CONSIDERATIONS REGARDING THE USE OF REAL-TIME KINEMATICS RTK METHODS, THE ROMANIAN POSITION DETERMINATION SYSTEM AND GNSS TECHNOLOGY IN 3D LAND SURVEYS

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ABSTRACT
The use of the existing 2D land survey is oftentimes insufficient in facilitating a fast evolution, and in making up for the increase in lack of terrains, this aspect requiring a fundamental change in the current survey system. This paper presents a 3D survey system for recording land rights for land areas, based on the current land survey, namely the 2D survey. A general description and the component definitions of the 3D land survey are detailed inside this paper. In addition, a description of the RTK measuring method which uses GNSS as a marking technique for 3D spatial parcels is also given, in detail. Delimitation in 2D surveys was made using x, y surface coordinates in the projection surface, while in Three-dimensional surveys the coordinates x, y, H are required, altitude in Romania being related to the quasi-geoids and the normal Black Sea 1975 altitude system.

Keywords: bi-dimensional land survey, survey recording, spatial property parcel

INTRODUCTION
In addition to registering real rights in the Land Registry and many other aspects, one of the land survey system’s objectives is to ease the planning of civil engineering and other development activities. In the last couple of years, as a result of population growth, economic development and other aspects, the rapid development has left an unexplored area in developed regions, especially around the capital Bucharest, or in other large cities in Romania, such as Cluj Napoca, Timișoara, Iași, Constanța etc. In these areas, the terrestrial resources have been used almost completely, especially in the interest areas, and the development also began horizontally, in surrounding areas. In the future, these legal aspects will cause a slowing down of the development for both the underground and surface areas. The solution to these issues requires the creation of a Three-dimensional land survey.
MATERIALS AND METHODS

1. Using three-dimensional land surveys – a possible solution in Romania

As it is described by Doytsher et al. [4], the main task in defining and implementing a Three-dimensional land survey is being developed. Three-dimensional models and the execution of changes in the definition and character of the land survey are still poor in Romania, and bi-dimensional surveys, meaning general surveys, are being implemented, with only a few administrative units having been updated with this system [2]. These changes will allow the passing from a plane land survey to a Three-dimensional one. The basic principles for 3D land surveys imply two essential changes, which are:

1. Each surface point which describes the outline of the property must be described by the x, y coordinates, in the horizontal control network (the Stereo 70 projection system) and the height in the vertical control network (in Romania, the Black Sea 1975 altitude system), transforming such information into a plane and an elevation system.

2. Another definition of the “parcel” concept is a foundation for Three-dimensional land surveys. The main purpose is not only to define the 3D land survey system, but also to maintain the legal aspects of the Survey, the physical evidence in the field which is superior from a legal point of view in relation to land mapping.

In 2D land surveys, one can use the physical marking and the application of licenses. In the 3D land survey system, the existence of licenses for physical space parcels is not possible. As long as the 3D survey variant includes the surface of the ground, the physical evidence can be implemented, and thus, the future 3D land survey system can be divided into two parts:

I. “3D land survey surface”: 3D land survey referring to the surface of the ground, allowed by physical evidence;
II: “3D land survey non-surface”: 3D land survey for above or under the surface, for which physical evidence is not possible.

The separation of the 3D land survey will facilitate a quick and easy transition. “3D land survey surface” will allow people to keep the “block number” and the “parcel number” thanks to the main 2D partition, adding the volume element for the identification of the parcel. As a consequence, “3D land survey non-surface”, the new partition of the above and below the “3D land survey surface”, could be put into application. We must underline
that the transition to a 3D land survey should be a simple process in the case in which a rapid implementation is required. Thus, the transition must rely on the classic 2D land survey which is used all over the world and is well studied and established.

The current concept of a property body in dealing with plane surfaces must be replaced by an alternative space concept, which is a cornerstone in defining the three-dimensional cadastre. Suppose we separate the two parts of land registration.

2. Three-dimensional 3D surface of the land survey

Establishing “Surface-3D Cadastre” and solving the problems mentioned above, the concept of three-dimensional requires a transition of the plane parcel into a body space, based on two requirements that must be imposed:

1. The essence of the body space must keep the parcel as flat as viewed from above.
2. Allocation of property size and body volume by determining that the third dimension. These two claims allowed at least two precise definitions of the spatial three-dimensional parcel:

**Definition A:** The three-dimensional parcel is a prismoid, the vertical edges, viewed from above, are a polygon composed of boundary points of the bi-dimensional parcel. While the upper and lower edges are parallel to the surface at a $Z_{\text{up}}$ height and $Z_{\text{down}}$ depth. If $S$ is the projected area of the three-dimensional parcel (which is the recorded area of the bi-dimensional parcel), then, according to this definition, the volume of the parcel is:

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

(1)

![Fig. 1. a and b illustrate the spatial body according to definition A [6]](image)

**Definition B:** The three-dimensional parcel is a prismoid, the vertical
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edges, viewed from above, are a polygon composed of boundary points of the bi-dimensional parcel. While its horizontal edges are parallel to the average sea surface, from the upper edge $Z_{up}$ height from a maximum $H_{max}$ height in the interior of the parcel, and the image below, at a depths $Z_{down}$ from a minimal $H_{min}$ height in the interior of the parcel. If $S$ is the projected area of the three-dimensional parcel (which is the recorded area of the bi-dimensional parcel), then, according to this definition, the volume of the parcel is:

$$V = S \cdot (Z_{up} + Z_{down} + H_{max} - H_{min})$$  \hspace{1cm} (2)

**Fig. 2.** a illustrates spatial body according to definition B; b illustrates Basic body of 3D-parcel [6]

To complete this definition, we must define a base 3D body for the parcel, which is a prismoid whose vertical sides, viewed from above, are composed of polygons and the limits of the two-dimensional parcel; the horizontal edges are parallel with the average sea surface. It reaches the top point of maximum height $H_{max}$, and it reaches the bottom point of minimum height $H_{min}$ inside the parcel. The base core of the 3D parcel creates the basic space layer, from which the two horizontal edges of the space parcel are linked directly under B. For both definitions, $Z_{up}$ and $Z_{down}$ represent the values provided by national authorities, as a function of the parcel’s location. These two definitions allow a continuation of the flatness on the paper map used.

„Non-surface 3D land survey” is made up from the above and under parts in relation to the „Surface 3D land survey”. It is made up of „3D non-surface space body”, which is defined as: a mathematical 3D body is made up of closed edges. Each edge could have a mathematical representation, or a plane surface made from a polygon, or both variants. One part can be vertical, horizontal or even inclined. The body’s volume is calculated according to the mathematical shape. This is a general function, that includes definitions A and B suggested by ”Surface 3D land survey”.


3. The three-dimensional space parcel – a concept which must also be current in Romania

Presenting the proposed method for solving the problem. As a solution for the deviations resulted from the transition from the coordinates in the old S42 Krasovski ellipsoid network, towards the new ETRS-89 GRS-80 ellipsoid network in Romania, officially implemented in Romania in 2009, a method based on using data through RTK-type means has been developed.

This method is being used together with the Romanian Position Determination System ROMPOS, which was officially implemented in 2008 in Romania, and which is still free for all users. This method includes the gathering of more accurate data to the ones available in the land archives, as proof for the limits which can be derived, and the re-estimating of these limits based on field markings. The correlation of limits to the horizontal control network can be made by using the RTK method together with the ROMPOS, in a local network defined by the data available regarding land surveys; only after the points have been marked can the connection take place, by attributing the (x) and (y) coordinates. This method implies the existence of landmarks and field markers for at least two points in the area, included in the land survey domain. If the two points are close to the points at the surface of the parcel and their number is greater than two points and the reliability is greater at re-introduction and marking, the transmission to the horizontal control network will be made by building a DTM or a TIN grid according to definition A or by measuring Hmax and Hmin according to definition B, in the WGS 84 system. Then, the ellipsoid system will be replaced by a vertical control network, by using the geometric levels through the boundary points.

4. Determining the elevation of the outline points through GNSS using the RTK kinematics method and ROMPOS

For the application part of this experiment, a method was set up for measuring the heights through GNSS, using the RTK measuring method and ROMPOS, related to the local network. These values are the differences in ellipsoid height related to a base point (e.g. the point in which the GNSS base antenna is stationary and is positioned using RTK).

In Romania, the vertical control network is based on normal altitudes Black Sea 1975 and uses the quasi-geoids as a reference surface, unlike ellipsoidal altitudes from the WGS-80 ellipsoid which result from RTK.

Accuracy requirements which are obtained from using the GNSS in 3D land surveys.

Considering the problems that exist in bi-dimensional land surveys in
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Romania, it seems likely that an accuracy of less than a decimetres in (x, y, h) will be acceptable for ordinary practical purposes [13]. Keeping this in mind, different accuracies from various methods will be examined in order to set up a national land survey database. Working with RTK GPS allows accuracy better than one decimetres for (x, y, h) [6]. These accuracies, together with the development of technologies and methods for improving the accuracies obtained from GPS RTK positioning, will increase the importance of RTK, combined with ROMPOS, while at the same time diminishing the problems regarding reaching certain accuracies [9]. One must observe that the changes in dimension of the 3D space parcel (due to definitions A and B), as a result of geoids bending, are negligible. This approximation is justified by the level of accuracy necessary for recording the terrains mentioned above.

5. Determining elevation (height) by using the RTK-GNSS measuring method

In the scope of this paper, a method was developed for measuring heights by GNSS-RTK method of measuring relative to the local network [11]. These values are differences in ellipsoidal height relative to a base point (e.g. the point on which the base RTK antenna is positioned).

In Romania, the vertical control network is based on normal heights Black Sea 1975, unlike the ellipsoidal heights resulting from GNSS-RTK measurements. Replacing the ellipsoidal heights network by a network of normal heights requires a transition through a wave pattern in each area studied. The shift to a normal vertical control system is done by geometric levelling at one of the limit points (border). Relative to this point, the local datum is moved in accordance with the resulting difference in heights. It should be noted that for small parcels, the loss in accuracy due to this replacement is negligible [12].

An example of this approach can be found in [10], where a GPS vertical control network is proposed as an alternative to the existing network in the area studied.

Thus, in the future, it will be possible to relate the high points of each parcel to the vertical control network immediately, using the GNSS-RTK technology.

6. Experiments and tests using the GNSS-RTK for determining the three-dimensional 3D land survey surface

Three experiments were conducted to test the RTK method:
- On a parcel near Baia Mare (Baia Sprie), in an urban area with open skies covering an area of 3251 square meters.
- The second is an agricultural area, buildable parcel with open skies, which has an area of 12,563 square meters.
- A third area is the outskirts of Săcălaşeni village, with houses.

In order to transform these three parcels into “3D surface – land survey” body space, the following steps were followed:
1. Acquisition of data on each parcel and all related maps.
2. Finding landmarks or witnesses (stones or wooden stakes) on the field that was measured and recording them in a database. For the urban parcel, the corners of old buildings and old fences surrounding the property have been used as important details that will stand the test of time. For the agricultural parcel, the witnesses were electricity poles or old stakes and stones of the limit.
3. Data laptops computing the measuring lines, as a local area network, based on identifying elements that were determined in the second stage.
4. Measurement of marked points. RTK uses points marked with local coordinates as control points with coordinates to be used in the solution to locate the respective area. Then, through a real-time connection of RTK-GNSS data, it directs people using GNSS rovers for all property boundaries, which were measured from the line of measurement, because the local network was based on it. This step was repeated until the determination and mapping of all property boundaries. There were several limits that could not be resolved.
5. Correlation of limits with the horizontal network. A connection with the horizontal network could be achieved by one of the following ways:
   a). limits to be measured again with the RTK-GNSS method in the Stereographic 1970 projection system used officially in our country in civil matters. Seven parameters are used for the transition from WGS'84 to the Stereographic 1970 projection system, this being made also with the aid of the Transdat 4.01 transformation program, used officially in Romania and agreed by ANCPI (National Agency for Cadastre and Real-Estate Advertising).
   b). Using a raw data file that is created when delimitation is made in step 4. Converting by seven parameters or by Transdat 4.01 to the Stereographic 1970 projection system took place at the same time, as was the conversion of the ellipsoidal height of limits that were measured simultaneously [5].
6. Determination of heights measured inside the parcel surface, in
order to build the TIN network.

7. Measuring points around the area are linked to the National Geodetic Levelling Network. It makes all ellipsoidal heights into normal heights Black Sea 1975.

Restoring the limits lasted 1hr 27 minutes for the urban parcel and 1 hour 43 minutes in the case of the agricultural parcel. As mentioned previously, the time for recovery of limits was similar in the three cases studied, with the actual reintroduction rate being significantly different for each determination relative to the others.

DISCUSSION

The system of outlining and reintroducing limits is proposed only for the projected area for the top of the “3D land survey – surface” body space. Establishment of the “3D land survey – surface” layer, by means of the proposed method, requires:

I. In the case of the urban land with open skies: it takes 30-60 minutes of work, about an hour, for 1000 m\(^2\).

II. In non-urban land with open skies: about 20-30 minutes for an area of 1,000 m\(^2\).

Obviously, this proposed method is not possible in order to determine all three-dimensional 3D land survey systems. The Netherlands has tested it and they have made cadastral maps all over the country, which were constructed in 3D high-density, with centimetres accuracy. Elevation was measured and calculated by the method of laser scanning across the country by people in the field of measurements. While the method proposed here is not relevant for large scale wide areas, it is practical for small areas, local, which require no special effort. Specially, it can be used to update and fully restore, and for measuring after the establishment of a 3D land survey system.

The method proposed in this paper and the definitions of the three-dimensional spatial parcel can be applied directly to every day work by geodetic engineers, to restore or outline a plot, in an area of the 3D land survey in the near future. Such a method can offer several advantages, such as accuracy and uniformity in determinations, but also one main disadvantage, namely the requirement for open skies for the GNSS satellites, or areas where there is no obstruction from buildings or vegetation [6].

Solving the problem will focus on “Surface-3D land survey” body space, which is the essence of the three-dimensional land survey. Comparing the process of determining the boundaries of a conventional 2D
parcel, with the limit and marking process for a three-dimensional surface “Surface-3D land survey” body space, according to definitions A and B, it is inferred that the two are quite similar. Additional requirements for three-dimensional land survey are:

1. Provision for each border point with height “h”, for both according to definition B, and linking it to the vertical network.

2. Building a DTM or TIN grid, in order to describe the surface of the ground, according to definition A. Measuring the height of the points to find the maximum and minimum height, according to definition B. Adding height (elevation) to the parcel (projected area of the body space), they were not required in the bi-dimensional 2D land survey (classic land survey).

Therefore, we do not need to fix any problems that occur in height, and so this process itself does not introduce new potential conflicts with currently available data. However, to restore the parcel in two-dimensional 2D land survey may undergo more changes and inconsistencies resulting from:

1) Classic method of topographic measuring and classical recording of the parcel, existing documents, lack of uniformity, determinations and their degree of precision, which do not match the accuracy of modern measuring tools currently being used. Therefore, the restoration of the point on the limits of the property will result in different locations for the same number of points, and the distance between these locations can be quite large.

2) Lack of guidance and uniformity in the processes and methods for the marking and reintroduction of border crossing points. Some of these difficulties can be overcome by using modern technology such as GNSS (GPS, GLONASS, etc.).

CONCLUSIONS

Developments in the last decade have led to an increased use of the method of measuring in real time (RTK-GNSS), that allows the measurement of the position of the GPS antenna in real-time, at a predetermined time interval (a few seconds), with an accuracy up to several centimetres [8]. The GNSS-RTK measurement method (NAVSTAR-GPS and GLONASS) provides an important and progressive tool for restoring and marking property limit points, the only disadvantage being the requirement for open skies, which in many cases cannot be met. Therefore, absolute accuracy is low for the points found on the limit of the existing property, and requires the re-establishment of these checkpoints, not the reintroduction on control points, but on the landmarks and fences that are
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identified around the land. Three-dimensional land survey is still in its beginnings in Romania, and several articles have been presented, and in addition to these, the Technical University of Civil Engineering in Bucharest and the Faculty of Geodesy teach aspects regarding Three-dimensional land survey [1]. The future is in the Three-dimensional land surveys, because a number of daily problems cannot be solved using bi-dimensional or plane land surveys.

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