Digital Topographical Maps – Positional Accuracy

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SUMMARY

The accuracy analysis of the different measurement techniques may be used in many sciences. The science's first aim is the determination and measurement of the real world objects, without measurements our knowledge is meagre. Maps are widely used in decision making to understand better the natural processes. Civil engineering, land navigation and other important applications need good basic maps and accurate measuring techniques. But how can we compile an accurate map? Which is the most accurate method? Exactly, how can we characterize the used measuring technique and the accuracy of our measurement? These are the most important questions of the science of cartometry. Some time ago, cartometry used only traditional techniques and instruments, nowadays the digital revolution of the world put microcomputers into our hands. We are using digital maps, desktop mapping software, the Global Positioning System, on-screen or softcopy-maps etc.; that means we can not use only the traditional methods and instruments, new ways are necessary.

My presentation shows the basics of cartometry to highlight the problem of accuracy in the vector and raster environment, and an interesting and very useful method to express the accuracy of the digital map (Circular Map Accuracy Standard-CMAS), the data-collecting instrument and the sampling strategy and method (stratified random sampling). For the past 60 years other countries have been using (USA) well-defined map qualifying methods such as NMAS, NSSDA and ASPRS. My presentation compares these methods to each other and to the method which was used to derive the results in my thesis. Map accuracy is an important part of metadata and my thesis shows its place in the different metadata-descriptions (related to the Hungarian Standard 7772-1(1997), FGDC Digital Geospatial

Metadata Standard,(1998), and INSPIRE Draft Implementing Rules for Metadata (2007)).

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1. INTRODUCTION

My thesis intends to answer the following specific question: Can quantitative accuracy of digital topographical maps be determined by using spatial sampling and adjustment methods, and applying the measurement method of DGPS? The theoretical foundation of this research is based on traditional cartometrical measurement methods (measurement and calculation from simple geometrical features), map standards (Digital Topographical Data Base Standard (DITAB), Hungarian Standard, Number 7772-1), rules of adjustment calculations (least square method) and fundamentals of satellite geodesy (DGPS). For testing the quantitative accuracy of topographical maps I will use an up-to-date GPS-receiver, the DigiTerra Explorer v4. I will test the 3D-accuracy of this GPS-receiver, and use it for testing the quantitative accuracy of maps. The measuring capabilities of the different GIS software packages are different, so checking the different Measurements-Toolboxes I will use: DigiTerra Map v3, Digiterra Explorer v4, ITR4, AutoCad Map 2004, GeoMedia 5.1 Professional, ArcMap 9.1. I will investigate the accuracy of coordinates, straight lines, closed curves, simple geometrical areas and irregular shaped areas measurements using adjustment calculations.

2. EXPECTED RESULTS

The expected results will be the following:

- Analysis the quality of the map digitalization in six different GIS software packages.
- Testing the DGPS- assumptions and accuracy. Check the spatial objects positional accuracy on maps (segment number 54-411).
- Description and presentation of qualification techniques of digital topographical maps (NMAS, NSSDA and ASPRS); using stratified random sampling, positional accuracy and circular probability. This technique is widely-used in the USA since 1947, but has not yet been applied in Hungary.
- The thesis aims to apply Circular Map Accuracy Standard (CMAS), as a part of a metadata-description (Hungarian Standard 7772-1, FGDC, INSPIRE).

3. PRINCIPLES OF CARTOMETRY

The first aim of cartometry is measurements from maps and the cognition of the characteristics of the mapped objects. Cartometry is an important technique of the natural sciences and in engineering, an important tool in geography, geology, biological sciences, agriculture, forestry and mining. Working with digital geographical information means a range of functions for creating, acquiring, and integrating, transforming, visualizing, analyzing, modelling and archiving information. All these functions and workflows are based on measurements on maps. GIS designers have employed the results of analytic cartography and traditional cartometry, so the modern measurement methods of GIS and cartometry are based on the traditional methods (such as area measurement by tracing the parcel perimeter etc.). It is important to know the basics of the traditional and modern methods of measurements in the vector and raster model to understand better how cartometry works in digital environment. In cartometry and in GIS generalization has a broad importance. Generalization is a process of representation of the real world by different models. When measuring objects on a map; one must take into account the effect of generalization (a water body should be most accurate, a road running alongside the river can be shifted somewhat etc.).

4. ACCURACY OF A DIGITAL MAP

Since surveying includes mainly measurements, and every measurement involves unavoidable, i.e. accidental errors, the nature and properties of such errors must be investigated. It will enable, first of all, to evaluate the accuracy of the obtained measurement results (the quality of the production evolved by measurements) and second, to draw correct and highly reliable conclusions from these measurement results.

If the measurements were made under conditions which allow all of the results to be regarded as equally reliable, they are known as equal observations. To evaluate the accuracy of a given series of equal observations the mean square error of a measurement is used. To compare two homogenous series of observations it is necessary to determine for each of the series the mean square error of a measurement whose weight is unity, or the error of the weight unit.

There are several methods to determine the accuracy of a digital map. My thesis shows the equations for calculating the quantitative accuracy based on a parameter Circular Map Accuracy Standard (CMAS). Accuracy represents absence of systematic error or bias, and where bias is absent; the mean of a variable corresponds to its true value. By accuracy determination we must compare two different media: a map and the ground by measuring the differences in position. If two points have been depicted on a map without an error, the scaled distance between them should correspond to the ground distance between them. This kind of accuracy can be measured and expressed numerically; we shall call this quantitative accuracy. If the two points have been depicted on a map with an error, showing positional accuracy is not so easy. One feasible method for calculating accuracy in this occasion is CMAS, which can be visualizing in a circular probability diagram.

5. DIFFERENT GEOSPATIAL POSITIONING STANDARDS

CMAS is not the only well-known and used method for calculating positional accuracy of digital maps. My presentation shows the fundamentals and basic equations of National Map Accuracy Standard (NMAS), National Standard for Spatial Data Accuracy (NSSDA), American Society for Photogrammetry and Remote Sensing Accuracy Standards for Large-Scale Maps (ASPRS). In my thesis I calculated the positional accuracy of the topographical map segment number 54-411 based on the equations of CMAS, NMAS, NSSDA and ASPRS, too.

6. METADATA

Metadata is structured information that describes, explains, locates, or otherwise makes it easier to retrieve, use, or manage an information resource. Metadata is often called data about data or information about information. Accuracy of maps or digital databases is an important part of metadata. Nowadays the right explanation of geographical data becomes more important. Many data are available via Internet; the users could download them for free. The users use these data for decision making, and decision and cost are closely connected to each other. A good decision is based always on responsible data, so that's why users must know the substantive accuracy of their map or database. This section of my presentation is about metadata standards, which are widely used by GIS-firms in Hungary. I introduce the Hungarian Standard 7772-1, the FGDC standard (FGDC Metadata Quick Guide) and INSPIRE Draft Implementing Rules for Metadata (2007).

7. PRELIMINARY WORKS AND DATA COLLECTING

The process of representing a map by a discrete set of its points is known as digitizing. This data after conversion is in the binary format, which is directly readable by computer. The basic concept was that I buy a digital topographical map in a raster format from the FÖMI (Institute for Geodesy and Remote Sensing), than digitalize it and determine accuracy parameters for the quantitative accuracy. The smallest GIS-firms in Hungary do not have enough money to buy a topographical map in a vector format - it is too expensive. The vector format is available in a DGN,-MIF/MID,-SHP,-e00 format only in a scale of 1:100000 and 1:50000 (DTA-100 and DTA-50; for civil engineering purposes these scales are too small, the most suitable scale is 1:10000). The topographical maps, which have a scale of 1:10000 are only available in a raster format (the vector format is now ongoing) and at resolution 0.846m. They are available in different formats; Jpeg, GeoTiff, Tiff-PackBits or in a 8-bit-Tiff format. Their price ranges between 1500 and 4800 Hungarian Forint (6-20 EURO).

I chose the topographical map segment number 54-411, because it contains the town of Szekesfehervar and the range of our Faculty. The format of this raster-file was 8-bit-Tiff format, the size of them 159 Mb, and the size of one pixel element was 0.846m.

The different GIS-firms in Hungary use different GIS-environments; but does different GIS-environment have any effect for the accuracy of the digitalization? When a person digitalized a raster map and used it for some further investigations; he wants to know exactly the accuracy of his digitalization. Very important is to know these parameters, because maps are the input data for the spatial decisions; good decision is based always on accurate maps; and the final decision can not have better accuracy than the input data.

For the testing I used six different GIS software packages which are widely used in Hungary. These six software packages were the following:

1. DigiTerra Explorer v4.
2. DigiTerra Map v2.3.
3. GeoMedia 5.1.

4. ArcMap 9.1.
5. AutoCad-Map 2004
6. ITR4

For testing all possible occasions, which can occur during a digitalization-process; I tested these software packages for digitalizing single points, straight lines, curved lines, simple geometrical figures (triangle) and a closed curve. The ratio of sampling was 100. To eliminate systematic errors I digitalize straight lines and curved lines fifty times from North-West to South-East, and than fifty times from South-East to North-West; single geometrical figures and closed curves fifty times clockwise and fifty times counter clockwise. After the digitalization I adjusted the results and determined the most probable value.

Many geospatial accuracy standards use RMSE to estimate positional accuracy. RMSE is the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. The independent source of higher accuracy for identical points can be very multifarious; one probable kind of them is data collecting on the field. There are many efficient methods for data collecting; I mean that the most useful and most efficient of them is the GNSS-system. I chose the DigiTerra Explorer v4, because it can receive the GPS- and EGNOS signals too, and is current in Hungary; many agricultural and civil engineering projects use this instrument. For the determination of the root mean square error and the average discrepancy of the measuring I used a very simple testing-procedure. On the roof of our Faculty are three pillars, which are ideal for testing GPS-receivers. There are not any obstacles in any direction. I put the GPS-receiver on the top of one of these three pillars, and measure my position one hundred times. I recorded 3-dimensional coordinates, but used for my investigations only the plan coordinates (Y,X) in the Hungarian Projection 72.

8. TESTING QUANTITATIVE ACCURACY

In quantitative accuracy evaluation we are comparing the two or three dimensional surface of the ground with another surface mapped in two dimensions with height represented by means of spot heights and contour lines. The test measurements on the first surface can never be entirely error-free; the second surface is never completely defined. Identical points on the two surface are well-defined points. A well-defined point represents a feature for which the horizontal position is known to a high degree of accuracy and position with respect to the geodetic datum. For the purpose of accuracy testing, well-defined points must be easily visible or recoverable on the ground, on the independent source of higher accuracy, and on the product itself. To find these well-defined points I used stratified random sampling which is most often used when accuracy needs for an entire map. In my investigation I used the stratified random sampling strategy, because the points which were used to show the topographical features of the ground do not contain any spatial variation. All points were digitalized with the same method (on-screen digitalization), and thus have the same root mean square error. The DigiTerra Explorer v4. software is capable of making random sampling, we just need to define a frame and a unit. The frame was a grid cell network (length:50*50m, area:2500m^2). This size was based on my prior knowledge of the study region. On average, every cell contains 15-20 points; after defining these cells I made a random sampling using the Sampling Module of the DigiTerra Explorer v4. From every cell I sampled two points randomly. The most important viewpoint for sampling was the following: the observation parameters would be good for receiving GPS-and EGNOS-signals. Every cell contains on average 15-20 points, but among these points only 5-6 were eligible as locations for GPS-measuring. That's why I chose only 2 points from every cell (the total number of the digitalized points was 8973 pieces and after stratified random sampling 1669 pieces). Testing quantitative accuracy on the field I used the DigiTerra Explorer v4. data collecting instrument. I worked with three different layers: the topographical map as a raster-map, the sampling points as a vector-file in dxf-format, and the actually measuring file in a DigiTerra Map v2.3 format. The procedure was very simple: navigate to the sampling point and measure its coordinate with the DigiTerra Explorer point-measuring method. The measure takes only a few seconds, so measuring the whole sampling frame takes only three days (30 hours). After the measurements I calculated the accuracy of the map based on the equations of CMAS, NMAS, NSSDA and ASPRS. The final section of my presentation is about the documentation of map quality and accuracy using different metadata-standards: Hungarian Standard 7772-1, FGDC Metadata Quick Guide and INSPIRE Draft Implementing Rules for Metadata (2007).

9. RESULTS

My thesis intends to answer the following specific question: Can quantitative accuracy of digital topographical maps be determined by using spatial sampling and adjustment methods, and applying the measurement method of DGPS? In the following pages I summarize the achieved results of testing, reporting and documenting positional accuracy of digital topographical maps.

The used GIS-environment does not influence the accuracy of digitalization. I tested six different GIS software packages with the method of on-screen digitalization; only the accuracy of the Digiterra Explorer v4 was not sufficient; this software was not made for drawing and editing, but for field data collecting. The less accurate was the digitalization of a curved line and a closed curve; much better was the accuracy of a point, straight line and simple geometrical feature digitalization.

The cursor shape indicates and influences the accuracy of digitalization. Digitalization with a simple cross-hair cursor (AutoCad Map 2004, ITR4) or with a multiple cursor (DigiTerra Map v2.3., ArcMap 9.1.) is more accurate than digitalization with some other pointers such as arrow. To eliminate the systematic errors from the digitalization I digitalized straight lines and curved lines equal number of times from North-West to South-East, and also equal number of times from South-East to North-West; single geometrical figures and closed curves equal number of times clockwise and counter clockwise.

My thesis shows that using DGPS is not the best method for data field collecting. Real-time corrections are available only for the southern direction with no obstacles, because EGNOS-satellites are visible on the southern horizon (from Hungary). I mean that the best method for the field data collecting would be a combined method using GPS-technique and traditional technique like total station and taping. Where GPS does not work, there can be useful the knowledge of the traditional methods can be useful.

For determining map or digital database accuracy stratified random sampling is an adequate method. This type of sampling is often used for determining accuracy of a map or digital database. When sampling, the effect of generalization must be take into account. Only well-defined points can be used for the sampling and testing. A well-defined point represents a feature for which the horizontal position is known to a high degree of accuracy and position with respect to the geodetic datum. For the purpose of accuracy testing, well-defined points must be easily visible or recoverable on the ground.

Testing quantitative accuracy: The RMSE and the average discrepancy in the field (in the point position) are on average 40cm, which means that on the map the point position is only on average 0.04mm. The standard errors are for the field points are also 40cm, and for the map points also 0.04mm.

Circular probability means that may imagine a point on the map, corresponding a series of concentric circles; the radius of each circle corresponding to a different probability value. The widely used is Circular Map Accuracy Standard (CMAS), and the corresponding probability value of it is 90 %. When we imagine the map-point with their coordinates on the ground, and draw on it a circle which has a radius of the CMAS (in my investigation the radius is 90.7cm); 90 % is the probability, that the true position of the point lies within this circle. On the map the CMAS value is 0.09mm.

I tested four methods for the determination of the accuracy of the topographical map segment number 54-411 (Chapter 4, NSSDA, NMAS and ASPRS Accuracy Standards for Large Scale Maps). These methods produced the same results.

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BIOGRAPHICAL NOTES

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