs through the use of digital or analytical stereo plotters or comparators, from which the precise ground coordinates of corner beacons can be calculated or measured. This approach was used in Switzerland (Weissman, 1971) and it involved the signalization of ground marks by painting the tops of 140 mm by 140mm boundary corner stones and the determination of their grid coordinates by transforming stereo model coordinates instead of scaling them from the maps. The results of course depend on the type of camera used, the topography and the scale of photography. As an example, a mean distance error of 0.05m (for a camera with a focal length of 170mm and scale of photography 1:7,000) was obtained. This is comparable to those obtained by ground based methods. The main concern for this approach however is the lack of traverse stations to occupy when it is necessary to carry out a revision necessitated by land transactions.

The second method entails first, the preparation of base maps by photogrammetric stereo-compilation. The base maps show physical features which coincide or coexist with the legal boundaries or are used to locate points of detail that can be used as control for simple ground surveys. The cadastral maps are then compiled from a combination of photogrammetric plotting of boundary points and lines that are visible from the air with simple graphical methods of survey to locate specific land parcel boundaries. Similar to the first method, the results depend on the type of camera used, the topography and the scale of photography. This method has been used in the United States of America (Karn, 1981), Kenya and Uganda (Dale, 1979).

In the third method, instead of compiling the boundary lines and points using stereo photogrammetry, orthorectified (differentially rectified) photographs are used. Ortho-rectified photographs are photographs that have been corrected for tilts and displacement due to relief, are first produced and then the parcel boundaries are identified and scaled off the orthophotographs monoscopically, and therefore sufficient for cadastral purposes according to (Konecny, 2008). This approach has been used successfully for land registration in Palestine (Mikkonen and Corker, 2000), Australia and Canada (Dale, 1979) and is currently being considered for the renewal of cadastral maps in a number of countries (Al-Ruzouq and Dimitrova, 2006).

The fourth approach which has been used in Thailand (United Nations, 1990), Botswana, England and Wales (Dale, 1979) involves the use of simply enlarged but rectified photographs to identify land parcel boundaries. The enlargements are reproduced in the form of photomaps and used as a backdrop for graphical compilation of parcel boundary outlines. This approach however is only appropriate for relatively flat terrain for reasonably accurate measurements of distance and area.

The final approach entails the identification and plotting of land parcel boundaries using simply enlarged and unrectified photographs and has been used in Kenya to prepare the so called Preliminary Index Diagrams (PIDs), which are only approximate (Mwenda, 2001). This approach results in the lowest positional accuracy, because no due care has been expended to correct for effects due to tilt and displacement due to relief. The positional accuracy of the resultant cadastral maps by using this approach is quite variable but can be estimated if photographic information and knowledge about the terrain is available.

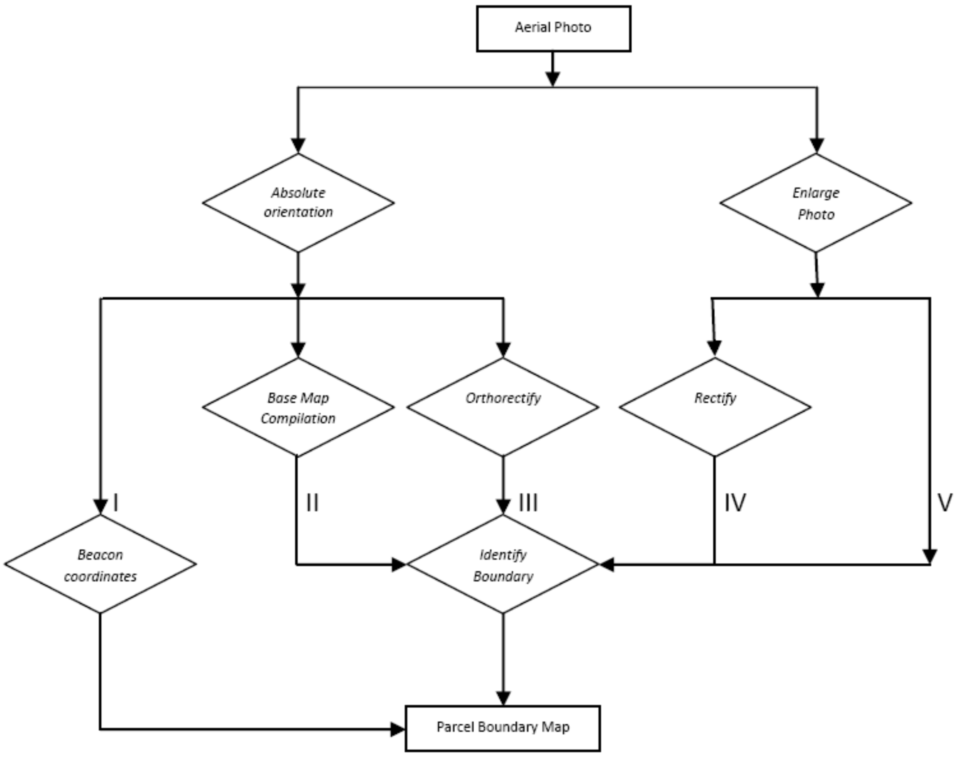

Figure 1: Photogrammetric Approaches in Land Parcel Boundary mapping.

POSITIONAL ACCURACY ASSESSMENT

The common types of errors in digital spatial data sets include positional error, attribute error, temporal error, logical inconsistency and incompleteness, of which the positional and attribute error are considered the most important (Shi and Liu, 2000). In this paper, positional errors are considered. Positional errors are brought about by field measurements, digitization and other processing and can be either systematic or random. The systematic errors can be eliminated by correctional procedures, while the random errors can be modeled by either using analytical or simulations approaches. The estimation of the accuracy of a geospatial dataset on the basis of the inherent systematic errors is considered.

The determination of positional accuracy of cadastral boundary based on unrectified and uncontrolled aerial photography is an interesting undertaking, because of the promise to model the inherent systematic errors. The positional accuracy can be estimated in three possible ways: use of an independent source of higher accuracy, for example, a larger scale map; use of internal evidence, particularly for already digitized maps such as presence of overshoots and undershoots, which are indications of inaccuracy; and finally, by computing the accuracy from the knowledge of errors introduced by different sources. In particular, if the sources combine independently, the estimation of the overall accuracy can be achieved by the summation of the squares of each independent component and taking the square root of the sum. The last approach is considered herein. Then an independent higher accuracy dataset is used as a check.

If the parcel boundary maps based on unrectified photography are digitized from maps that have been scanned and georeferenced to fit digital orthophotography or other planimetric mapping, the positional accuracy of the parcel layer can be estimated if the extent of initial errors in the source document is known, the error in georeferencing and the errors introduced by vectorization can also be estimated. Table 1 presents the process steps in boundary mapping by photogrammetric approach using unrectified aerial photographs together with the related errors.

Dataset	Process	Related Error (geometric)
Aerial Photograph ↓	*Photo capture*	Flying height and scale of photography limit the geometric accuracy $\sigma_{xy} = 12.5\mu m \times \frac{1}{scale}$; $\sigma_z = 0.1‰ \, FlyingHeight$
	Photo-enlargement	Depends on the factor of enlargement; errors on the photograph are enlarged by the factor of enlargement
Paper map ↓	*Parcel Boundary Mapping*	Errors due to failure to correct for tilt and displacement due to relief : $dr = \left(\frac{r \times h}{H}\right)\left(\frac{H-h}{f}\right)$
	Scanning	The scanning resolution limits the geometric accuracy of features; scanning resolution should be more than the accuracy of the paper map
	Geo-referencing	The root mean square of the georeferencing process depends on the accuracy of the Ground Control Points and the identification of the points on the scanned document
Vector dataset	*Vectorization*	This largely depends on the experience of the individual doing the vectorization.

Table 1: Process steps and related errors in parcel boundary mapping.

Error in the Source Document

The accuracy of a map prepared by photogrammetric techniques depends on the accuracy of the ground control and the ability to identify them on the imagery (interpretation), the scale of aerial photography and the scale of mapping. In digital photogrammetry context, mathematical models exist for estimating the expected standard error in position and height of the points (Konecny, 2008).

The positional accuracy of positions from enlarged and unrectified aerial photography cannot however be determined using the said model because the photography has not been subjected to the photogrammetric restitution procedures. The accuracy instead depends on the amount of radial distortion present, the nature of the photographed terrain and reliability of interpretation. The error due to relief displacement is considered the most important. The error due to the failure to perform photogrammetric restitution can be determined by establishing the amount of error that could have been caused by displacement due to relief, which varies radially. Although various methods of rectification can be applied to aerial photographs of different terrain types, orthorectification results in the most reliable solution. The positional error (on the photograph) of a point due to relief displacement is given as:

$$dr = \frac{r \times h}{H} \quad (1)$$

In which *dr* is the positional displacement of a point, r is the radial distance of the point from the principal point, *h* is the ground height of the object point above the average ground elevation, while H is the flying height.

On the ground (i.e., multiplying by the scale), this translates to:

$$dr = \left(\frac{r \times h}{H}\right)\left(\frac{H-h}{f}\right) \quad (2)$$

Where f is the focal length of the camera used.
r can be measured on the photograph and for a 23 cm by 23 cm aerial photograph, the value for r is 162.63 mm (for the worst positional accuracy of the resulting dataset). This assumption is based on the fact that the nadir point is not known and that the displacement due to relief is worst at the diagonal edge of the photograph. With the knowledge of the map scale (if an analogue map is used for representation), it is therefore possible to estimate the amount of positional error.

Georeferencing and digitizing errors

Further errors are introduced during the georeferencing and digitization of datasets. The amount (*dg*) of error depends on the cartographic errors, among them the map projection used, digitizer used (Chrisman, 1983). (Kohli and Jenni, 2008), for example, obtained digitizing error that varies from ±0.05m to 0.20m for a map at a scale of 1:500.

Combined Effect

The crucial issue is how to combine the separate error effects. Considering that each error tends to occur as the spatial information is passed from one phase to another in the sequential process, it is therefore sufficient to consider the processes to be independent.

Sufficient results of combined geometric errors can be obtained by adding the variances of the distributions (Chrisman, 1983). Considering the error in source document, georeferencing and vectorization errors, by the law of propagation of errors, the error for a point in most cases described by the *root mean square* can be determined as:

$$\sigma_{\max} = \sqrt{\left(\left(\sigma_{dr}\right)^2 + \left(\sigma_{dg}\right)^2\right)} \quad (3)$$

For linear features such as rivers, roads, administrative or property boundaries, the *epsilon distance* (or band) as was first introduced by Perkal (Chrisman, 1983) is used. It describes the distance from either side of a line and from its two end points. Although normal distribution can be used to estimate the limits of the positional error along the line, the points along the line cannot however be regarded as independent of each other and possible models are presented in (Liu and Tong, 2005). The accuracy of a polygon is determined by its boundary linear epsilon band.

Test Case

The test case involved three datasets: a parcel boundary dataset derived from unrectified aerial photography; a vector road dataset derived from a road map at a scale of 1:5,000 and a Digital Terrain Model for an area in Nairobi, Kenya at an elevation ranging from around 1,500m to 1,600m above sea level. The photographs (at an average scale of 1:25,000) from which the parcel boundary dataset was derived, were captured with a camera of focal length 153mm. The positional accuracy of the parcel boundary dataset used as a backdrop in Figure 2 was estimated based on the knowledge of the process presented in table 1. Given that the aerial photographs were not orthorectified, terrain roughness is therefore considered as the main cause of position inaccuracy.

The DTM interpolated from contours (at a vertical Interval of 20m) was used to estimate the positional displacement due to relief. Using equation 2 together with the DTM, an error surface was generated using ArcGIS software with the position error ranging between 0m and 17.8m. The root mean square of the georeferencing process was about 0.01m, which changes the overall error value only minimally. It is important to note that the georerencing error does not include the digitization error, because the dataset was not digitized. It was therefore expected that the road corridors contained in the land parcel dataset would lie within a maximum buffer distance of 17.8 m around the road dataset (of comparably higher accuracy – vectorized from a road map at 1:5,000) whose plotting accuracy is 1.25m.

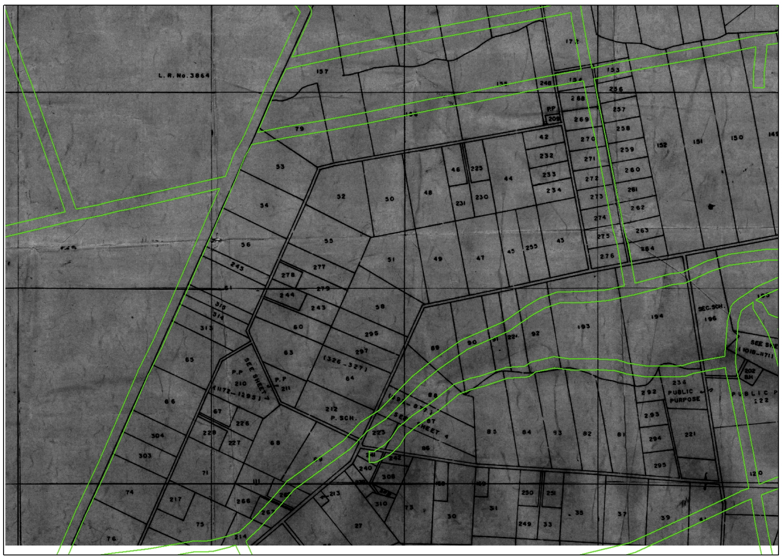

Figure 2: Buffer zone of road-centre line datasets (in green) superimposed on a parcel boundary dataset.

In figure 2, a buffer of 17.8m generated around the road dataset (shown in green colour) was superimposed on the parcel boundary dataset, all based on the same coordinate system. As expected, some sections of the road corridors were within the buffers and as illustrated in the figure, there is not much correspondence between the buffers and the road corridors. This can be attributed to the fact that some updates to the parcel boundary datasets had been made to reflect the transactions, which in most cases are not actually marked on the ground.

CONCLUSSION AND FUTURE WORK

The objective of this paper was to present an approach of estimating the positional accuracy of a parcel boundary dataset based on uncontrolled and unrectified aerial photograph. The error as estimated assumed that only the displacement due to relief to be the most important source of error, and therefore did not consider the effect of the accuracy of the DTM used and also the effect of photo enlargement before plotting the land parcel boundaries. This would probably change the values of the estimated error if considered.

This paper has presented an approach for estimating position error as a geometric quality assessment process, with the intention of using it later, particularly in deriving appropriate buffer (search) distances in geometric feature matching procedures like automatic registration and feature alignment. In a planned research in geospatial data integration, positional accuracy assessment is a necessary initial step to determine the integrity of the datasets involved. The next step in the research will investigate the derivation of variable buffers and also the automatic derivation of road centre lines from a parcel boundary dataset as a possible counterpart dataset for feature matching.

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