Establishing an Accurate Continuous Nationwide Cadastre Based on the Cadastral Triangulation Method

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Key words: coordinate based cadastre, boundaries matching, least squares adjustment

SUMMARY

Conversion of a graphical, paper map based, cadastre as well as a relatively non-accurate digital cadastre to a new cadastral system based on accurate coordinates having legal validity for parcels boundaries restoration, is a major challenge within the cadastral community in many countries. This challenge to solving the conversion problem being characterized by optimally determining the turning points position and improved cadastral accuracy motivates the development of modern techniques suitable to perform the aforementioned task. Solving this issue on nationwide level requires development of new approaches to joining separate cadastral blocks into a seamless continuity while overcoming relatively large discrepancies (at least according to the Israeli experience) between adjoining parcellations caused mainly by low level accuracy measurements in the first half of the 20th century.

The Cadastral Triangulation (CT) method, which has been recently proposed by the authors, enables achieving the required solution based on global transformation of adjacent cadastral blocks. This paper presents an expanded and advanced application of the newly proposed CT method based on the Gauss-Helmert model of Generalized Least Squares Adjustment, aiming to obtain optimal transformation parameters of the separate parcellations (cadastral projects).

The results of applying the proposed method to real data that presented in the paper demonstrate its effectiveness in connecting adjoining cadastral blocks. The efficiency of the method is expressed by a decrease of system residuals in comparison with presently used methods for matching cadastral boundaries.

The proposed method may definitely be used as a primary computational algorithm for implementation of a coordinate based cadastre on a nationwide level.

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1. INTRODUCTION

Cadastre is a systematic method of land property registration and management that includes information about land parcels, e.g. their boundaries, areas, ownership, mortgages, pledges, etc. (Henssen, 1995, Dale & McLaughlin, 1988). Cadastre constitutes an essential factor in the national economy establishing a strong basis to the existence of human society (Dale, 1997, Kaufmann & Steudler, 1998, Kaufmann, 1999). Good practice in land property administration, which includes development of modern cadastral systems, gives rise to a strong foundation of sustainable national development (Williamson, 2001, Bennett et al., 2008).

The Israeli cadastre, as cadastral systems in various countries throughout the world, is based on paper block maps and mutation plans, field measurements books, computation files and physical marking of parcel turning points on the ground. These turning points have legal validity whenever parcel boundary restoration is needed. However, despite their legal status, the original cadastral documents suffer considerably from the lack of completeness, and the physical marking is mostly based on ground surveying of low accuracy. As a result, the coordinates of parcel turning points are of low accuracy with great difficulty in integrating the adjoining blocks into the spatial cadastral continuity. The latter situation leads to complex difficulties in the process of transforming the existing paper-based cadastre to a legal-coordinate based cadastre, which will enable using the coordinates of the turning points as a legal basis for parcel boundary restoration. In order to achieve this goal it is necessary: (i) to develop an optimal method of original cadastral documents processing referring to separate parcellations (separate cadastral projects); and, (ii) to develop a model of joining the separate parcellations into one cadastral continuity maintaining a rigid topological structure on a nationwide level.

We handled the first task (Klebanov & Doytsher, 2008) by applying the Gauss-Markov model of Least Squares Adjustment (Koch, 1999) as an optimal method of parcels turning point position definition, considering all available information recorded in the original cadastral documents. We proposed to implement a Block Adjustment process, customary in photogrammetry, for solving the second task (Klebanov & Doytsher, 2009) defining it as the Cadastral Triangulation (CT) Method. The current paper presents an expanded and advanced application of the CT method for the second task based on the Gauss-Helmert model of Generalized Least Squares Adjustment (Wolf & Ghilani, 1997, Koch, 1999).

The outline of this paper is as follows. First, in Section 2, we give the motivation of performing the presented research as an extension of the previously research carried out by the authors regarding separately processed parcellations. Section 3, describes the mathematical model of the proposed method and gives some essential definitions and details of the involved matrices. Section 4, describes the results of the practical implementation of the proposed method by processing a cluster of 11 adjacent cadastral blocks, as well as the accuracy analysis in comparison with the existing method of fitting adjacent parcel boundaries. In section 5, we conclude and outline possible directions for future research.

2. MOTIVATION

The solution proposed in our early work (Klebanov & Doytsher, 2008), enabled obtaining optimal positions of parcel turning points belonging to separate cadastral blocks (or any other cadastral parcellation) based on application of the Gauss-Markov adjustment model to the original cadastral documents processing. However, the optimal connection of separately processed parcellations into a homogeneous seamless space remained a very complicated task (Shmutter & Doytsher, 1992). Some attempts have been made to find local solutions of the optimal connection problem (Doytsher & Gelbman, 1995, Nimre & Doytsher, 2000, Takashi et al., 2001, Tong et al., 2005, Felus & Schaffrin, 2005).

The fact that only a minority of the ground marks of parcel control points have been left (unruined) in the field due to development and construction activities, prevents the possibility to directly measuring these in the field. As a result, in new cadastral projects, computation of transformation parameters for coordinates of parcel turning points which have not been found in the field, is required. Our work (Klebanov & Doytsher, 2009) proposed a comprehensive solution for defining a homogeneous cadastral space based on Block Adjustment of Independent Models, aiming to obtain identical coordinates of peripheral common turning points. The proposed solution, named the Cadastral Triangulation (CT) Method, dealt with finding the appropriate parameters of planar similarity transformation, aimed at converting point coordinates of separate parcellations computed in original inaccurate geodetic grids into the modern accurate target grid (IL2005) based on satellite geodesy and permanent ground stations (Steinberg & Even-Tzur, 2004).

This paper describes a comprehensive model of the CT Method based on global coordinate transformation, aimed at creating a homogeneous seamless cadastral space of high accuracy from separate optimally pre-processed cadastral projects. The proposed solution, in comparison to our previous work (Klebanov & Doytsher, 2009), enables to consider additional factors (e.g. final accuracy of transformation basic points) based on the Gauss-Helmert model of Generalized Least Squares Adjustment (Wolf & Ghilani, 1997, Koch, 1999).

3. PROPOSED METHOD

Generally, the Cadastral Triangulation method, as recently presented in our work (Klebanov & Doytsher, 2009), refers to separate cadastral projects (see Figure 1, Projects I, II, III), optimally pre-processed, as well as to models determined in some local coordinate systems (origin grid). The peripheral common turning points, belonging to adjoining cadastral parcellations, play the role of model tie points (see Figure 1, Points 1-3, 5-7). Serving as control points, linking models to the ground coordinate system, are the points that have been measured when the cadastral projects were carried out, and remained (unruined) in the field up to now. The latter points were named "authentic" points (see Figure 1, Points 4, 8-14). It should be mentioned that generally there are not very many authentic points presently located in the field, nor are they necessarily dispersed in an optimal manner, especially in reference to old cadastral projects. As these points have two sets of coordinates – in the original grid by analytical pre-processing of the old cadastral measurements, and in the target grid (IL2005) by modern re-surveying – these authentic points play a central role in the global transformation of the cadastral turning points that have not been found in the field.

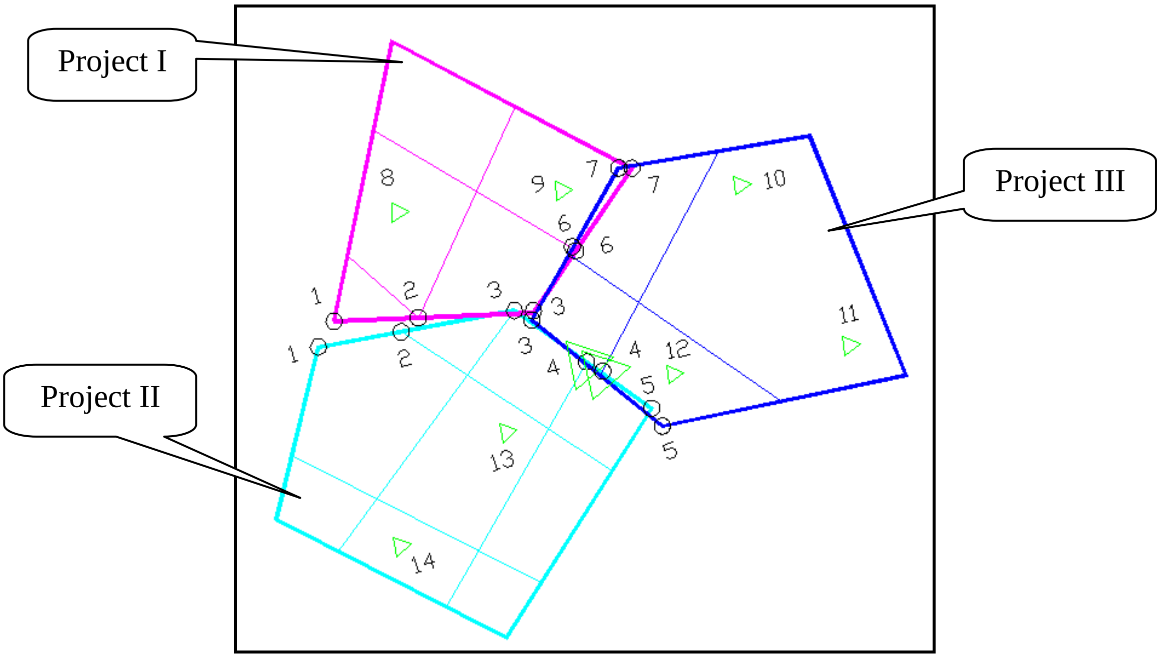

Figure 1. Optimally pre-processed separate cadastral projects

The proposed CT method treats the separate cadastral projects, aiming at creating homogeneous seamless space (see Figure 2), through applying the mechanism of global transformation by transforming each of the cadastral projects separately.

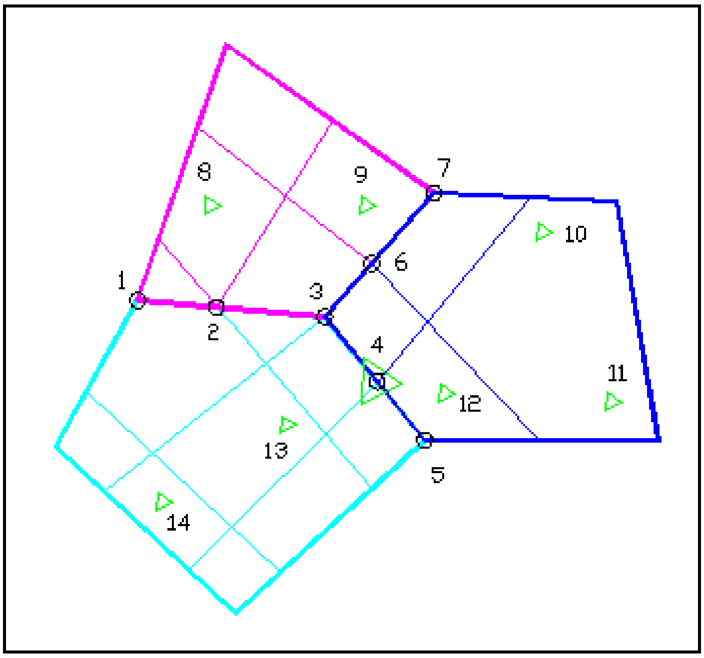

Figure 2. Creating homogeneous seamless space from separate cadastral projects

The proposed method might be implemented with any number of transformation parameters, not even necessarily with the same number of transformation parameters for all the parcellations involved in the adjustment process. We considered similarity transformation (in its general case of four transformation parameters) as one of the most appropriate kind of cadastral transformation due to its conformal qualities having important legal consequences to cadastral parcellation. We also considered affine transformation with six parameters as another appropriate kind of cadastral transformation due to its ability compensating for non-orthogonal characteristics of the old cadastral maps.

Additional research may be applied regarding the number of authentic points and the influence of their scattering on the final results.

Our new approach to Cadastral Triangulation method is based, as stated, on the Gauss-Helmert model of Generalized Least Squares Adjustment (also referred to as a mixed model). The aforementioned model assumes the existence of inevitable errors both in the position of pre-processed parcels turning point and in the position of authentic points that have been identified on the ground and re-measured in the accurate target grid (IL2005).

<u>Mathematical model</u>

The linearized mathematical model of planar similarity transformation has the following expression (Kraus, 1993):

$$\begin{bmatrix} Y_t \\ X_t \end{bmatrix} = \begin{bmatrix} a & -b \\ b & a \end{bmatrix} \begin{bmatrix} Y_o \\ X_o \end{bmatrix} + \begin{bmatrix} c \\ d \end{bmatrix} \quad (1)$$

where

Y_t, X_t - points coordinates in the target grid

Y_o, X_o - points coordinates in original grid

a, b - transformation parameters of scale m and rotation K calculated as $a = m * \cos K$, $b = m * \sin K$

c, d - shift transformation parameters

The coordinates of the points in original grid, as a result of the pre-processing phase, are always known both for the tie as well as for the control points. Transformation parameters of separate parcellations are always unknown. Regarding point coordinates in the target grid, they are unknown for peripheral tie points and known for authentic control points (by definition of the latter).

Equations (1) determine functional relations between point coordinates in the target grid y_t and unknown transformation parameters β (provided given point coordinates in the original grid y_o) in the process of the local transformation. The general form of the functional relations might be expressed as:

$$y_t = F(\beta) \quad (2)$$

For a *peripheral non-authentic* turning point i (Figure 1, Points 1-3, 5-7) belonging to two adjacent parcellations j and k, equations (2) might be expressed as:

$$y_{ti}^j = F(\beta^j),\ y_{ti}^k = F(\beta^k) \quad (3)$$

According to (3), the discrepancies of point position in two adjacent parcellations produce the following form:

$$y_{ti}^j - y_{ti}^k = F(\beta^j) - F(\beta^k) \quad (4)$$

The latter expression, which includes both transformation parameters and point coordinates, might be written as the following mathematical model:

$$F(\beta^{jk}, y_{ti}^{jk}) = 0 \quad (5)$$

Where

$$(\beta^{jk})^T = [a^j\ b^j\ c^j\ d^j\ a^k\ b^k\ c^k\ d^k],\ y_{ti}^{jk} = y_{ti}^j - y_{ti}^k$$

The objective of the proposed adjustment process is to find such transformation parameters which by being applied to all adjacent parcellations and minimizing point position residuals, would enable connecting the separate parcellations into a seamless cadastral space. Accordingly, the mathematical model of adjustment process for peripheral common turning point might be expressed as:

$$\hat{y}_{ti}^{j} = \hat{y}_{ti}^{k} \text{ or } \hat{y}_{ti}^{jk} = \hat{y}_{ti}^{j} - \hat{y}_{ti}^{k} = 0 \qquad (6)$$

where

$\hat{y}_{ti}^{j} = y_{ti}^{j} + \varepsilon_{i}^{j}$, $\hat{y}_{ti}^{k} = y_{ti}^{k} + \varepsilon_{i}^{k}$

y_{ti}^{j} and y_{ti}^{k} are vectors of point coordinates computed according to (3) based on estimates of transformation parameters $\hat{\beta}^{j}$, $\hat{\beta}^{k}$

ε_{i}^{j}, ε_{i}^{k} are vectors of point i residuals in parcellations j and k computed respectively to accuracy of point coordinates in the original grid

In order to find the required solution, we apply the Generalized Least Squares Adjustment, (also known as the Gauss-Helmert (or mixed) adjustment model) (Koch, 1999), to the model (6):

$$X_{i}^{jk}\beta^{jk} + Z_{i}^{jk}\varepsilon_{i}^{jk} + w_{i}^{jk} = 0 \qquad (7)$$

where

$$X_{i}^{jk} = \frac{\partial F(\beta^{jk}, y_{ti}^{jk})}{\partial \beta},\ Z_{i}^{jk} = \frac{\partial F(\beta^{jk}, y_{ti}^{jk})}{\partial y_{t}},\ w_{i}^{jk} = F(\beta_{init}^{jk}, y_{ti}^{jk})$$

Due to usage of the linearized form of planar similarity transformation (1), the estimates of adjusted transformation parameters are computed after a single iteration as $\hat{\beta}_{adj} = \beta_{init} + \hat{\beta}$.

We assume the initial approximation of unknown transformation parameters β_{init}^{jk} as follows - scale $m = 1$, rotation $K = 0$ (which means $a = 1, \quad b = 0$) and shift parameters $c = d = 0$.

Following are the fragments of Jacobian matrices X, Z, vectors of unknown parameters β^{T}, residuals ε^{T} and w for peripheral point i belonging to parcellations j,k:

$$(\beta^{jk})^{T} = [\underline{a^{j}} \quad \underline{b^{j}} \quad \underline{c^{j}} \quad \underline{d^{j}} \quad \underline{a^{k}} \quad \underline{b^{k}} \quad \underline{c^{k}} \quad \underline{d^{k}}]$$

$$\left[X_{i}^{jk}\right] = \begin{bmatrix} Y_{oi}^{j} & -X_{oi}^{j} & 1 & 0 & -Y_{oi}^{k} & X_{oi}^{k} & -1 & 0 \\ X_{oi}^{j} & Y_{oi}^{j} & 0 & 1 & -X_{oi}^{k} & -Y_{oi}^{k} & 0 & -1 \end{bmatrix},$$

$$(\varepsilon_i^{jk})^T = [\underline{\varepsilon_{yi}^j} \; \underline{\varepsilon_{xi}^j} \; \underline{\varepsilon_{yi}^k} \; \underline{\varepsilon_{xi}^k}]$$

$$\left[Z_i^{jk}\right] = \begin{bmatrix} 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 \end{bmatrix},$$

$$\left[w_i^{jk}\right] / from\beta_{init}^{jk} = \left[y_{ti}^j - y_{ti}^k\right] / from\beta_{init}^{jk} = \left[y_{oi}^j - y_{oi}^k\right] = \begin{bmatrix} Y_{oi}^j - Y_{oi}^k \\ X_{oi}^j - X_{oi}^k \end{bmatrix}$$

Note: if the turning point i, besides the parcellations j and k, belongs also to parcellation m, one of the following equations $F(\beta^{jm}, y_{ti}^{jm}) = 0$ or $F(\beta^{km}, y_{ti}^{km}) = 0$ should be added to (5) and, consequently, $\hat{y}_{ti}^j - \hat{y}_{ti}^m = 0$ or $\hat{y}_{ti}^k - \hat{y}_{ti}^m = 0$ to model (6).

For *authentic* points (Figure 1, Points 4, 8-14), we propose to apply the approach known as the "Schmid & Schmid concept", which assumes that all parameters comprising the mathematical model are observations (Schmid & Schmid, 1965). This approach enables to provide the necessary flexibility for the Generalized Least Squares solution considering final accuracy of the ground surveying of authentic points in the target grid along with their accuracy in the original grid. The latter fact might be significant factor affecting adjusted points position especially when both accuracies are of the same (or close) order of magnitude.

Accordingly, for a *non-peripheral authentic* point i (Figure 1, Points 8-14) belonging to parcellation j (an internal boundary turning point, a geodetic control point, a building corner point, etc.), mathematical model (6) might be expressed as follows:

$$\hat{y}_{ti}^j = \hat{y}_{ti}^{sj} \text{ or } \hat{y}_{ti}^j - \hat{y}_{ti}^{sj} = 0 \qquad (8)$$

where

$\hat{y}_{ti}^j = y_{ti}^j + \varepsilon_i^j$, $\hat{y}_{ti}^{sj} = y_{ti}^s + \varepsilon_i^{sj}$

y_{ti}^j is the vector of point coordinates computed according to (3) based on estimates of transformation parameters $\hat{\beta}^j$

y_{ti}^s is the vector of known coordinates of the authentic point i based on ground surveying

ε_i^j is the vector of point i residuals in parcellation j computed in respect to the accuracy of point coordinates in the original grid

ε_i^{sj} is vector of point i residuals in parcellation j computed respectively to accuracy of ground surveying in the target grid

The required solution is obtained by applying the aforementioned Gauss-Helmert adjustment model (7) (Koch, 1999) with some variations in the involved matrices and vectors:

$$(\beta^{sj})^T = [\underline{a^j} \quad \underline{b^j} \quad \underline{c^j} \quad \underline{d^j}]$$

$$\left[X_i^{sj}\right] = \begin{bmatrix} Y_{oi}^j & -X_{oi}^j & 1 & 0 \\ X_{oi}^j & Y_{oi}^j & 0 & 1 \end{bmatrix},$$

$$(\varepsilon_i^{sj})^T = [\underline{\varepsilon_{yi}^j} \ \underline{\varepsilon_{xi}^j} \ \underline{\varepsilon_{yi}^{sj}} \ \underline{\varepsilon_{xi}^{sj}}]$$

$$\left[Z_i^{sj}\right] = \begin{bmatrix} 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 \end{bmatrix},$$

$$\left[w_i^{sj}\right] / from\beta_{init}^{sj} = \left[y_{ti}^j\right] / from\beta_{init}^{sj} - y_{ti}^s = \left[y_{oi}^j - y_{ti}^s\right] = \begin{bmatrix} Y_{oi}^j - Y_{ti}^s \\ X_{oi}^j - X_{ti}^s \end{bmatrix}$$

Note: if authentic point i, besides the parcellation j, belongs also to parcellation k (*peripheral authentic* turning point (Figure 1, Point 4)), model (8) should be additionally solved for the k parcellation.

The aforementioned model (7) has the following solution for estimates of corrections to the approximation of unknown parameters and for point position residuals (Mikhail & Ackerman, 1976), (Koch, 1999):

$$\hat{\beta} = (X^T (Z\Sigma_{xs} Z^T)^{-1} X)^{-1} X^T (Z\Sigma_{xs} Z^T)^{-1} w$$

$$\hat{\varepsilon} = -\Sigma_{xs} Z^T (Z\Sigma_{xs} Z^T)^{-1} (X\hat{\beta} + w) \tag{9}$$

where

$$\Sigma_{xs} = \begin{bmatrix} \hat{\Sigma}_x & 0 \\ 0 & \Sigma_s \end{bmatrix}$$

$\hat{\Sigma}_x$ - is the covariance matrix of point coordinates estimates in the original grid computed during pre-processing (Klebanov & Doytsher, 2008). Matrix $\hat{\Sigma}_x$ has a block diagonal structure composed of sub-matrices referring to separate parcellations:

$$\hat{\Sigma}_x^j = \hat{\sigma}_{0x}^{j\,2} (N_x^j)^{-1}$$

where for j parcellation

$\hat{\sigma}_{0x}^{j\,2}$ - unit variance estimate

N_x^j - normal matrix

Σ_s - is the covariance matrix of authentic point position accuracy computed from ground surveying in the target grid.

Covariance matrix of unknown parameters estimates is computed as $\hat{\Sigma}_\beta = \frac{\hat{\varepsilon}^T \Sigma_{xs}^{-1} \hat{\varepsilon}}{r} (X'(Z\Sigma_{xs} Z^T)^{-1} X)^{-1}$, where r is the system redundancy.

For peripheral non-authentic turning point i belonging to adjacent parcellations j, k, m, … ($\hat{y}_{ti}^j = \hat{y}_{ti}^k = \hat{y}_{ti}^m = ...$), the adjusted coordinates might be computed in target grid as $X_i^j \hat{\beta}_{adj}^j + \hat{\varepsilon}_i^j = X_i^k \hat{\beta}_{adj}^k + \hat{\varepsilon}_i^k = X_i^m \hat{\beta}_{adj}^m + \hat{\varepsilon}_i^m = ...$.

4. REAL DATA PROCESSING

The proposed method has been tested on real data that includes a group of 11 adjacent cadastral blocks (see Figure 1). Except one of the cadastral blocks, all the other blocks include mutation plans that have been prepared according to preliminary municipal planning aimed at replacing existing parcels by new ones, generally measured with higher accuracy. The cadastral block maps have been digitized (by scanning the maps and by semi-manual sampling of the parcel turning points) – each block in its local grid (a grid which played according to the suggested method the role of origin grid). Some of the internal parcel turning points which also belong to the mutation plans have accurate coordinates (from the mutation plans). Thus parcel turning points belonging both to cadastral parcellation and to mutation plans fulfilled, according to the suggested method, the role of authentic points with two sets of coordinates – one in the local grid (from digitization) and another in the national geodetic grid (from accurate measurements carried out while preparing the mutation plans). The covariance matrix of digitized points coordinates has been set according to the estimated accuracy of the scanning and sampling process: about 0.8 mm on the map, which is 2 meters on the ground (as these block maps were plotted at a scale of 1:2,500). The covariance matrix of point coordinates surveyed during the mutation plans preparation has been set according to the estimated accuracy of geodetic network and ground measurements of 0.1 meter.

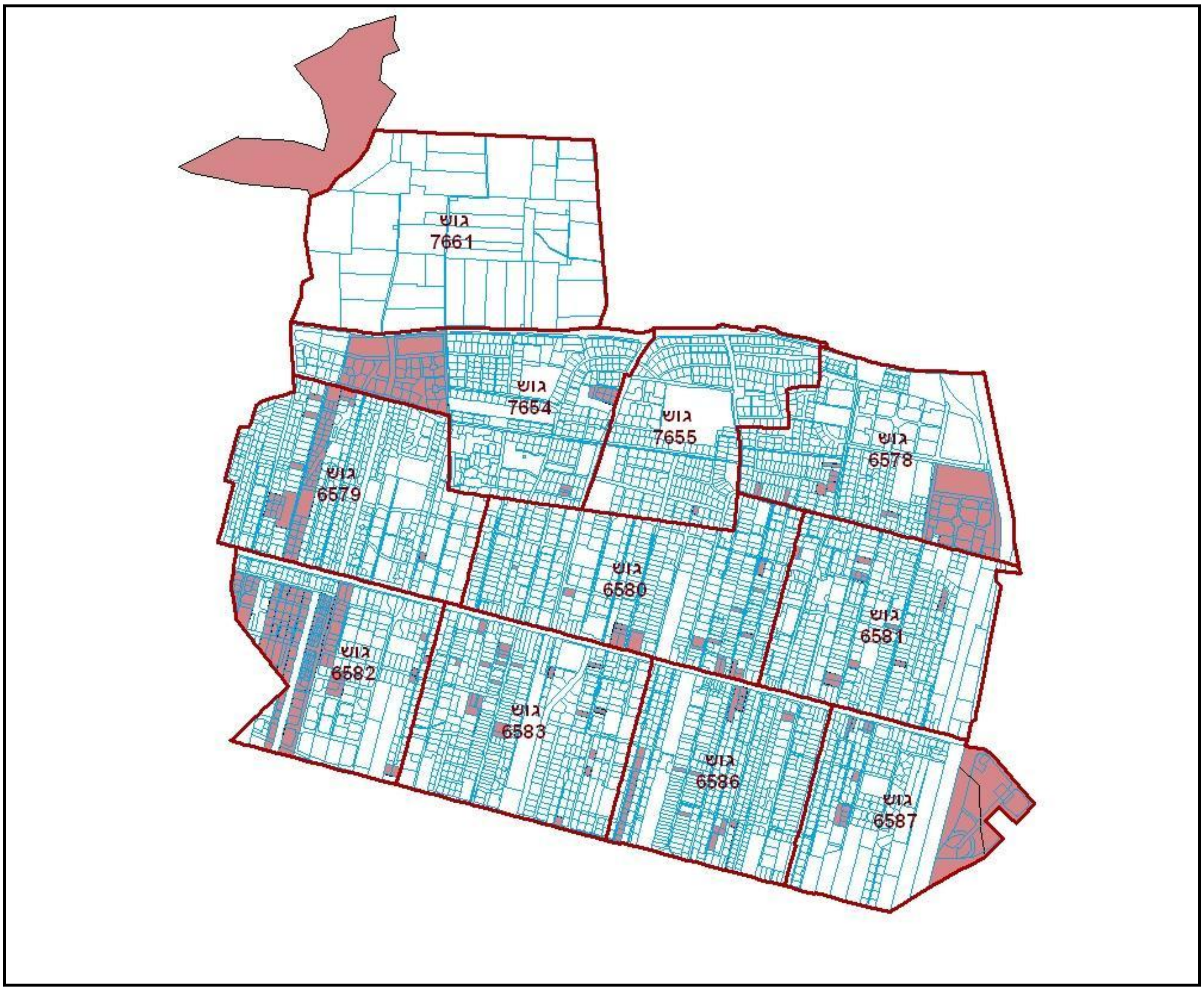

Figure 3. Tested site: 11 blocks (dark areas are the mutation plans)

Aiming to compose a seamless cadastral continuity, two methods have been carried out: (i) the existing - which is used nowadays by the Survey of Israel (SOI) to join adjacent cadastral blocks); and, (ii) our proposed method. According to the existing method, block maps have been separately transformed based on the authentic points belonging to each separate block. Following that, adjacent blocks have been connected by computing the average position of adjacent peripheral turning points. According to the proposed method, transformation and connection operations have been performed simultaneously during the adjustment process. We implemented twice the proposed method on the 11 cadastral blocks of the test area by using two types of transformation: (i) a four parameters similarity transformation; and, (ii) a six parameters affine transformation. The results are summarized in Table 1.

Table 1. Point position accuracy of the existing and the proposed methods

Type of transformation	Existing method (meters)		Proposed method (meters)		Improvement Ratio (existing vs. proposed)	
	MSE	Max residuals	MSE	Max residuals	MSE	Max residuals
Similarity (4 parameters)	1.71	5.15	0.90	2.20	1.9	2.3
Affine (6 parameters)	3.48	13.04	0.61	1.38	5.7	9.4

Notes: (i) Residuals of the existing method have been computed as the differences between positions of peripheral block points (separately transformed) and their average positions; MSE has been computed as the sum of squared differences divided by the number of points

(ii) Residuals of the proposed method have been computed according to equation (9); MSE has been computed according to $\sigma_0 = \sqrt{\frac{\hat{\varepsilon}^T \Sigma_{xs}^{-1} \hat{\varepsilon}}{r}}$, where r is the system redundancy

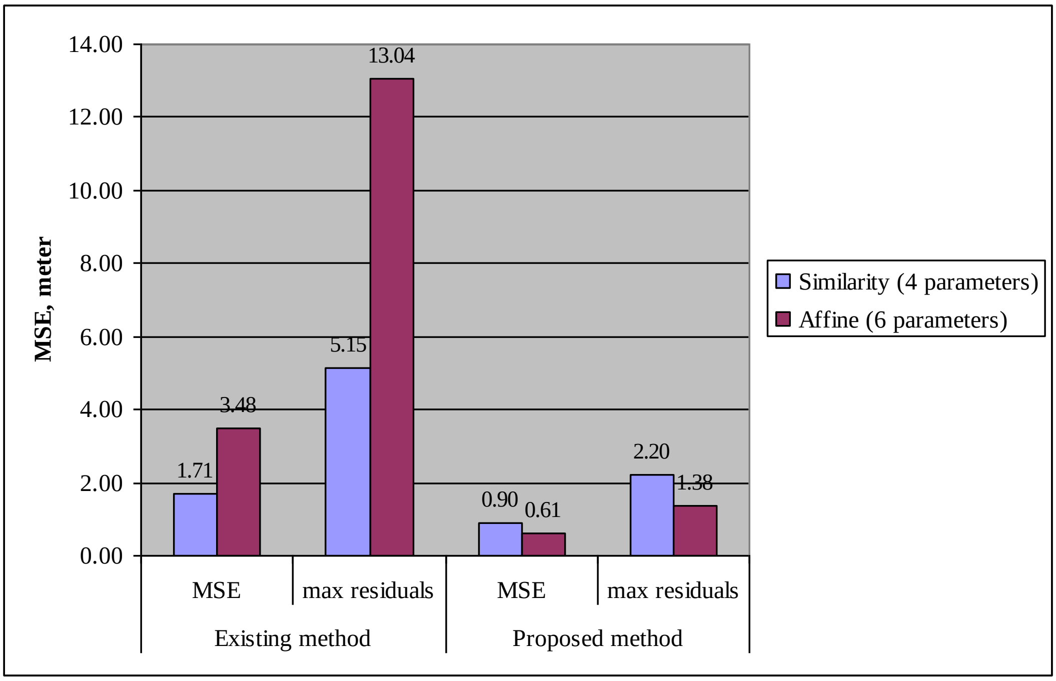

Figure 4. Point positions accuracy

Taking into account the initial estimated accuracy of the scanning and sampling process (2 meters), it can be observed from Table 1 and Figure 4 that the proposed method is able to join separate cadastral blocks that have been digitized separately into a seamless cadastral continuity while achieving an improved homogeneous accuracy in comparison with that of the initial estimated accuracy. The achieved accuracy is 0.90 meter for the similarity transformation and 0.61 meter for the affine transformation, and residuals up to 2.20 and 1.38 meters respectively. On the other hand, the existing method caused a considerable decrease in point position accuracy and residuals (poorer quality than that of the proposed method by a factor of 1.9 to 2.3 for the similarity transformation). A more significant decrease of point position accuracy is observed when the affine transformation is applied (poorer quality by a factor of 5.7 to 9.4).

It is worth noting that the proposed method is able to reach improved results when applying a six parameters affine transformation for composing cadastral continuity based on graphic source whereas for the existing method a four parameters similarity transformation appears to be a preferable. Apparently, affine transformation of cadastral blocks as separate entities in the existing method causes large discrepancies of peripheral point boundaries of adjacent blocks. On the other hand, in the proposed method while applying a global adjustment, the flexibility of the affine transformation enables successfully matching adjacent block boundaries and significantly improving position accuracies.

5. CONCLUSION AND FUTURE WORK

Applying the proposed CT method to the global adjustment of adjoining parcellations enabled us (i) to convert separate cadastral works prepared in different origin grids into a uniform cadastral continuity in the geodetic target grid; (ii) to reduce position discrepancies between adjoining cadastral parcellations; and, (iii) to increase the position accuracy of parcel boundary turning points compared to the existing boundary matching method.

An additional study is planned to analyze issues that might considerably affect the outcome of the proposed method. Among these are the optimal number of transformation parameters referring to the separate parcellations during the global transformation and adjoining boundaries adjustment. An additional topic is the issue of optimal vs. non-optimal scattering of authentic points within the adjusted area as well as their number.

Applying the proposed CT method on a nationwide level, including calculation of tens of thousands of transformation parameters and millions of peripheral turning point coordinates, is certainly not a simple task from the computational resources required standpoint. Therefore, additional efforts are planned to simplify the proposed solution - to improve the adjustment model - in order to obtain the optimal algorithm and increase the effectiveness of the entire computational process.

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BIOGRAPHICAL NOTES

Mr. Michael Klebanov graduated from the Technical University of Cheliabinsk, Russia, in 1985 and received his Engineer Degree (cum laude) in Civil Engineering. In 2000-2002, he completed advanced studies at the Technion - Israel Institute of Technology, Division of Geodetic Engineering, towards a Licensed Surveyor Degree. He received in 2008 a Master Degree in an M.Sc./Ph.D. direct track in Mapping and Geo-Information Engineering from the Technion and is currently a Ph.D. candidate. Since 1991, he has served with the Survey of Israel – the national agency for geodesy, cadastre, mapping and geographic information systems of Israel.

Prof. Yerach Doytsher graduated from the Technion - Israel Institute of Technology in Civil Engineering in 1967. He received a M.Sc. (1972) and D.Sc. (1979) in Geodetic Engineering also from the Technion. Until 1995 he was involved in geodetic and mapping projects and consultation within the private and public sectors in Israel. Since 1996 he is a faculty staff member in Civil and Environmental Engineering at the Technion, and is currently the Dean of the Faculty of Architecture and Town Planning. He also heads the Geodesy and Mapping Research Center at the Technion.

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