REINSTATING AND MARKING SPATIAL PARCEL BOUNDARIES AS A BASE FOR A 3D DIGITAL CADASTRE BY MEANS OF REAL TIME KINEMATICS GPS

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ABSTRACT

The inability of the existing 2D Cadastre to facilitate the rapid developments on one hand and the growing land shortage on the other hand necessitates a fundamental change in the cadastral system. Based on the existing 2D cadastre, a 3D cadastre system for land rights registration is proposed in this paper. A general description and definitions of its components are detailed. Additionally a description of a GPS RTK reinstating/marking technique for 3D spatial parcel is also detailed

Key words: Two–dimensional Cadastre; Three-dimensional Cadastre; Spatial body; Three dimensional Parcel; Surface-3D Cadastre; Non Surface-3D Cadastre.

INTRODUCTION

In addition to land-right registration, one of the objectives of the cadastre is facilitating Civil Engineering planning and development activities. In recent years, as a result of population increase, economic development, and high living standard, the rapid development left no unexploited land in the developed areas, in particular in the northern part of the state of Israel, in the area of Tel-Aviv and in the area of the Capital, Jerusalem. In these areas, land resources have been utilized almost completely (Doytsher, Forrai and Kirschner, 2001).

The increasing population density and land shortage in densely populated areas required additional solutions for urban development, such as more efficient utilization of the above land, subterranean, and submarine spaces.
Yet, these solutions may cause legal difficulties. For example, according to Israeli law, parcel bounded by the center of earth and heavens. So, a parcel owner can stop the digging of a tunnel passing through subterranean space of his parcel, although this tunnel could be essential planned for solving traffic problems.
Additionally, cadastre has a dual nature. The duality of the cadastre originates from cadastral mapping on the one hand and from physical marking or reinstating on the other hand. From a legal point of view, physical evidence in the field is superior to cadastral mapping in Israel. Hence the importance of physical evidence of boundary points, preferably permanent ones is self-evident. Unfortunately there are no everlasting or indestructible points, thus parcel boundaries must be reinstated again (Fradkin, 1998). In future such legal aspects will cause a slow-down of development both below and above the surface. Solving these issues requires a three-dimensional cadastre.

THREE-DIMENSIONAL CADASTRE – A POSSIBLE SOLUTION

As described by Doytsher et al (2001), the primary task in the process of defining and implementing a three-dimensional cadastre is developing three-dimensional models by performing changes in the definition and character of the present cadastre. These changes will enable the transition from a planar cadastre to three-dimensional cadastre.
The basic principles of the 3D-Cadastre involves two essential changes, which are:

1. Each surface point describing property boundaries is to be described by (x,y) coordinates in horizontal control network and height h in a vertical control network, thereby transforming the planar information into a spatial one;
2. An alternative definition of the concept of "parcel" as cornerstone for the three-dimensional cadastre.

The main goal is not only to define 3D cadastral system, but also to maintain the legal aspects of Cadastre. Physical evidence in the field is superior to the legal point of view of cadastral mapping. In 2D cadastre, surveyors using marking wedges in the field implement this evidence.
3D cadastre system permits existing of parcels in the space. Physically, marking wedges in the space is not practicable. As long as 3D parcel includes earth surface, physical evidence could be implemented. So, the future 3D cadastral system may be separated into two parts:

I. *"Surface-3D Cadastre": 3D cadastre related to the earth surface, permit physical evidence.*

II. *"Non-Surface-3D Cadastre": 3D cadastre above or below the surface, which physical evidence is not practicable.*

Separating the 3D cadastre will facilitate a simple and rapid transition. "Surface-3D Cadastre", will enable people to keep using the main 2D partition, "Block number" and "Parcel number", adding the element of volume to the parcels. Accordingly, by the "Non-Surface-3D Cadastre", new partition of the space above and below the "Surface-3D Cadastre" could be implemented.

It must be emphasized that the transition to a 3D cadastre should be a simple process if rapid implementation is required. Thus, the transition should be founded on 2D Cadastre. But, is separating the cadastre system leading to separate definitions of "parcel" in a future 3D Cadastre?

A SPATIAL THREE-DIMENSIONAL PARCEL

The present concept of a parcel in the planar approach must be substituted by an alternative spatial concept; this is a cornerstone in the definition of the three-dimensional cadastre. Let us separate the discussion into two parts of cadastre.

"Surface-3D Cadastre"

Establishing the "*Surface-3D Cadastre*" and solving the issues mentioned above, the three-dimensional concept requires the transition of planar parcel into a spatial body, based on two demands:

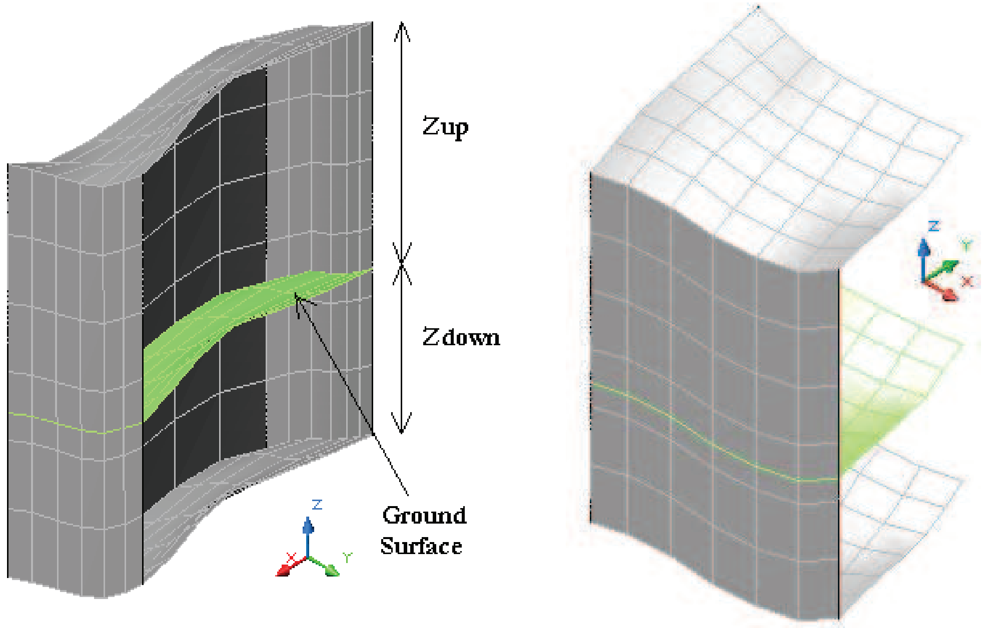
1. The essence of the spatial body must preserve the shape of the planar parcel as viewed from above.
2. Allotting volume dimensions to the body by determining its third dimension.

These two demands permit at least two precise definitions of the spatial three-dimensional parcel:

Definition A

The three-dimensional parcel is a prismoid. Its vertical edges, as viewed from above, are a polygon consisting of the boundary points of the two-dimensional parcel. While its upper and lower edges are in parallel to the surface at a height Z_{up} and depth Z_{down}. If S is the projected area of the three-dimensional parcel (which is the registered area of the two-dimensional parcel), then, according to this definition, the volume of the parcel is:

$$V = S \cdot (Z_{up} + Z_{down}) \qquad (1)$$



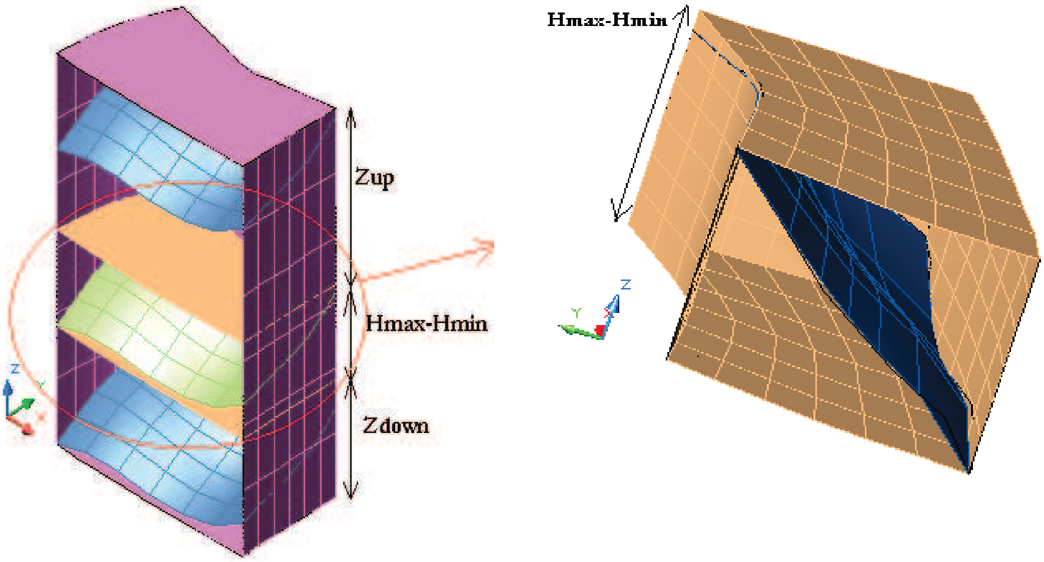
A b

Figure (1): a and b illustrate the spatial body according to definition A.

Definition B

The three-dimensional parcel is a prismoid. Its vertical edges, as viewed from above, are a polygon consisting of the boundary points of the two-dimensional parcel. While its horizontal edges are parallel to the mean sea surface, the upper edge at height Z_{up} from a point of maximum height H_{max} inside the parcel, and the lower edge at a depth Z_{down} from a point of minimum height H_{min} inside the parcel. If S is the projected area of the three-dimensional parcel (which is the registered area of the two-dimensional parcel), then, according to this definition, the volume of the parcel is:

$$V = S \cdot (Z_{up} + Z_{down} + H_{\max} - H_{\min}) \qquad (2)$$



a b

Figure 2: a illustrates spatial body according to definition B;
b illustrates Basic body of 3D-parecl.

For completing this definition, we must define a Basic body of 3D-parcel, which is a prismoid whose vertical edges, viewed from above, are polygon consisting of the boundaries of the two-dimensional parcel; its horizontal edges are in parallel to the mean sea surface. The top edge touches the point of maximum height H_{max}, the bottom edge touches the point of minimum height H_{min} inside the parcel.

The basic body of the three-dimensional parcel creates the basic spatial layer, from which the two horizontal edges of the spatial parcel are linked directly according to B.

For both definitions, Z_{up} and Z_{down} are values supplied by the National-authorities as a function of the parcel location.

These two definitions allow the planar map paper continuity of usage.

"Non-Surface-3D Cadastre"

The "*Non-Surface-3D Cadastre*" is founded above and below the "Surface-3D Cadastre. It consists of "3D Non-surface spatial body", which is defined as:

> A 3D mathematical body consists of enclosed sides. Every side could have mathematical representation, or a flat surface composed of polygon, or both of them. A side may be vertical, horizontal or even sloped. The volume of the body is calculated according to its mathematical shape.

This definition is general, it includes definition A & B suggested by *"Surface-3D Cadastre"*.

ASPECTS OF BOUNDARY MARKING/REINSTATING OF SPATIAL PARCEL BY MEANS OF RTK FOR DIGITAL THREE-DIMENSIONAL CADASTRE

The discussion will concentrate on "*Surface-3D Cadastre*" spatial body. Comparing the process of conventional reinstating boundaries of a 2D-parcel, with boundary marking process of "*Surface- 3D Cadastre*" spatial body, according to definition A & B, reveals that the two are very similar. The additional requirements are:

1. Providing every boundary point with height 'h', for both of the definition A& B, and linking it to the vertical network.
2. Constructing DTM or TIN grid, in order to describe the earth surface, according to definition A. Measuring and finding the maximum and minimum height points, according to definition B.

Adding heights to the parcel (the projected area of the spatial body) was not required in the 2D cadastre .It is a novel process related to the 3D Cadastre. Therefore, we will not need to reinstate heights, so the process it self does not introduce any new potential conflicts with the existing data. However, the reinstating of parcel boundaries in the field in 2D Cadastre may suffer several ambiguities resulting from:

1) The registering surveying method, as documented in the field notebooks, lack homogeneity, and their degree of accuracy that does not match the accuracy of modern survey tools used at present. Therefore, reinstating the same boundary point while using different field notebooks will result in different locations for the same points, where the distance between these locations may be several decimeters.
2) The survey is based on different traverses that meet different survey standards; these standards have undergone changes, resulting in traverses inhomogeneity, even in the case of traverses of the same degree of accuracy.
3) Lack of instructions and uniformity in the stages and the methods of reinstating and marking boundary points.

Some of these difficulties may be overcome by using the **GPS** technology. Surveying by means of GPS technologies existed already during the eighties (Langley, 1993 and 1998). The application of this satellite technology permits all surveyors to receive the same frequencies L_1 and L_2 from each satellite. This solves the problem of uniformity and homogeneity of the measurements with an acceptable degree of accuracy. The discrepancies between the different surveys are rather small, in particular when assigning coordinates to boundary points for the analytical cadastre.

Developments in the last decade resulted in the novel "*Real Time Kinematics (RTK) GPS*" survey technology, which permits measuring the position of the

GPS antenna immediately in real time at a predetermined time interval (several seconds) with an accuracy down to few centimetres (Langley, 1998); (Lemmon and Gerdan 1999).
The RTK principle provides an important progressive tool for marking and reinstating of boundary points. Its drawback is the requirement of open sky.
Fradkin (1998) has indicated that with respect to cadastre mapping, the most problematic property of the old Israel horizontal network is neither its lack of absolute accuracy nor the mistakes in orientation, but its inhomogeneity. Hence the low absolute accuracy of existing boundary points requires establishing their reinstating not on control points but on identified field monuments in their vicinity. Based on this, a system for boundary reinstating with a complete analysis of results is proposed.

OUTLINE OF THE PROPOSED METHOD

As a solution to the deviations resulting from the transition from the old Israel network Cassini Soldner to the new Israel network, Israel Transverse Mercator (ITM), a method based on the usage of the field notebook data as a local network, by means of RTK was developed. This includes collecting the most accurate data available in archives from which evidence of the boundaries may be derived, and reinstating these boundaries based on field monuments. Linking the boundaries to the horizontal control network can be realized by RTK in a local network defined by the field notebook; only after marking the points, linking will be carried out by assigning the x and y coordinates. This method requires the existence of at least two field monuments in the area, contained in the field notebook. The closer the points to the area of the parcel and the larger their number, the higher the reliability of the reinstating/marking is.
Linkage to the horizontal control network will be realized by constructing a DTM or TIN grid of elevations according to definition A or by measuring H_{max} and H_{min} according to definition B, in WGS 84 system. Next, the ellipsoidal system will be replaced by a vertical control network by means of geometric levelling of the boundary points.

Measuring heights by means of GPS

In the scope of this paper, a method has been developed for measuring heights by means of RTK relative to the local network. These values are the differences in ellipsoidal height relative to a base point (for example the point on which its base RTK antenna is positioned).
In Israel, the vertical control network is based on orthometric heights, unlike the ellipsoidal heights resulting from RTK. Replacing an ellipsoidal heights network by an orthometric heights network requires a transition via an undulation model in each area.

The transition to the orthometric vertical control system is realized by the geometric levelling of one of the boundary points. Relative to this point, the local datum is moved in accordance with the resulting difference in heights. It is argued that in small parcels the loss in accuracy due to this replacement is negligible.

Steinberg and Papo (1998 and 1999) indicated that adopting the ellipsoidal control network, which is based on GPS measurements, is feasible. An example to this approach may be found in (Salus, 2000), where a GPS vertical control network is proposed as an alternative to the existing network.

Thus, in the future, it will be possible to link the height points in each parcel to the vertical control network immediately.

ACCURACY REQUIREMENTS

Due to the existing problems in the Israeli two-dimensional cadastre, it appears likely that an accuracy of less than decimetre in (x,y,h) will be acceptable for practical purposes. In view of this, the accuracies of various methods will be examined for constructing a cadastre database.

Working with RTK GPS, permit obtaining accuracies better than one decimetre. These accuracies, together with development of technologies and methodologies for improving the accuracies achieved by RTK GPS positioning, enhance the importance of RTK, while diminishing the problems of attaining accuracy.

It should be noted that changes in the dimensions of the three-dimensional spatial parcel (due to definition A and B) as a result of the curvature of the geoid are neglected. This approximation is justified by the accuracy level required for the abovementioned land-right registration.

EXPERIMENTS

Two experiments were done in order to test the method by RTK: The first on a parcel located near the Technion, in Haifa, in an urban open-sky area; its area is 1.547 metric-dunam. The second is an agricultural area, non-urban open sky parcel; its area is 3.813 metric-dunam.

In order to transform these two parcels to “surface 3D-Cadastre“ spatial body, the following steps were followed:

1. Retrieving the field notebooks of every parcel and all the maps related to them.
2. Finding field monuments that were measured and are documented in the notebooks. In the urban parcel, buildings corners and old boundary wedges were used as monuments. In the agriculture parcel the monuments were electricity poles and old boundary wedges.
3. Computing the measurement lines in the notebooks as a local network,

based on monuments were founded in step 2. See figure 3.

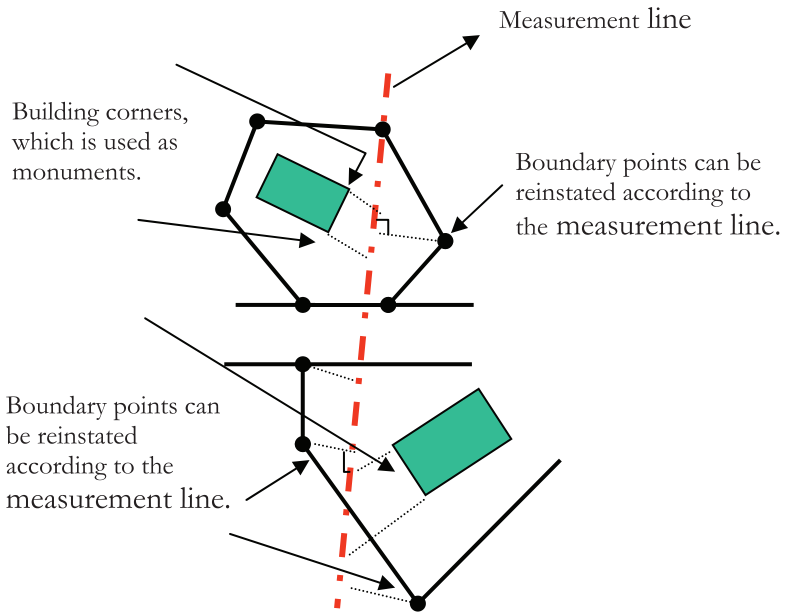


Figure 3: Example of Measurement line.

4. Measuring the monuments. RTK uses the local monument coordinates as control point coordinates to be used in the localization solution. Then, by a real time data link, it directs the surveyor to all the boundaries, which were measured from the measurement line, that the local network was based on it. This step was repeated till stacking out all the boundaries. Only a few boundaries could not be solved in local network.
5. Linking boundaries to the horizontal network. Linkage could be done by one of the following ways:
   a. Measuring boundaries again by RTK in localization map system – ITM. Seven parameters used for transition, from WGS'84 system to ITM.
   b. Using raw data file, which is created when stacking out points, in step 4. Convert it by seven-parameters transition to ITM.
   Ellipsoidal heights for boundaries were measured at the same time.
6. Measuring heights inside the area of the parcel, in order to build TIN grid.
7. Measuring points near the area linked to the vertical Israeli network by levelling. Transform all the ellipsoidal heights to orthometric heights.

Reinstating the boundaries took 1 hour 40 minutes in the urban parcel and 1 hour 50 minutes in the agricultural parcel. As was mentioned earlier, the reinstating time was similar in both cases; the actual reinstating rate was significantly different.

CONCLUDING REMARKS

The system for boundary reinstating is proposed only for the projected area of the upper side of the "3D-surface cadastre" spatial body.
Establishing the "3D-surface cadastre" layer, by means of the proposed method, requires:

I. In urban open-sky land: About 30-60 surveyor's work-hour, for 1 metric-dunam (1000 m^2).
II. In non-urban open-sky land: About 20-30 surveyor's work-minutes for 1 metric-dunam (1000 m^2).

Obviously, such method proposed, is not practicable for establishing all the 3D cadastre system.
Stoter (2000) described an experiment carried out in Holland, in which cadastre maps were constructed in high 3D density with sub-decimetre accuracy. Heights were measured and calculated by the Laser Scanning method throughout the whole country. Such a method is relevant to large-scale work over countries scope. It is not designated for small areas.
While the proposed method is not relevant to large-scale work over large areas, it is practical for small areas. Specially, it can be used to update, reinstate and complete measurements after establishing 3D-Cadastre system.
The method proposed in this paper and the definitions of the spatial three-dimensional parcel may be directly applied to the daily work of the surveyor for reinstating or marking parcel boundaries in the area of the future three-dimensional cadastre. Such a method may offer several advantages such as accuracy and homogeneity. Its main drawback is the requirement of open sky for GPS satellites.

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