A Method For Building Legal Digital Cadastre Without Using Cadastral Measurements Field Book Data – Is It Accurate Enough?

Jad JARROUSH, Dmitri BRICKMAN, Israel

SUMMARY

Usually, in countries where the cadastre system is based on the Torrens method, the cadastral block map is accompanied by field books and field sheets. The field book is the entity that documents the measurements of the boundaries of cadastral parcels during the land settlement process, and describes their linkage to the national cadastral control grid. Correspondingly, the field sheet plan is compatible with the same block map which documents all the fronts' measurements between the boundary points and other geometric constrains such as distances between boundary points and national control points, parallel boundary lines, etc…

Since most of the cadastral blocks were established in the far past, their measurements are based on the chain method. Thus, according to the instructions of many surveyor regulations, in order to reinstate the position of the boundary points in the field today, the surveyor should compute the coordinates of the cadastral boundary points in the up-to-date national control grid and mark them physically with wedges. This process involves analyzing and computing the documented measurements in the field book which is considered to be a complex and expensive process since it consumes time and effort. In some cases, field books have even got lost. In these cases, the instructions of cadastral regulations recommend surveyors to digitize the graphical block map and try to manually adjust the documented measurements in the field sheet with the graphical digitized point coordinates.

This paper proposes a new method that enables surveyors to automatically adjust the measurements and geometric constrains of field sheets using the least-squares technique and based only on digitized coordinates of boundary points of graphical cadastral block maps, and without using the measurements of the cadastral field book. The paper also demonstrates the accuracy of the results of the proposed method by illustrating a case study of calculating the grid coordinates of boundary points of a specific cadastral block and comparing them with the computation results using measurements data of field books. The method is implemented by Geo-Cadastre, a unique cadastral application based on Autodesk's AutoCAD software. Geo-Cadastre was specifically designed for cadastral computations complying with the requirements of the Israeli cadastral regulations. Geo-Cadastre includes unique cadastral functions which are also suitable for other countries. Geo-Cadastre was developed in cooperation by Omnitech, an authorized value added reseller of Autodesk in Israel, and Geo-point, a geo-technological, cadastre, real-estate and civil engineering firm.

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1. Introduction

The State of Israel is currently in a process of transforming its analog cadastre system into a legal digital system. This process is defined as a national geodetic process (herein denoted as "*the process*"). The process is implemented by the Survey of Israel (SOI), Israel's government agency for mapping, geodesy, cadastre and geoinformatics, responsible for the national infrastructure in these domains. One of the geodetic computational challenges that the SOI encounters during the process is adjusting the measurements data of the chain method that described the cadastral block and parcels geometry, which are documented in the field books, with the cadastral front measurements documented in the block sheets (Benhamu 2006; Jarroush 2006). The challenges in this process are related to the time and effort required for successfully completing it. The steps which are needed for fulfilling the process of transforming the current Israeli cadastre to a digital system involve the following tasks:

1. Searching the SOI archive for all the authentic cadastral measurement foundation materials which enable licensed surveyors to reinstate the original boundary points in the field. Cadastral foundation materials include field books, block sheets, mutational plans, etc…
2. Calculating the coordinates of the boundary points in the original grid network which was used during the land settlement. Since the cadastre system in Israel is based on Torrens method, and since most of the lands have been settled using the chain method measurements, this task involves mostly computing the coordinates based on the chain method measurements technique. In other situation, especially after the introduction of Total Station measurements, this process might be easy since the final coordinates derived from Total Station are taken as a final result for this task.
3. Adjusting the measured fronts of the cadastral parcel with the fronts calculated from the computed coordinates in task (2) above. This task includes also adjusting geometric constrains of the boundary points such as straight lines or parallel boundary lines, etc…
4. When there are mutational plans inside cadastral blocks that had changed an original division of a specific block, a topological procedure may be needed for closing spatial geometric gaps inside the block.
5. Looking for authentic cadastral points which are measured and documented in the foundation measurements data in task (1), linking them to the up-to-date national control grid via the surveyors' ordnance. The coordinates of the authentic points are used for transforming or computing all the boundary point coordinates to the up-to-date national control grid.
6. Building the topological relationships between the boundary points, the fronts and

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parcels while trying to adjust the computed area derived from coordinates to the legal areas which are registered in the real-estate land registration office (Benhamu 2006).

The above tasks may be successfully accomplished only if the cadastral foundation materials are found. Unfortunately, in several cases, especially in the northern part of Israel, neither field books nor block sheets may be found. In other cases only block sheets exist. In these two situations final coordinates of digitized points in the Israeli new Transverse Mercator (ITM) grid are supplied by the SOI for fulfilling the second and the third tasks mentioned above. If there is a block sheet for a cadastral block that has no field book for reinstating and computing boundary coordinates, the fronts' distance measured and documented in such a block sheet should be adjusted carefully.

The result of the process is to define a digital cadastral block using coordinates in the national grid when these coordinates are used as an evidence to define the location of the cadastral parcel boundaries in the court.

Obviously, such a process is too complex and consumes significant time and effort, and in the normal case the accuracy of the final coordinates of the boundary points calculated using the least-square technique described in Jarroush (2009) and in Klebanov and Doytsher (2008) might reach 15 to 50 cm. In other cases, when using digitized coordinates derived from paper block, due to the lack of foundation cadastral materials, the accuracy might surpass 1 meter.

2. Motivation – Semi-Digital Cadastral Block

In light of the above, the process of transforming the analog cadastre system in Israel into a legal digital system suffers from complexity, lack of cadastral foundation materials, and low inherent accuracy of the derived "Digital Cadastral Block".

The complexity of the process could be divided into two main domains:

1. Mathematical complexity: the mathematical complexity is discussed in several papers, e.g., Jarroush (2006) and Klebanov and Doytsher (2008). The researches have used the least-square technique for adjusting the chain geodetic measurements with front distance measurements combined with geometric constrains. In addition it is trying to adjust the legal register areas of the cadastral parcel with the computed areas calculated by coordinates according to the Israeli surveyors' regulations. Unfortunately, to date there are no clear instructions for calculating the weights of the measurements for acquiring homogeneity in the least -squares computation results. This task is very important and shall be treated as soon as possible by the SOI.

2. Time and effort complexity: the steps that require the largest effort are (a) looking for the authentic cadastral points in the field (task 5 in section 1 above); and (b) the computation of the field book chain method and adjusting the cadastral parcel fronts registered in the block sheets to those calculated from coordinates.

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Obviously, there is a need to minimize the time and effort and optimize the accuracy of the results of the "Digital Cadastral Block" when the field book does not exist, through the cadastral foundation materials used for reinstating the boundaries. The solution should include a new process for adjusting the digitized coordinates which are provided by the SOI to meet the parcel measured front distances that are documented in the block sheet and their registered areas that are documented in the real-estate registration office. The result of such a new process would be called "*Semi-Digital Cadastral Block*".

3. The Proposed Solution for Building the Semi-Digital Cadastral Block

For establishing the Semi-Digital Cadastral Block we should use the digitized coordinates of the cadastral block that are provided by the SOI with the measured front distances and geometrical constrains which are documented in the cadastral sheet block, in addition to the legal registered areas of the cadastral parcels in one least-square process execution. Since the field book does not exist, such a process would suffer from the lack of the noises of the original measurements. Actually, without these noises the coordinates of the digitized cadastral boundaries points would be bad artificial pseudo measurements used for reinstating the authentic wedges in the field.
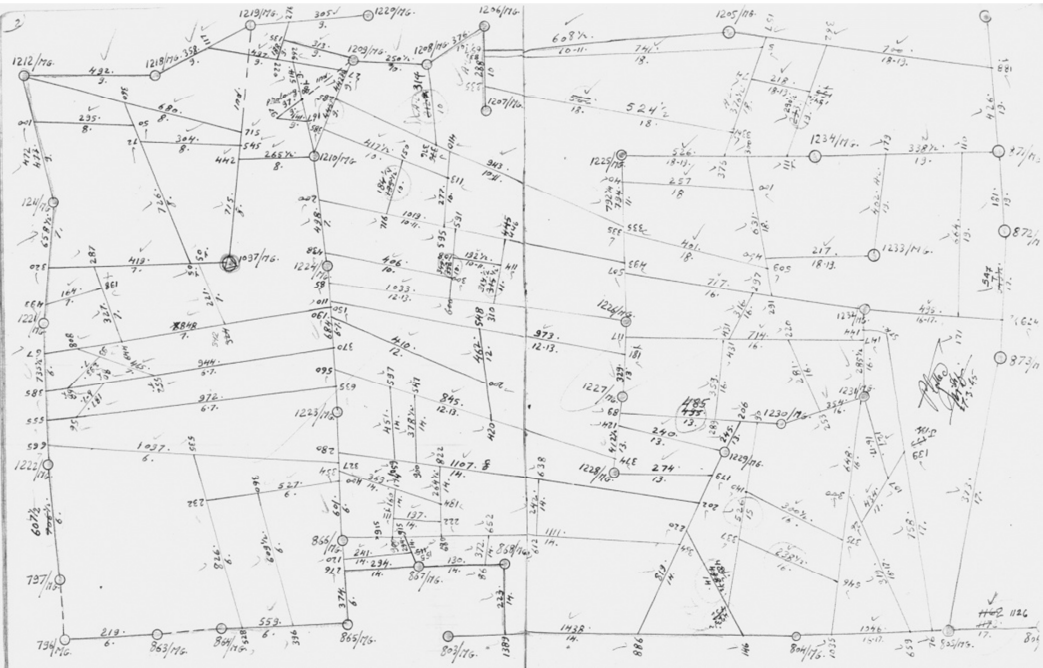

Figure 1: The main network measurement structure of the field book which usually exists at the beginning of each field book

Thus, the main idea of the proposed solution is to build a virtual field book measurements (pseudo measurements) based on the main control point network of the original field book.

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This solution might be derived from:

1. *When the field book exists*: using the first documented page of the field book which contains the main network measurements used as a base for all the chain method measurements that are documented inside the field book (see Figure 1).

   The main control point coordinates could be taken from the SOI cadastral database (these points are shown as circles in Figure 1). Using these coordinates, the surveyor may compute all the other *picket point* coordinates. Those points exist along and between two control points or different other picket points like them. Computing the control point network of the field book enriches the whole geodetic process by adding the original measurement noises.

2. *When the field book does not exist*: building automatic measurements lines of the "pseudo chain measurements" between the control points of the cadastral block. This process could be managed either manually or automatically using existing algorithms from the graphics domain (such as the TIN triangulation algorithm). Figure 2 illustrates quick manual building of main field book network consists of authentic control points of the original field book that contains the measurements of the cadastral block parcel boundaries.
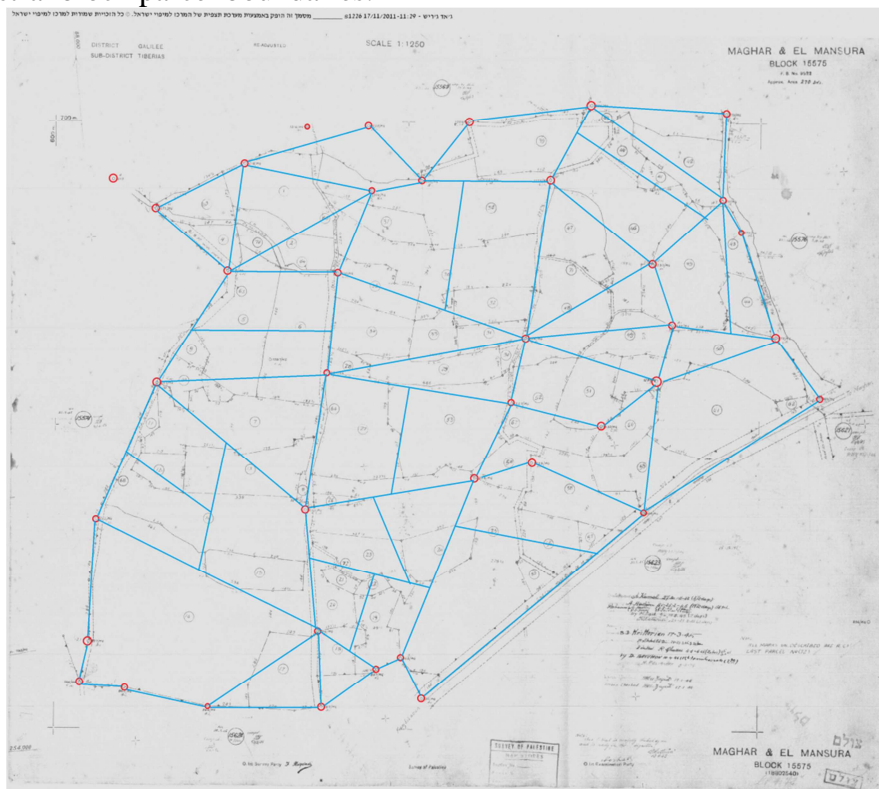

Figure 2: Illustration of a pseudo main network built manually as a base for virtual chain method measurements of a field book that documents the cadastral parcels boundaries geodetically in such a cadastral block

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For inserting the measurement errors or noise, for each measurement line between two control points, the proposed method suggests a measured length with small disclosure that meets the criterion of the Israeli surveyors' regulations which were valid at the time of the registration of the specific cadastral block. For example, until the 1998, the disclosure "ΔL" permitted between the measured front length "L" and the computed length derived from the coordinates of the front's points are given by Formula (1):

$$
(1) \quad
\begin{aligned}
L < 50\,m \quad &: \quad \Delta L_{max} = 8\,cm \\
L \geq 50\,m \quad &: \quad \Delta L_{max} = 0.0016 * L
\end{aligned}
$$

3. After building the "pseudo control point network", the proposed method suggests to ascribe each boundary point in the cadastral block to the closest measurements line that has been built by (1) or (2).
4. For each boundary point which was ascribed to the closest measurements line, the "run" and the "offset" parameters of the chain method should be computed for building the final "*pseudo field book measurements*".

Combining one least-square adjustment computation of the "*pseudo field book measurements*" with the legal measured front lengths and all other geometric constrains which could be derived from the field sheets is the basic process for establishing the "*Semi-Digital Cadastral Block*". This process is equivalent to task (3) in section (1), and was described in full in Jarroush (2009) and Klebanov and Doytsher (2008). It is very important to highlight that in order to attain better results, any authentic cadastral points that exist in the field such as boundary wedge or specific object monuments should be measured and combined in the least-square method as a fix point.
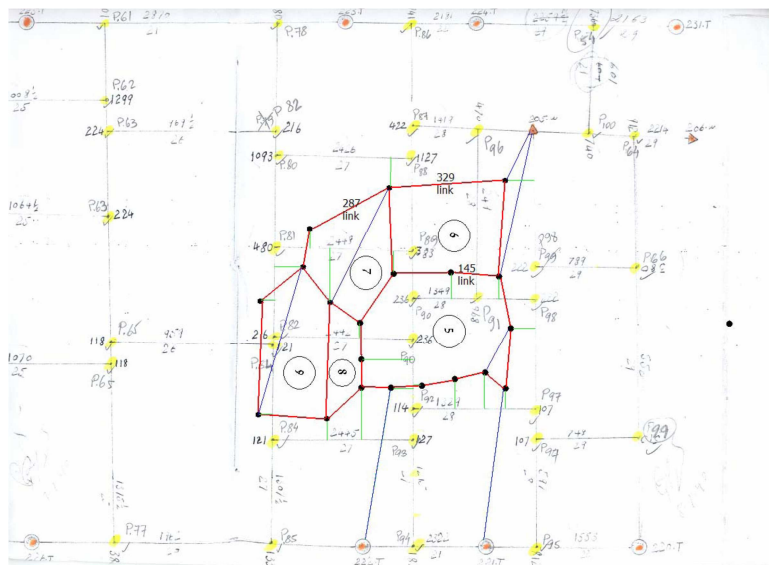

Figure (3): Cadastral parcel boundary points measured using the chain method.

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The main difference between the least-square process involved in the proposed solution and the least-square of the original field book measurements is related to the computation method of the measurement weight matrix: in the proposed solution which uses the "pseudo field book measurements", the weights of the chain method measurements are computed by adding 0.5 mm with the scale of the cadastral block sheet for each measurement according to the covariance expansion law. This act considers the fact that the "pseudo measurements" suffer from another noise derived from the graphical sheet drawing inaccuracy.

Thus, the proposed solution gives higher weights for the measured front lengths, the geometric constrains of the boundaries and to the cadastral authentic object points (such as building or wall corner etc…), than the weights for the "pseudo field book measurements". The main two questions that we have to answer are:
1. How accurate is the "*Semi-Digital Cadastral Block*" in describing the boundaries compared to the "Digital" one?
2. How fast is the "*Semi-Digital Cadastral Block*" in describing the boundaries compared to the "Digital" one?

A case study of a real cadastral block described in both the "Semi" and "Full" digital solution will help us answer these two questions.

4. Work Tools

In order to implement the proposed solution in section (3), a special application based on AutoCAD has been developed by Omnitech, an authorized value added reseller of Autodesk in Israel, and Geo-point, a geo-technological, cadastre, real-estate and civil engineering firm.

The application, called Geo-Cadastre, includes:
- Geodetic coordinate geometry computation functions specializing in Israeli cadastral measurements such as dynamic and interactive chain measurements, etc.
- Building chain method lines inside the CAD project for interactive and dynamic chain measurements, in order to update the whole CAD project based on updated input measurements at any time.
- Automatically ascribing points to measurement lines in the chain method for automatic building of "*pseudo field book measurements*"
- Least-square computations with different weighting methods. The least-square computation function enables surveyors to add fixed coordinates of authentic cadastral measured points that exist in the field sheet and is a part of the field book measurements. Figure 4 describes an example where corners of walls are the boundaries of the cadastral parcel. These points must be measured and inserted as fixed points in the least-square.

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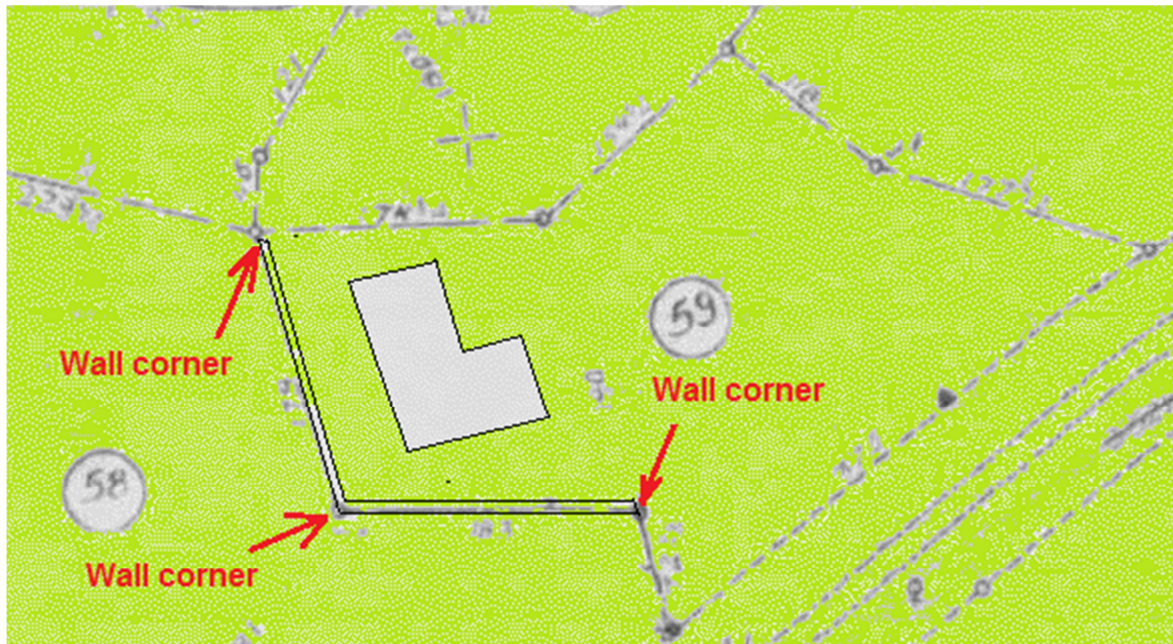Rome, Italy, 6-10 May 2012

Figure (4): An example where corners of walls are the boundaries of the cadastral parcel

- Authentic points may be measured using land survey techniques or through photogrammetry. Photogrammetry may enhance the solution as the surveyor may use the aerial photos to find past authentic points in that do not exist in the field today.

- A tool for detecting measured fronts suffering a fatal error. Eliminating measurements with fatal errors is an important task with any least-square process, since errors would spread to all the results, leading to an inaccurate cadastral product. The fatal measurement error detection criterion is based on surveyors' regulations and best practices prevailing in each country.

The automatic functions of Geo-Cadastre provide an easy and fast execution of the proposed solution for building "*Semi-Digital Cadastral Block*".

5. Case Study: Building Semi-Digital Cadastral Block Number 15575

In order to answer the two questions of how accurate and how fast the proposed solution is, a real task was executed on cadastral block number 15575 with 1:2500 scale.

At the first stage of the experiment, the block was built as a "digital legal block" according to all the steps described in section 1:
  a. Field book and sheet have been acquired from the SOI cadastral archive. The control point coordinates of the field book control network were also acquired.
  b. The control point network measurements of the field book related to block 15575 (described in Figure 1 above) was input into Geo-Cadastre as the basic chain method

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lines details.

c. All the true measurements of the entire field book have also been input into Geo-Cadastre with all the control point coordinates.

d. The fronts' measured lengths with all the constraints were provided to Geo-Cadastre as well.

e. The cadastral parcels have been defined topologically using the computed points including the registered legal areas as they were acquired from the archives of the Israeli real-estate registry office.

f. Least-square process has been executed and "Digital Legal Cadastral Block" with its final boundary point coordinates has been computed.

At the next stage of the experiment the digitized points coordinates of the SOI archive have been acquired, transformed to the old Israeli control network of the 15575 block field book using the main control points consists the block network described in each field book at the beginning (see red circles in Figure 2).

Steps (a) and (b) above have been executed but instead of step (c), the digitized points have been used for building the "pseudo field book measurements" according to section (3). Then steps (e) and (f) have been executed also and finally the "Semi-Digital Block" was derived.

6. Analysis of the Results

After executing the proposed solutions on block 15575, three entities existed:
1. The boundary point coordinates of the digitized block taken from the SOI.
2. The boundary point coordinates of the "Legal Digital Cadastral Block".
3. The boundary point coordinates of the "Semi Digital Cadastral Block".
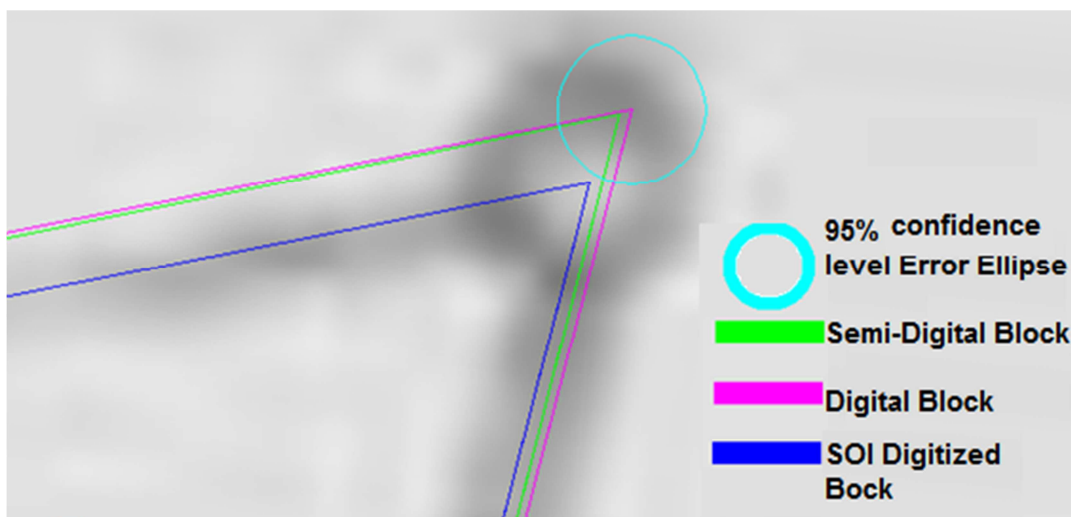

Figure (5): A boundary point which is described by the three entities: digital block in magenta, semi-digital in green and the digitized in blue; the cyan circle describes a 95% confidence level error ellipse derived from the

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least-square process of the digital block.

Two methods were employed in order to check the results of the proposed solution:

- Checking if the "Semi-Digital" boundary points are located inside the error ellipse of the computed coordinates derived from the full digital block definition least square process at 95% confidence statistical level. Figure (5) describes an example for a specific situation when the proposed solution enhances the digitized boundary point and let it get inside the error ellipse of the digital block which is considered the most accurate.
-
- Comparing the number of the measured length of the parcel fronts that passed the criteria described in Formula (1) after and before executing the proposed solution. Since the weights of the front measurements in the semi-digital solution is higher than those used in the full digital solution, as described later above, we assume that the percentage of the fronts length that might meet the criteria in Formula (1) would be higher in the semi digital block from the digital block solution, and it is a desirable result.
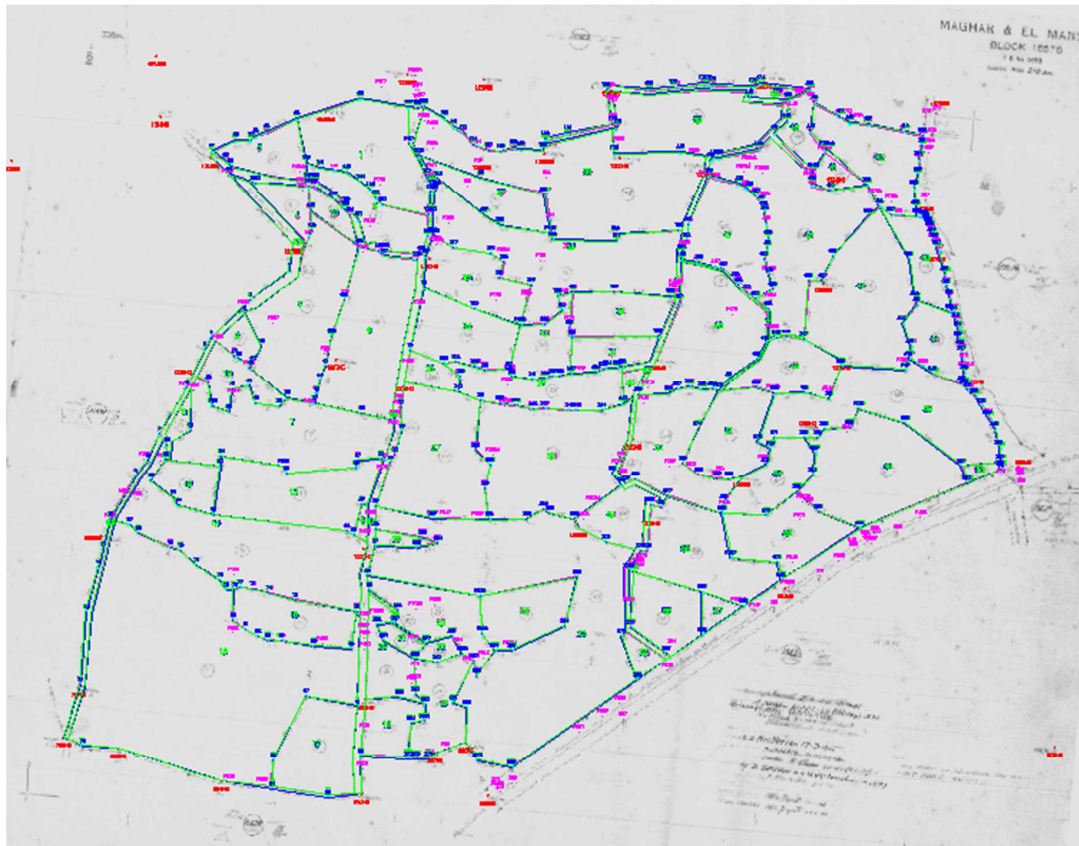

Figure (6): The block results of the three entities: digital block in magenta, semi-digital in green and the digitized in blue

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The results of the first checking method showed that only **17% of the digitized points** were inside the error ellipse computed in 95% confidence level of the digital block boundary points, versus **68% in the Semi-Digital block** derived from the proposed solution of this paper (see Figure 6).

The results of the second checking method are shown in Table 1:

Table (1): Statistics of the fronts that meet the criteria in Formula 1 before the least-square and after the least-square in the digital block solution and in the proposed semi-digital block solution.

	Description	Digital Block				SOI Digitized Block			
		Before Least Square		After Least Square		Before Least Square		After Least Square *(Semi-Digital)*	
1	Total Fronts	319	100%	319	100%	319	100%	319	100%
2	Fronts that meet the criteria	79	25%	314	98%	75	24%	315	99%
3	Fronts that did not meet the criteria	240	75%	5	2%	244	76%	4	1%

It is obvious that the "*Semi-Digital Block*" solution derived the same or even better results
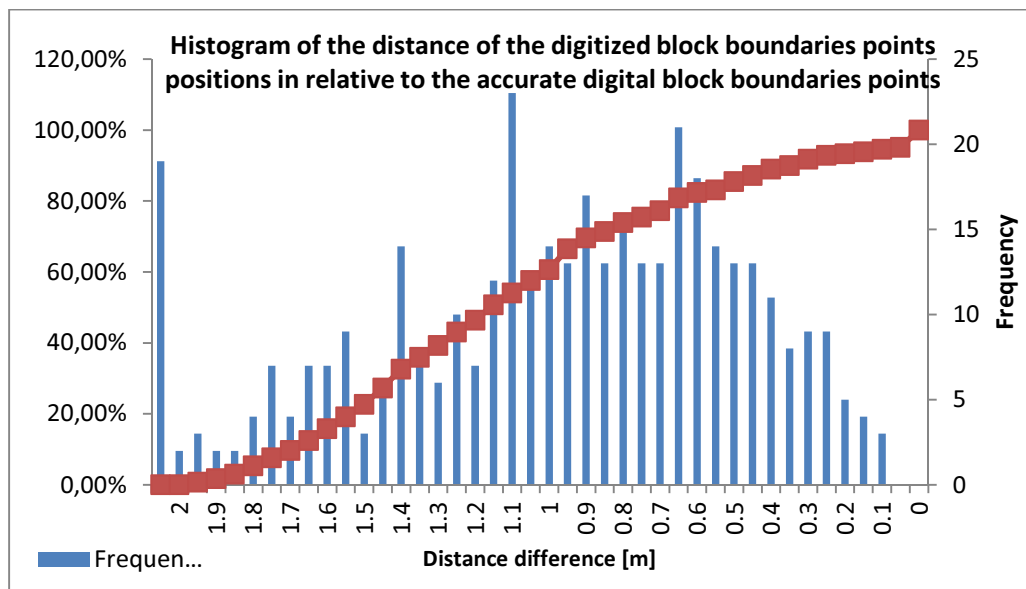

Figure (7): Histogram describes the distances of the SOI digitized block boundaries points positions in relative to the accurate digital block boundaries points

In addition, the percentage of the boundary points of the "SOI Digitized" block that have been inside the 95% confidence error ellipse of the digital block least square solution, increases

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from 17% to 68% when executing the proposed solution for producing the "Semi-Digital" block.

For further investigation, two histograms were built with their accumulated percentages:
- The histogram that describes the distance of the digitized block boundary point positions relative to the accurate digital pair.
- The histogram that describes the distance of the semi-digital block boundary point positions relative to the accurate digital pair.
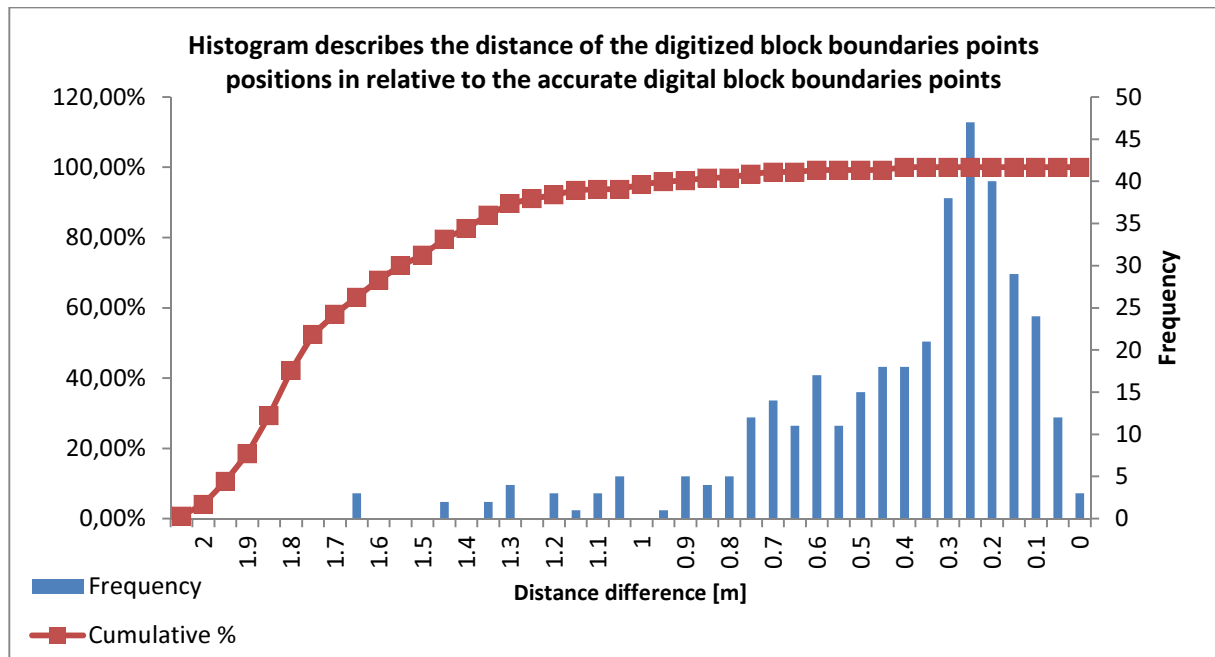

Figure (8): Histogram describes the distances of the semi-digital block boundaries points positions in relative to the accurate digital block boundaries points

The results show that only 50% of the digitized block boundary point positions are far more than 1.1 meters from the accurate digital block boundary points. This indicates that the accuracy of the digitized cadastral block provided by the SOI is about 1 meter.

After execution of the proposed solution for semi-digital cadastral block it could be shown that more than 95% the points are less than 1 meter from the digital block solution. The gravity center of the distances is around the 0.3 meter.

Note that Jarroush (2009) has shown that the digital block solution error ellipse in 95% confidence level might be between 0.15 to 0.5 meters in the average case in the Israeli cadastre.

It is to highlight that the least-square process, in both the semi and the full digital block, has managed to close all the legal areas with the calculated area of the cadastral parcel derived from coordinates which was considered as a complex manual task for most of the Israeli licensed surveyors.

7. Summary

In fact, the proposed method of building "*Semi-Digital*" cadastral block in this paper skips the step of computing all the coordinates of the boundary points derived from the real field book measurements and instead trying to build a "*pseudo field book measurements*" automatically from the digitized block points provided directly from the GIS national database of the SOI.

The experiment which was executed on block 15575 in the northern part of Israel with scale of 1:2500 has proved that the semi-digital solution enhances the accuracy of the digitized block entity and brings the parcel legal fronts and areas to meet the criterion of the Israeli regulations. Thus such a "***Semi-Digital***" cadastral block could be used:
- As a base for zoning plan with low level scale such like 1:2500, 1:5000 and more.
- As a base for building the legal digital cadastral database for blocks for which no field book exists in the archives of the SOI.
- As an initial entity for detecting boundary invasions using aerial photogrammetric solutions.

In the authors eyes, the "Semi-Digital" Cadastral block could be used also for building the legal digital cadastral database (LDC) in rural areas with the exception of situations in which inaccuracy of 0.5 meter could affect excluding or including whole trees (such as olive trees) from a specific parcel.

In addition, the time effort needed for building the semi-digital cadastral block compared to the digital block could be less than 90%, thus in different areas of the country the SOI could save a lot of money by using it for building its LDC.

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BIOGRAPHICAL NOTES

Dr. Jad Jarroush was born in Nazareth in 1977. Jad earned a B.Sc. in Geodetic Engineering with honors in 2000, a B.Sc. with honors in Civil Engineering and M.Sc. in Geodetic Engineering in 2002, and a PhD in Mapping and Geo-Information Engineering in 2009 - all from the Technion, Israel's Institute of Technology. In 2010 Jad founded Geo-Point, in partnership with Ofek Arial Photography, one of the largest companies in the Middle East in this field. Geo-point specializes in geo-Information, cadastre, real-estate and civil engineering, especially in building information management (BIM). Jad is currently the CEO of Datumate, a vendor of geomatic expert systems. Jad is active in the academy at the Faculty of Environmental and Civil Engineering in Israel's Technion. Jad is also a professional consultant in the cadastre field to the Survey of Israel (SOI). Jad's main fields of interest include cadastre, 3D cadastre, dynamic cadastre, legal digital cadastre, GPS RTK, VRS GPS, VRS RTK GPS,3D infrastructure presentation models and ground photogrammetry.

Mr. Dmitri Brickman was born in Russia in 1964; he earned his M.Ac. in mechanical engineering in 1986. Dmitri started to develop applications for AutoCAD in 1989. Dimitri is currently the Autodesk development manager of Omnitech, an authorized value added reseller of Autodesk in Israel. Dmitri has more than 20 years experience of developing Autodesk programs, and developed more than 30 applications on top of Autodesk solutions such as AutoCAD, AutoCAD Map3D, AutoCAD Civil3D, AutoCAD Architectural, Revit and more. In the last two years Dimitri specialized in Autodesk solutions for surveyors, catering for the needs of the Israeli land surveying market.

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