SPATIAL DATA QUALITY: ACCURACIES OF POSITIONS AND HEIGHTS

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Abstract

Geodetic infrastructure which is defined by coordinate system, datum, position and height parameters as well as their accuracies is very important in terms of spatial data quality. Base maps produced using this geodetic infrastructure are the basic information sources for any kind of GIS applications. In order to establish a suitable spatial data infrastructure, the fundamental geodetic infrastructure is very important. In Turkey, the establishment of Turkish National Fundamental GPS Network was the first step for creating an accurate and reliable geodetic infrastructure for geospatial data management in Turkey. In 2005 new regulations for large-scale mapping and spatial data production were defined. Public institutes, universities and representatives of the private sector firms participated in the preparation process of these regulations. Currently, another workgroup consisting from almost the same actors is working on the standardisation of geospatial data and GIS related applications.

In fact the key issue for a reliable and accurate geospatial data management is the standardisation in GIS based applications. Considering this requirement, some standardisation process is also ongoing in Turkey being parallel to the establishment of national geodetic frame.

As part of these processes fundamentals of spatial data quality should be defined in Turkey. One of the important parameters for the quality of large scale/high resolution spatial data is the accuracies of position and height. Accuracies of position and height have a direct impact on the production cost of the data and therefore determine its applicability. Production of large scale spatial information in Turkey is conducted with respect to the legal standards defined in the Regulations for Large Scale Mapping and Spatial Data Production. In these regulations, minimum accuracy measures are defined for the production of spatial information at different accuracy levels. However it is possible to make spatial data production with higher accuracies. The accuracies in the regulations are given in a network hierarchy, i.e. with respect to the upper level network. In terms of the reliability and analysis of the large scale spatial data, the accuracies of this data (absolute accuracy, datum dependent accuracy) should be determined. How should be determined the absolute positional and height accuracies of the existing large scale spatial data as well as the absolute positional and height accuracies of the spatial data produced in a hierarchical structure with respect to the regulations? How could this procedure be automated? In this study, possible methodologies introduced for the computation of absolute positional and height accuracies are discussed. The positional and height accuracies of the spatial data produced with respect to the official regulations have been determined through the suggested methodology and the results are discussed.

Keywords: Geodetic infrastructure for GIS, Geospatial data quality, geospatial data standards

1. Introduction

One of the features of today's technology is that it creates an interchange where application of data and information (useful data) for the production of information, data processing and communication devices and innovation. This leads to the creation of the network community (Castells, 2005).

Information technology is creating a digitized world. Geographical information area is one of the leading areas of today where innovative implementations are created and used in order to adapt contemporary technology and the investment made in this field increasing with the passing of time.

The process of transformation from conventional static maps and plan approach to implementation of spatial information and systems is very rapid. Development through the innovation and the use of innovation is dependent on the production a subsequent utilization of spatial data, and compliance with well defined standards at all phases of this process.

Standards developed for Geographical/Spatial Information area (sector) can be classified as;

- Official standards, global, regional or local standards produced by standards organizations. Standards produced by specialized institutions such as ISO/TC211, Open GIS, IHO etc.
- Legal standards; standards produced in accordance with the national or international legislation; standards produced in accordance with the regulations for large scale mapping and etc.
- Operational (de facto) standards (Industry Standards), regulations, industrial and occupational instructions, documents etc.

In all standardization works, one of the general rules is that all new standards must be compatible with the existing and legal standards.

Standards in the area of Geographical/Spatial Information area are developed in accordance with the "Information Engineering Design and Standard Development" principles. According to these principles standards are developed in the main 4 categories listed below;

- data
- duration
- organization
- technology

and a standard is all about one of these categories. These categories have subcategories as well. "Usability of data" standard contains the subcategories of "data quality", "quality evaluation", "accuracy" and "reporting" standards (URL 1).

In this study the position and height accuracy standards will be examined with respect to the official regulation in Turkey.

2. Accuracy of Spatial Information

If Geographical/Spatial Information can be expressed in general in relation to objects that are linked directly or indirectly with a location in respect of the earth as information on objects and events, then geographical information that is dependent on location precision forms the special geospatial information group. All types of geodetic network points, maps and plans can be included in this group. Spatial information forms the principal infrastructure of information systems developed in the fields of cadastral, land development, engineering work and studies.

Accuracy in the creation of spatial information is also an important parameter that affects cost. Therefore, accuracy standards have been defined for the accurate creation of this information. In general spatial data is created in accordance with the accuracy specified in the national and legal standards. These standards take into account the following in their formation;

- the status of the country's geodetic infrastructure,
- the status of the country's technology and information level,
- the equipment and hardware park in the country,
- the economic capabilities of the country.

High levels of accuracy incur very high costs, therefore standards are specified, by optimization of the conditions in line with the requirements. In Turkey spatial information is produce in accordance with the "Regulations for Large Scale Mapping and Spatial Data Production" (BÖHHBÜY, 2005). In this standard the point position and height information is produced in a hierarchical structure in compliance with the geodetic network approach. Geodetic network point positions, position accuracies, heights and height accuracies are calculated at one level higher order network. The other details position and height accuracies are calculated in accordance with the geodetic control points it is linked to and is documented. Detail point positions and heights are calculated. If required the detail point position and height accuracies can be easily obtained form existing documents.

Accuracy is an indicator of the produced information quality and it is perceived as such in the implementation. Spatial information with high accuracy is a higher quality information and in engineering applications care is taken to use the most accurate position and height data of higher points that is available. However at the moment taking into account of the accuracy data in the Geographical Information System is not currently on the agenda of institutions in Turkey.

During the creation of the Turkish National Spatial Data Infrastructure, the accuracy information will have to be taken into account. This is because institutions like ISO/TC211 and Open GIS that produce official standards and national institutions such as USA Federal Geographical Data Committee (FGDC) have adopted the accuracy standards and have started implementing it on the GIS applications (URL 2; URL 3).

3. Accuracy Standards for Positions and Heights

Geodetically the location and height accuracies are expressed with different parameters. Towards this end there are many accuracy and scale definitions. In this study, definitions and parameters adopted by the international standardization institutes ISO/TC211 (URL 4) and Open GIS (URL 5) will be used and solutions for the resolution compliance problems between these international standards and BÖHHBÜY will be proposed.

Where accurate data has been obtained;

- data users can analyze the digital values they obtained with the, location and height data; for example mean square error values of length, area, volume etc. can be found,
- they analyze whether they can reach the digital accuracy expected with the GIS data, and can evaluate how the existing GIS data can be used.

However in GIS all evaluations should be carried out automatically via software not manually by hand (URL 2). The above matters that are taken into account by some engineering applications should be extended to all precise engineering applications. In fact this is a requirement for GIS and especially for the use of large scale spatial information.

3.1. Accuracy definitions

Absolute accuracy: this is the measure of error for a point for a specific spatial reference system (datum). This accuracy contains all known and anticipated errors.

Relative accuracy: This is the error for the distance between two points or the accuracy of one point relative to the other. If the absolute error is known for two points, then relative error is calculated using the relative ellipse approach.

Vertical linear error (LE): This is the accuracy of the vertical coordinate (height) for a point.

Horizontal circular error (CE): For a point, this is the horizontal position accuracy for latitude and longitude (or easting and northing).

3D spherical error: This is the 3D location error of a point and is the sum of vertical linear error and horizontal circular error. This error is acceptable where the three coordinates' accuracy is of the same scale. Generally vertical linear error and horizontal circular errors are used.

In calculation of errors, lack of correlation and normal distribution is assumed. Accuracy information for 3D is recorded using the 2x2 symmetric variance-covariance matrix. Confidence Probability is specified as (0.5, 0.6827, 0.9 and 0.95) (URL 2). According to this, the notation will be,

$$C = \begin{bmatrix} m_x^2 & m_x m_y & m_x m_z \\ m_x m_y & m_y^2 & m_y m_z \\ m_x m_z & m_y m_z & m_z^2 \end{bmatrix} \qquad (1)$$

or if it is without correlation for 3D Cartesian coordinates

$$C = \begin{bmatrix} m_x^2 & & \\ & m_y^2 & \\ & & m_z^2 \end{bmatrix} \text{ or for 2D coordinates } \quad C = \begin{bmatrix} m_x^2 & \\ & m_y^2 \end{bmatrix} \qquad (2)$$

Photogrametrically obtained position and height accuracies for control points are calculated by taking into account variance-covariance matrices. Standards have been developed for obtaining absolute position and height accuracies from monoscopic and stereoscopic images (URL 2).

3.2. Obtaining Absolute Accuracy

Absolute accuracies in respect of position and height are found by comparison against absolute values. For the absolute accuracy of geodetic point form any order or the detail point is calculated by determination of a position on a higher level from the hierarchical level of the selected test points (URL 3). This value will be acceptable for all points in the test area. Absolute accuracies can be found by control measurements as in BÖHHBÜY. In Turkey, control measurements must be taken into account and evaluated in this context.

In practice, in situations where accuracies cannot be obtained, accuracy must be approached by precision. Precision can be found automatically by evaluating the data from production. Position and height precisions of geodetic network points can be found directly by the adjustment of these networks. In return detail point precisions, can be obtained from the fundamental error propagation law without any need for adjustment.

If instead of absolute accuracy the definition of absolute precision is taken, for example the position precision of benchmark point is the precision calculated according to the Turkish National Fundamental GPS Network (TUTGA). For this the observations for all points from all levels should be obtained by a combined adjustment taking TUTGA point positions as fixed. However, according to BÖHHBÜY, a point’s position is calculated by taking the positions and heights of higher order points as fixed in the hierarchical network structure. In this situation the problem of obtaining the absolute precision of location and heights calculated in the hierarchical network structure must be solved.

3.3. Network precision calculation in hierarchical network structure

In the BÖHHBÜY point positions are produced using C1, C2, C3, benchmark and detail points with 5 accuracy levels. Each one of these is calculated by taking each ones position and height precisions from one order higher network point positions as fixed. At the highest order the TUTGA network is the fundamental network and network precision means precision in relation to TUTGA.

As stated before, the network precision of spatial data can be found by adjusting all data or by taking into account the variance-covariance values of a higher order network. However not producing simultaneously, and deficiencies and delays in organization between institutions on collecting and processing raw data at different times can make this application difficult.

Here an approach that can be suitable for automation is proposed. By using the variances obtained as result of hierarchical adjustment, determination of variance areas (for example separate for easting and northing) by two variable polynomials and integration of network precision components from higher order network points.

According to this,

i- TUTGA=0, C1 adjustment values C1 field

ii- TUTGA=0, C1=0, C2 adjustment values C2 field

iii- TUTGA=0, C1=0, C2=0, C3 adjustment values, C3 field

iv- TUTGA=0, C1=0, C2=0, C3=0, benchmark points adjustment values, benchmark field

is calculated automatically.

Network precision of a benchmark point can be calculated by the combination of variances calculated from benchmark points adjustment (taking C1=0, C2=0, C3=0) and the variance components from C1, C2, C3 networks. In other words it will be,

$$\text{Benchmark}= \begin{bmatrix} m_x^2 & \\ & m_y^2 \end{bmatrix}_{C1} + \begin{bmatrix} m_x^2 & \\ & m_y^2 \end{bmatrix}_{C2} + \begin{bmatrix} m_x^2 & \\ & m_y^2 \end{bmatrix}_{C3} + \begin{bmatrix} m_x^2 & \\ & m_y^2 \end{bmatrix}_{Benchm.\ adj.} \quad (3)$$

For vertical network accuracy using a similar approach, the network precisions of the spatial data produced in accordance with BÖHHBÜY based on Turkish National Vertical Control Network (TUDKA) can be found by error limits in the guidelines. However as known error limits are specified as $3m_0$ and that is for a %95 confidence level.

In order to provide a numerical comparison and inspection capability, the position precision of the benchmark points has been calculated in accordance with,

i- combined adjustment,

ii- interpolation by polynomials obtained from hierarchical adjustment results,

iii- in accordance with the error limits provided by the regulations.

Precisions obtained as a result of the computations carried out and the accuracy limits provided in BÖHHBÜY are given in Table 1. The table values consist of results obtained from the project that covered the measurements at benchmark points by a densification work that was carried out using the GPS technique on the Anatolian side of Istanbul based on the Istanbul GPS Network (İGNA).

Table 1: Point position precisions (*values in cm)*

Network order	Hierarchical adjustment		Variance area Modeling		Combined Adjustment (absolute)		According to BÖHHBÜY			
							Hierarchical accuracies		Absolute accuracies	
	m_x	m_y	m_x	m_y	m_x	m_y	m_x	m_y	m_x	m_y
C1	0.60	0.40	0.60	0.40	0.60	0.40	3.0	3.0	3.0	3.0
C2	0.60	0.40	0.85	0.57	-	-	3.0	3.0	4.2	4.2
C3	0.88	0.57	1.22	0.80	0.80	0.60	5.0	5.0	6.6	6.6
C4 (Benchmark)	0.61	0.39	1.36	0.89	0.26	0.23	5.7	5.7	8.7	8.7

According to BÖHHBÜY point densification by GPS is in the form of intersecting a point one by one as opposed to the traditional network approach. As a result there is no error accumulation that occurs in traditional networks. The variances change due to the network connection points of the higher order network. As a result very close variance-covariance values for the hierarchical network points are obtained. For an area their averages can be used as the local accuracy. For this reason the values in the table are given as the average values of the test area. If point densification by GPS technique is carried out in accordance with BÖHHBÜY then much higher accuracies than those obtained by geodetic techniques. As can be seen from the table, the accuracy values are around ±1 cm.

The error limits given for all networks in accordance with BÖHHBÜY is for the %99.7 confidence level. Therefore the values in the table should be multiplied by three times the given calculated values. Therefore it can be seen that this is very much below the achievable accuracy limits.

5. Conclusions

The limits in the official regulations in Turkey are the lowest accuracy limits. Production with higher accuracies can be achieved. The contemporary data production technologies are reducing the cost of high precision data production. Work with high accuracy has been more economical. By taking into account that this trend will continue into the future high accuracies should be adopted.

The absolute accuracies of points from all orders can be obtained from control measurements. Control measurements made in accordance with the regulations are carried out by the institution producing the spatial data and are evaluated accordingly. The results found can be used as the absolute accuracy of the spatial data.

In situations where control measurements are not conducted or are not conducted with the required care and attention, hierarchical network adjustment results should be used to calculate absolute precisions and these precisions could be used as the accuracy of the spatial data.

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