Analytical Cadastre in Israel: Restoring Land Boundaries Based on Photogrammetric Tools

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Key words: analytical cadastre; photogrammetry; restoring land boundaries; GIS/LIS.

ABSTRACT

The modern replacement for the traditional form of cadastral information is the cadastral database. The definition and compilation of an accurate cadastral is based on analytic reconstruction of cadastral boundaries. In the mid 1990's, an analytical restoring process, which analytically imitates the traditional field-based process, was developed in Israel for urban areas, relying on precise field location of building corners. The paper presents an additional method for establishing an analytical cadastre in areas where ***measured land features no longer exist***. This method suggests a "virtual journey in time" process by combining two mapping realities: the current and the previous. Four "mapping environments" are being dealt with: the current reality (in terms of field surveying); new aerial photographs (taken recently); previous aerial photographs (enabling to measure the land reality at the time when the cadastral maps were prepared and the original land features still existed); and the previous reality (as defined by the cadastral maps and the original field books). Research results showed the feasibility of using this technique for improving the graphic cadastral data in order to establish the Analytical Cadastre.

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1. INTRODUCTION

Cadastre is the method of registering land, designed to ensure the rights of individuals and the state of their property. In Palestine (preceding the state of Israel) registration of land (as Registration of Deeds) began in 1867, when the country was under Ottoman Empire rule. Modern cadastral mapping started in Israel in 1926, based on the Torrence principles - Registration of Titles - the most advanced and innovative system at the time (Dale, 1976). This system defines the cadastral blocks and parcels based on official surveying and mapping that is carried out (in Israel) by the state and linked to the national coordinate network. Measurement results are recorded in field books and used to determine the boundaries of the blocks and the parcels, as well as other features (buildings, fences, electric poles, etc.). A typical sample of a field book page is depicted in Figure 1. All these measurements are depicted graphically on field plan sheets. Maps of the cadastral blocks are prepared based on the field sheet (see Figure 2), consisting of all parcels in the block and all included features. These cadastral maps contain neither the measured data nor any dimensions whatsoever of the parcel boundaries and serve only as a graphic presentation of parcel layout.

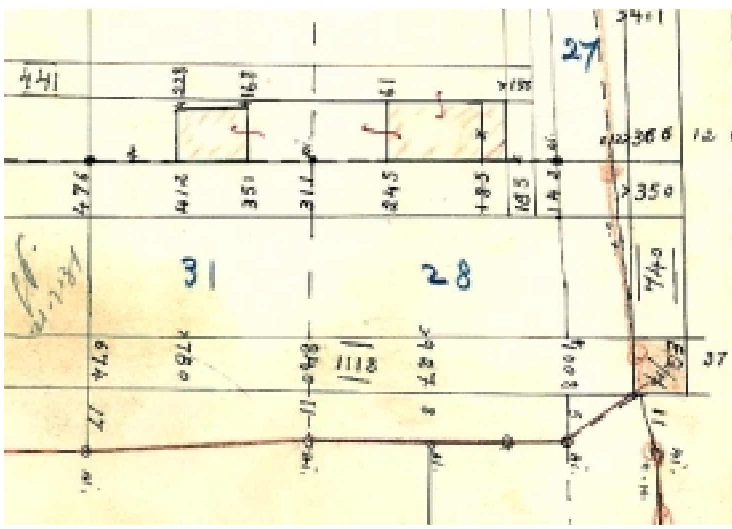

Figure 1. Typical Field Book Page

Most measurements for cadastral mapping were performed by using the chain surveying method. This method necessitates prior marking and measurement of a traverse network in the field. Until the 1980s, the cadastral blocks in Israel were based on a control network of relatively low accuracy. Calculation of the traverses was based on separate adjustment of each traverse (the Bowditch method) and not on a rigorous adjustment as a uniform network. Most blocks were plotted manually based directly on the chain surveying measurements, without calculating coordinates. The quality of the cadastral maps improved with the development of modern measuring instruments and introduction of the theodolite and electro-optical distance measuring in cadastral measurements. Concurrently the new block maps were being drawn by plotters based on calculated coordinates. Another improvement in quality and accuracy of cadastral maps took place in the course of the 1980s and 1990s following the increased accuracy of the Israeli control network.

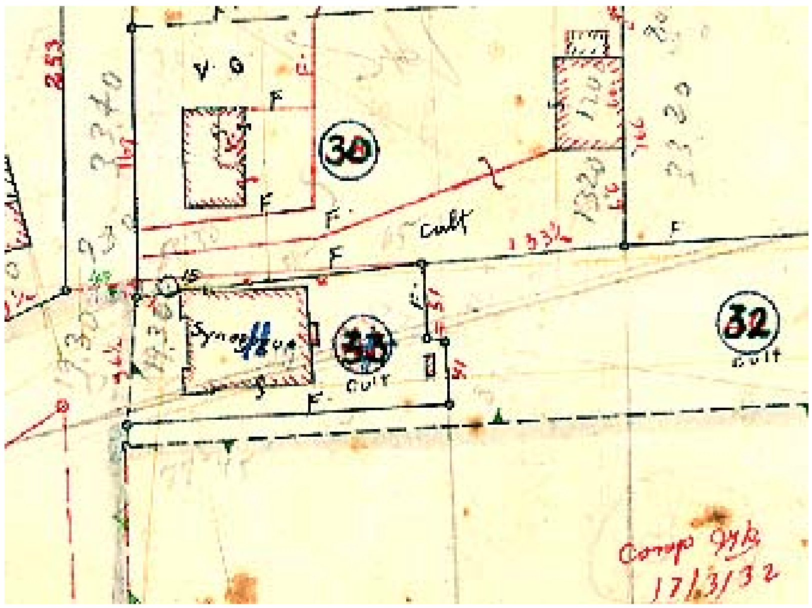

Figure 2. Typical Example of a Field Sheet

Currently, the cadastre in Israel has graphic characteristics and in its present form the existing cadastral information does not fulfill the requirements for establishing a modern LIS database. Most information is currently kept on paper (field books and field sheets), which does not permit its computerized management. Inherent contradictions and inaccuracies in the existing material cause difficulties in its use, delays in tracking and measuring the changes and in updating the cadastral map. It is important to note that according to the current surveying regulations in Israel, the cadastral maps have no statutory validation, thus restoring of boundaries must be performed according to the original measurements from the field books and not according to calculated coordinates. The final decision regarding the location of the boundary is made by a licensed surveyor on the basis of adjustment between the measurements and the actual situation in the field.

The solution for the problems of the current graphic cadastre is to establish an analytical cadastre in which the location of each entity is determined by the State plane coordinate system, coordinates that are sufficiently accurate for legal validation. According to the planned doctrine of SOI (Survey of Israel - the governmental agency responsible for geodesy, topographic and cadastral mapping) the data of the analytical cadastre will constitute a spatial information system (LIS) defining the statutory land division (Steinberg, 2001).

In order to establish an analytical cadastre, two possible solutions might be considered, namely, field restoring of land boundaries; or, field surveying of the existing land boundaries.

Resurveying all land boundaries could constitute a radical solution for the problem. For this purpose, it would be necessary to restore the boundaries according to the existing information in the field books and sheets, and measure these in relation to a new control network. Restoring the boundaries constitutes a tremendous effort in itself, whose estimated cost is extremely high. A possible alternative for restoring the boundaries could be surveying of the existing boundaries. This solution would in practice cancel and expunge the current statutory validity of the land boundaries and would in fact institute a new real estate order. This solution is impractical in Israel, a country with a legal real estate order.

2. INTEGRATING EXTERNAL INFORMATION

Based on the fact that the two previous methods (field restoring or field surveying of land boundaries) are impractical within the Israeli cadastral situation, digitizing the existing cadastral maps should be considered. Converting graphic data on existing maps to digital form would of course be the least expensive and the fastest procedure for obtaining such data. Based on these facts, much effort has been invested over the years in developing methods to convert analogue (graphic) cadastral maps into digital information (Gagnon, 1988; Williamson, 1996). There are about 15,000 cadastral block maps in Israel, prepared in different periods, employing different methods of measurement, calculation and drawing, as well as being on different scales. The result of just digitizing the existing maps would not be an adequate database for the analytical cadastre, both from the accuracy aspect as well as from the judicial validity aspect. This is due to the heterogeneity in the quality of the maps, and the accuracy limitations inherent in the digitization process in general, and the Israeli Surveying Regulations in particular.

As a result of the need to improve the quality of the data digitized from the cadastral maps, the option of integrating external information with digital data derived from maps was considered in recent years. Reconstruction of geometric and cadastral conditions is generally performed on each map using adjustment techniques (Morgenstern, Prell and Riemer, 1989; Hesse, Benwell and Williamson, 1990; Tamim and Schaffrin, 1995). Two types of external information can be distinguished: “cadastral” information and “geometrical” information. Cadastral information is the length of a front, right of way, etc. The geometric conditions define the shape of the entities described in the map (closed polygons, straight lines, circular arcs, parabolic curves, etc.), as well as the existing spatial relationships between the various entities (parallelity of lines, perpendicularity of lines, etc.). Although the improved coordinates possess the same juridical status as cadastral map, it is expected that the discrepancies between digitized coordinates from the maps and their counterparts as calculated from field books would be tolerable. This being the case, the calculation of field books might be replaced by digitization followed by imposing external information (external constraints) and employing adjustment techniques (Fradkin and Doytsher, 2002).

A regular digitizing process of the contents of a map, point by point, is unable to take into consideration the fact that these points describe geometric entities. Thus, ignoring the existing spatial relationships in the map during the digitizing and transformation process leads to mutual displacement of the points. The irregular nature of these changes combined with the drawing inaccuracies in the map itself, leads to distortions of the geometric shapes of the entities that were picked up, compared with the real entities. Correction of these distortions may both reconstruct the correct geometric shapes of the entities, as well as improve the accuracy of the coordinates of the points that define them (Shmutter, Doytsher, 1992).

In addition to the “geometric constraints”, “cadastral constraints” should be considered as the second group of conditions for improving the quality of the digitized content of the cadastral map. The improvement is achieved by integrating the cadastral constraints - lengths of fronts of the parcels that appear on the field sheets (Doytsher and Shmutter, 1991). The result of this procedure is dependent on the number of these external conditions. Based on the fact that in typical cases the number of conditions is insufficient to unequivocally define the mutual location of the points, the improvement of the cadastral quality is limited.

One of main factors affecting the discrepancies between calculated coordinates (from field books) or digitized coordinates (from graphic cadastral maps) and their true location (in the field) is the accuracy of control points. As noted, most of the traverses in Israel were formerly calculated by relying on a separate adjustment of each polygon and not on rigorous adjustment as a uniform network. Moreover, an attempt to improve the limited quality of these control points by adding new field measurements would fail, due to the fact that as a result of the rapid urbanization process in Israel, the majority of these control points can no longer be identified or found in the field. A possible solution might be the incorporation of a limited number of new control points, measured independently with the previous cadastral measurements. These new control points, if incorporated properly with previous cadastral measurements, might overcome the problem of the relatively low accuracy level of the old control points. Thus, the discrepancies between calculated coordinates of the cadastral boundaries and their true location might be significantly reduced.

3. ANALYTICAL RESTORING METHOD FOR URBAN AREAS

In conclusion, considering the facts presented in the previous chapter, a processing procedure of existing data only, cannot ensure correspondence between the calculated coordinates and the cadastral reality. A method is required for integrating a limited number of new measurements in the process of obtaining reliable coordinates for the turning points of cadastral boundaries. A substantial difference exists between calculating the coordinates of the boundary points from field books and between restoring them in the field by traditional methods. The conventional restoring process is local by its nature, relying only on findings in the near vicinity in neighboring parcels of the restored boundary and the original measurements. Therefore, a new method, suggesting an analytical restoring process that analytically imitates the traditional process, should rely on the precise location of several existing features in the field (features that are linked to the old measurements). The only way the location of these features can be obtained is by identifying them in the field and by measuring them in relation to a new GPS based control network (a network free of the constraints, inaccuracies and errors inherent in old control networks). An analytical restoring of the cadastral boundaries should comply with the following requirements:

- Combining the old measurements with a limited number of new measurements - in order to enable calculation of boundary points according to the new control network;
- Reliance on using features that are well defined in the field - features which do not require to be restored and can be identified with sufficient certainty; and,
- Based on features that are linked to the cadastral boundary points.

In a previous research in the mid 1990s, an analytical restoring method was developed in Israel for urban areas (Fradkin and Doytsher, 1997). Buildings were chosen to create the "link" between the current measurements and the historical measurements (a "link" between the new and the old networks). The decision was based on the fact that buildings in the field are clearly identified. There is no need to restore their location, only to identify them and ascertain that their shape has not changed since they were last measured and drawn on the cadastral map. Moreover, the relative ease of measuring the building corners, and the manner of mapping the buildings permits easy integration of old and new measurements.

The simple geometric link between the corners of a building in urban areas and the parcel boundaries assure that new measurements defining the coordinates of corners of a building, together with all previous measurements (frontages, lengths, and offsets) easily permit calculation of the coordinates of all parcel turning points. A theoretical simulation as well as practical field tests resulted in a high level of achieved accuracy of the suggested method. The differences between the analytically restored coordinates of cadastral boundaries and their true locations in the field were less than 10 centimeters. The only limitation of this method is that it is restricted to urban areas including an adequate number of buildings that have not been changed since the original cadastral measurements took place.

4. ANALYTICAL RESTORING IN SUB-URBAN AREAS

Based on the limitations of the previous analytical restoring method, a new method for establishing an analytical cadastre, mainly in sub-urban areas where **measured land features no longer exist,** is suggested and evaluated in this chapter.

In suburban areas, where the original measured land features no longer exist, the current land reality is usually different, thus causing severe difficulties when trying to restore the cadastral boundaries. Mere use of new aerial photographs, describing the current land reality, and applying modern photogrammetric methods cannot avoid the tedious manual restoration of the cadastral boundaries. In order to bypass the main problem of not being able to find the previous measured features, it is proposed to use aerial photographs from previous periods and thus, being able to re-measure the "vanished" features. The method thus suggests a "virtual journey in time" by using two sets of aerial photographs - one set that was taken recently and another set that was taken several years earlier when the original land features still existed and could be measured from the photographs. Thus, comparison of the two mapping realities, the current and the previous, is achieved. Four "mapping environments" can be defined:

- The current reality (in terms of field surveying, new control points etc.);
- New photogrammetric models (enabling to measure the current reality without field surveying);
- Previous photogrammetric models (enabling to measure the land reality at the time when the cadastral maps were prepared); and,
- The previous reality (as it is defined by the cadastral maps)

A sequential linkage between these four "mapping environments" will facilitate definition of an analytical restoration process for the cadastral boundaries, without the necessity of manual field restoring efforts. The applicability of the photogrammetric process to solving future cadastral problems is examined, thus defining another technique for establishing an analytical cadastre with sufficient statutorial reliability.

Based on the fact that the current field reality is totally different from the photogrammetric reality as depicted in the previous aerial photographs, it was suggested that a two-step photogrammetric solution process be applied: 1) the photogrammetric models of updated aerial photographs will be solved based on GPS measured control points, and then, 2) based on control points measured from the recent photographs and transferred to the previous aerial photographs, the previous photogrammetric models will be solved.

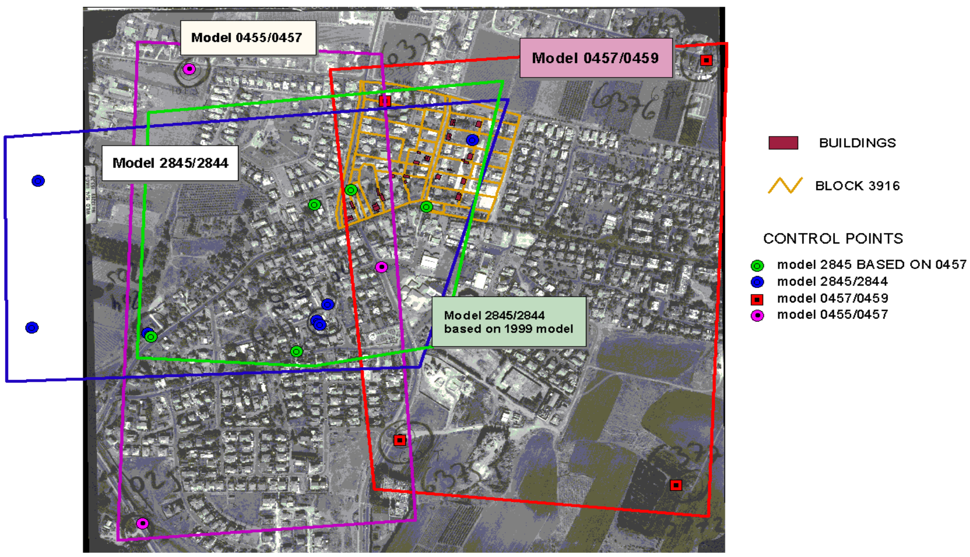

Figure 3. Layout of Aerial Photogrammetric Models

In order to implement the suggested method and evaluate its results, a site was located where buildings that were built many decades ago still exist. The information that was collected is composed of:

- The original cadastral measurements - the original 1930's field books, field sheets and cadastral map;
- Previous aerial photographs on a scale of 1:5,000 (from 1972); and,
- Current aerial photographs on a scale of 1:5,000 (from 1999).

The corners of these buildings were measured in four parallel sets of measurements – one by field measurement and other three by photogrammetric methods:

- Field measurements by GPS based land survey (marked as “GPS measurement”);
- The 1999 aerial models, where the photogrammetric solutions are based on GPS ground control points (marked as “99 model”);
- The 1972 aerial models, where the photogrammetric solutions are based on GPS ground (terrestrial) control points (marked as “72 model”);
- The 1972 aerial models, where the photogrammetric solutions are based on transferred control points from the 1999 model (marked as “72/99 model”)

In addition, the original field books of the 1930's survey were also computed, supplying another set of data (marked as “field book”). All four sets of measurements and the fifth set of calculated coordinates were compared. The results of the Mean and STD (standard deviation) values are depicted in table 1.

Table 1. Summary of Mean and STD Comparing Measurements Values (meters)

		Easting	**Northing**	**Radial**
“GPS measurement” vs. “field book”	Mean	-0.09	0.03	0.22
	STD	0.22	0.13	0.15
“GPS measurement” vs. “99 model”	Mean	-0.03	0.02	0.20
	STD	0.19	0.17	0.16
“99 model” vs. “72 model”	Mean	-0.02	-0.11	0.33
	STD	0.18	0.32	0.18
“99 model” vs. “72/99 model”	Mean	0.33	-0.14	0.46
	STD	0.21	0.31	0.23
“72 model” vs. “72/99 model”	Mean	0.35	-0.02	0.37
	STD	0.11	0.12	0.10

Table 1 summarizes the results of the comparison. It is evident that achieved accuracies of measurements from the two 1972 aerial models (“72 model” and “72/99 model”) are of the same order. In addition, the low STD result (radial of only 0.10m) in comparing the “72 model” (which was based on terrestrial control points) with the “72/99 model” (1972 aerial photographs solved on the basis of transferred control points from the 1999 aerial photographs), means that the method of transferring the control points from current photogrammetric models to earlier models is applicable. The implementation of this technique is appropriate for obtaining the measurements of buildings that no longer exist in the field, at a similar accuracy level as if using terrestrial based aerial models and measuring existing buildings.

Comparing photographic measurements from the “99 model” to the direct “GPS measurements” shows a radial STD of 0.16m and a Mean value of 0.20m. These values point toward the expected accuracy from these measurements, and they comply with a theoretical evaluation of this matter.

Comparing the “GPS measurements” with the results obtained from calculating the field books yields a STD of 0.13m (Northing) and 0.22m (Easting), which conform to results obtained in a previous work (Fradkin and Doytsher, 1998). According to the planned doctrine of SOI (Steinberg, 2001), their target is to achieve an accuracy of 0.05m when building an analytical cadastre. It is thus evident that accuracy improvements must be applied to the coordinates calculated from the original field books.

Different alternatives were presented in the second chapter of the article for improving the cadastral accuracy by incorporating external information (Doytsher and Shmutter, 1991;

Clatworthy, 1991). One of the possible implementations is based on the idea of calculation of field books in the first stage, and then using “Conformal” transformation to obtain coordinates in the new Israel state plane coordinate system in the second stage. The transformation is based on mutual points that have coordinates in two parallel systems, e.g., measured from the previous or current aerial photogrammetric models (in the new state plane coordinate system) as well as calculated from the field books (in the old state plane coordinate system).

Table 2. Summary of Transformation Results (meters)

	“99 model”	**“72 model”**	**“72/99 model”**	**“GPS measurements”**
MSE (Diagonal)	0.187	0.281	0.268	0.253
STD (Northing)	0.098	0.161	0.190	0.212
STD (Easting)	0.148	0.207	0.165	0.123

The statistical evaluation of the transformation residuals is presented in Table 2. The numerical figures are STD (standard deviation) values in the easting and northing directions – depicting the inner compatibility of the control points used for the transformation, and radial MSE (Mean Square Error) values – depicting the absolute accuracy of the transformation. In comparing the results it is important to emphasize the following:

- Transforming the calculated field book to the previous (1972) photogrammetric models yields similar results when using the “72 model” (solved directly on terrestrial ground control points) as well as the “72/99 model” (solved based on control points transferred from the 1999 photogrammetric models). The MSE values are 28cm for the “72 model” vs. 27cm for the “72/99 model”, and 16-20cm for the “72 model” vs. 16-19cm for the “72/99 model”.
- Transforming the calculated field book coordinates to the recent photogrammetric model (“99 model”) yields improved residuals - MSE of 19cm and STDs of 10-15cm.
- Transforming the calculated field book directly toward the field measurements (“GPS measurements”) of the corners of the building yields an intermediate level of residuals – an MSE of 25cm and STDs of 12-21cm.

Practically, there are no significant differences between the above numerical figures. It can be therefore concluded that using aerial photographs to indirectly measure building corners photogrammetrically, is no less accurate than direct terrestrial measurements. Similar accuracy is achieved when the previous aerial photographs solutions are based on direct terrestrial measurements or by an indirect transferring orientation based on the recent photographs. Moreover, assuming that measurements from the 1999 aerial photographs are more accurate than those calculated from the old field books, and considering the fact that the transformation toward the “99 model” produced the best results, it can be concluded that the resulting MSE values are within the range of the embedded accuracy within the cadastral information, an accuracy level which cannot be corrected further.

The insignificant differences between the two versions of the transformations toward the previous (1972) photogrammetric model (“27/99 model” based on recent (1999) photo models and the same early version (1972) based on direct GPS terrestrial measurements "72 model", mean that photogrammetric measurement accuracy is determined more by the camera characteristics than by the orientation.

The research results illustrate the feasibility of using the suggested method for improving existing cadastral data in order to establish an analytical cadastre. It should be noted that additional examination under different conditions such as: smaller scale of the aerial photographs, buildings with or without flat roofs, areas with hilly or mountainous terrain characteristics, etc. may strengthen the conclusions of the suggested method.

5. CONCLUSION

The cadastre as a land registration method is designed to ensure property rights. Both the boundaries of parcels and the ownership rights must be registered. In order to guarantee this, the State must have an accurate definition of the parcel boundaries. Thus, the existence of cadastral information as a "Legal Digital Cadastre" is the basis for proper management of real estate and all related economic sectors. This article proposes a new method, one of several other methods being researched, for improving the old cadastral data and thus establishing an Analytic Cadastre or a "Legal Digital Cadastre". The promising results of this research show the feasibility and the applicability of this method.

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BIOGRAPHICAL NOTES

Yohanan Gavish received his B.Sc. from the Technion – Israel Institute of Technology, Division of Geodetic Engineering in 1979. In 2001 he received his M.Sc. form the Technion, also in Geodetic Engineering. Since 1982 he has been with the Survey of Israel, where he was involved in cadastral measurements during the period 1983-1990, and head of the GIS department since 1990. His main responsibility is the defining and building the Israel National Cadastral Database.

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