STUDYING THE ACCURACY OF ORTHOPHOTOS ON THE EXAMPLE OF VARIOUS TERRAIN MODELS IN STUDY AREAS IN HUNGARY

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Abstract
Depending on the orientation data, the accuracy of the applied terrain models and the field content of the orthophotos data of different accuracy can be obtained in the course of analysing orthophotos. Considering the factors influencing accuracy, differences resulted by the application of different elevation models are studied in this paper in two study areas in Hungary. Primary aim of this study is to determine the magnitude of differences between the co-ordinates of reference points digitized from orthophotos and that of points measured by geodetic methods with the application of elevation models with various resolution and accuracy.

Keywords: orthophoto, Digital Terrain Model, LIDAR, TIN, GRID

1. Introduction

When orthophotos are made, aerial photos are taken of the surface of a terrain and the orthophoto of the area is composed using these aerial photos (Singh 1989, Weidner 1999, Junfeng & Jingfeng 2006, Gao 2008, Forkuo & Dordah 2011). In order to complete the task the interior and exterior orientation elements and the elevation data of the area (digital terrain model) have to be known. Exterior orientation elements determine the spatial position and orientation of the photos (at the time of taking them) in the field co-ordinate system. These are the co-ordinates of the projection centre in the geodesic co-ordinate system and the three spatial angles determining the direction of the camera axis as well (Congalton 2001).

Interior orientation means the restoration of the photo side beams of rays. Interior data of the camera (co-ordinates of the projection centre in the photo co-ordinate system) are considered to be known, thus the interior orientation of the photos is limited to a plane transformation task in digital photogrammetry.

The digital elevation model is a database that contains X, Y, Z spatial co-ordinates of certain points of a topographic surface. In this case this surface is the Earth's surface, so we have a terrain model. Since topographic surfaces are generally complex forms, they cannot be described by simple mathematical formations (Congalton 1991). Therefore, samples are taken from the terrain surface and the co-ordinates of only the selected points are stored in the terrain model (Borg et al. 2011). As a result of different solutions, data excess may occur in flat areas (there are much more points with elevation than required for the explicit definition of the terrain). In areas with more diverse relief, resolution may limit the accurate visualization of the terrain due to the lack of data. This results in distortions in the horizontal co-ordinates of the orthophoto.
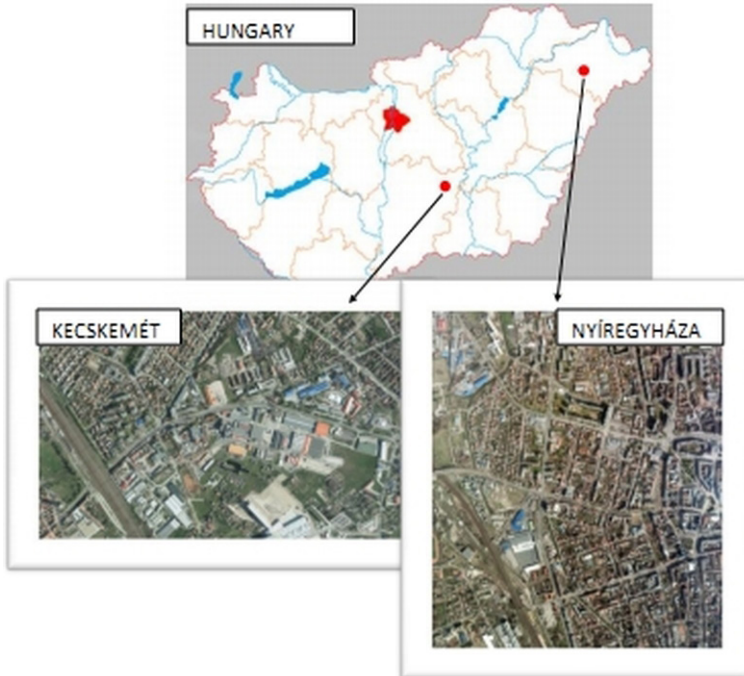
Fig. 1. Location of the study areas in Kecskemét and in Nyíregyháza

So called radial - displacement is resulted by the position of the height differences of the terrain compared to a reference plane (image plane). Displacement effect of the relief can be eliminated only by a digital terrain model.

In the present paper solely the effects of terrain models prepared with different procedures on the horizontal co-ordinates of orthophotos are studied. Displacement caused by these height differences increase from the image nadir point towards the edges with maximum values along the edge of the images. As a result, points in the image are projected not at the position of orthogonal projection, but shifted towards the image edges. The magnitude of these shifts is studied based on terrain models composed of different types of data sources. This paper aims to study the grade of influence of different terrain models on the accuracy of orthophotos. Measurements were made in two study areas. One study area is located in the suburban – industrial areas of Kecskemét and the other one in the central industrial areas of Nyíregyháza (Fig.1).

2. Materials and methods

Digital terrain models can be prepared with different techniques based on input data of various accuracies. As a result, their data content, structure and accuracy (distorting effect on horizontal co-ordinates) can be different as well (Baltsavias & Käser 2007, Congalton & Green 2009). Depending on the format in which data of the terrain models are stored, raster and vector models are created. TIN, GRID, DCM vector models were used in this study. In the data structure of the TIN (Triangulated Irregular Network) model the horizontal arrangement of points is irregularly distributed, points are connected by lines that form an irregular grid network contrary to the GRID model, where points form a regular square grid network.

Digital terrain models covering large areas were initially prepared solely by digitizing the contour lines of topographic maps. DCM (Digital Contour Model) describes the points with similar heights of the physical surface of a terrain by contour lines. Accuracy of

the terrain model composed in this way is primarily determined by the reliability of the base map that is influenced mostly by the technique of map preparation, relief conditions of the depicted area and the scale of the map.

Since height is a decisive element of terrain models obtained by various measurement methods, models constructed by contour map digitization, stereo-photogrammetric evaluation and LIDAR (Light Detection And Ranging) survey were applied in the research (Vallet 2007). Accordingly, one terrain model applied in the study was the EOV (United National Projection) DDM-10 (digital elevation model – 10), the base elevation level of which is the level of the Baltic Sea. Base map of this model is the 1:50000 scale military topographic map with Gauss-Krüger projection system, published in 1985-1991. The terrain model was obtained by digitizing the vectorized contour lines attributed with height values in a horizontal resolution of 10x10 metres. Height values of the contour lines in this case are whole numbers. Height resolution of the model is 1 m. Since height conditions are depicted with contour lines in topographic maps (points with height values at certain characteristic positions), we have no information on the height conditions of areas between the base contour lines. No height information is available regarding benches, ditches, embankments, cuts, etc. either as their visualization is solved by agreed symbols. Although, the terrain model was completed by stereo-photogrammetric survey / evaluation in order to display significant relief changes (e.g. motorway construction) the height representation cannot be regarded complete due to the content limits of the topographic base map.

The other terrain model applied in the study was created using stereo-photogrammetric survey / evaluation. Aerial imaging carried out prior to the interpretation, so the produced stereo image pairs show the real (actual) relief.

Stereoscopic orientation with a digital photogrammetric workstation was performed with automatic stereo-correlation procedure. Locations with weak correlation were controlled subsequently, because this procedure cannot give 100% reliability. In the course of subsequent controls, break lines were interpreted based on field elements (e.g. canal, embankment, bridge) where they were required. The terrain model which is corrected in this way, is composed of point fields measured in a 3x3 metres grid network.

The third applied terrain model was constructed from a point cloud obtained via LIDAR survey. "Laser data acquisition resulted in the improvement of the quality of spatial measurements as well apart from high efficiency. Laser technology is one of the most effective remote sensing method today considering speed, density and accuracy of data acquisition. On one hand, spatial data can be obtained even from one survey. On the other hand, the quality of the models is generally in close correlation to the interpolation methods applied in generalizing the models. The accuracy of terrain models, produced with using LIDAR systems reaches 1/8000 of the flight height. For example, in case of 1200 m flight height the value of accuracy is 15 cm. As a result, laser data make the construction of precise DTMs of areas with small height differences that would not be possible by other remote sensing techniques" (Verőné 2010).

Data structure of the terrain model constructed based on LIDAR survey, is TIN generated from scattered points, i.e. an irregular triangle network. Density of the measured points was 6 points/m2. Both the aerial photos and the orthophotos were made by the Eurosense Ltd. In the course of aerial triangulation, the exterior orientation parameters (absolute orientation) of the photos were determined with connecting the individual images (relative orientation) and with the transformation of the connected images with the help of tie points. Exterior orientation parameters include the shift and rotation values in the national co-ordinate system that characterised the position and

Fig. 2. Location of reference points in Kecskemét

orientation of aerial photo camera at the time of taking photos (Siristye & Zboray 2004). The required measurement of the connection points for relative orientation, was performed by a software using correlation. Control points for absolute orientation were defined subsequently. During aerial triangulation, accuracy below pixel size was achieved at the control and tie points and in the standard deviation values of the connection points. Resolution of the orthophotos produced in this way is 0.1 m. Real accuracy of the orthophotos is determined by the orientation data, the accuracy of the digital terrain model and the chosen pixel size in the plane of the orthophoto.

This study focuses on digital terrain models. Other factors influencing the accuracy of orthophotos were the same at both study areas. The same camera, pixel sizes and the same aerial triangulation interpolation procedure were applied.

Points required for controlling the terrain models were identified on the orthophotos and their co-ordinates were determined by digitizing them (Fig. 2). We tried to select such

reference points near the margins of images as well, however, the complete homogeneity of reference points in the entire territories of the study areas could not be reached due to field obstacles and sharp boundaries at certain areas.

There were three important aspects of reference points' selection. Firstly, exactly identifiable points were selected, which could be clearly separated from their surroundings both horizontally and vertically. Secondly points had to be unchanged since the date of production of aerial photos, and finally accessibility was also considered. Therefore, most of these points were centres or edges of shafts, pavement or road surface margins, location of road surface changes, characteristic points of road surface symbols in public areas. Because of potential uncertainty, pillars, utilities, boxes - that may have shadows - were used rarely. Digitizing of reference points was performed six times for control purposes. Digitizing, documentation and analysis of field measurements were performed using ITR5, ArcGIS and Microsoft Excel software. Field identification and

co-ordinate measurement of the digitized reference points were carried out with a Leica GS 15 satellite navigation device, based on network based method.

The GNSS Service Centre in Hungary is found in the Satellite Geodetic Observatory, Institute of Geodesy, Cartography and Remote Sensing (FÖMI) at Penc, where network based operation involves continuous measurements by reference receivers at points of known position. Therefore, cycle ambiguity, satellite track errors, atmospheric and other effects can be calculated and then corrections of the errors can be forwarded to the end-users in real time. From the end-user's aspect, cm scale GNSS measurements can be performed using a single receiver" (Busics 2010). Required corrections for our measurements were supplied by the stations operated by the FÖMI at Nyíregyháza and Kecskemét.

Following the field measurements, sum of differences, sum of squared differences, mean difference, Gaussian squared difference, standard deviation and median of difference, minimum and maximum differences and error range were calculated using the digitized and the measured horizontal coordinates. Statistical calculations included two-sample t-test, F-test and variance analysis.

3. Results

Measurements were always based on a single station, on a known point in the OGPSH (National GPS Network) in real time reference system, where base lengths never reached 1.5 km.

Since the real time reference system (network of permanent stations) with its guaranteed reliability replaced the reference system with traditional base points, it was sensible to perform the control of our measurements in the real time system. Determination was based on a single permanent station (one base solution) but measurements had to be repeated for control because base point determination was performed.

Measurements were repeated after 15 minutes with new initiation at every point. In order to control the base station, one known OGPSH point was involved as well. Since no significant differences were detected that would have influenced results of the study in effect, further control regarding the accuracy of the determination was performed. Applying repeated digitizition, the accuracy was controlled. Variance analysis revealed that repeated digitization of the points results in no significant differences, i.e. it does not
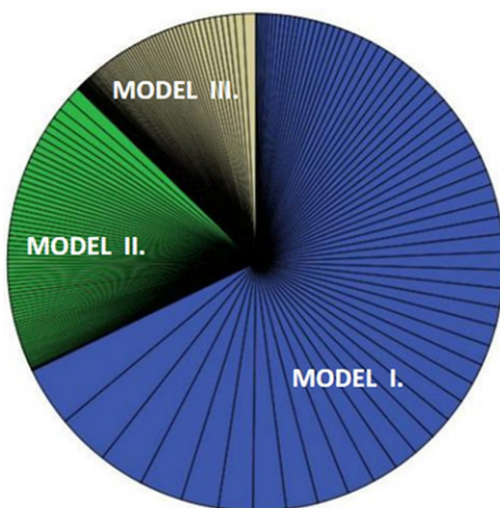

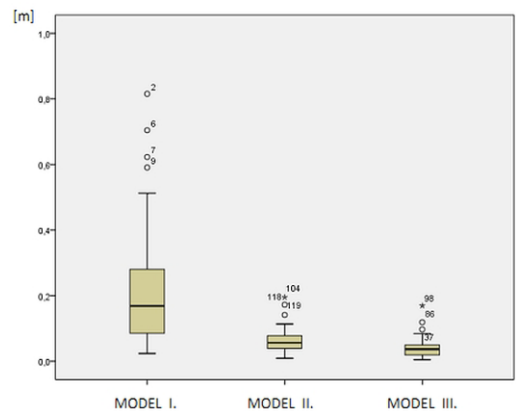Fig. 3. The distribution of the data in accordance with the three terrain models

Fig. 4. The descriptive statistical data in accordance with the three terrain models

influence the study.

Following the field measurements, the reference points were classified. First class included the centres or corner points of well identifiable artificial landmarks that could be separated vertically as well. Second class included artificial objects that were plotted dull on the image, but could be identified clearly in reality, e.g. grass grown in the corner of concrete cover. The differences between the co-ordinates of the points, digitized from orthophotos and defined by the use of the geodetic method were determined per point.

In order to present linear differences, isolines were created with 10 cm long intervals; then the results were classified in case of every terrain model.

Relative frequency, i.e. the percentage of sample in each class was displayed using the first and second class points in both study areas (according to the available terrain models). It was necessary to determine the dispersion of functions. Accordingly, it can be stated that every sample can be characterised by that smaller-and-smaller frequencies can be associated with greater-and-greater differences except for the digital contour line model. Model I shows the differences of the terrain model generated from contour lines. Model II displays the differences of the model calculated from photogrammetric calculations. Model III presents the differences of terrain models composed on the basis of laser surveys.

Following the unification (in accordance with the measured terrain models) of the data measured in Nyíregyháza and Kecskemét, the results were illustrated in a pie chart (Fig. 3). The distribution of the samples (the differences) is presented in an increasing order (clockwise). The number of the samples is the same in the case of each model. It can be proved on the basis of the diagram that the sum of the differences is the largest in the case of Model I, and the smallest in the case of Model III.

To make the statistical data of each model easier to read, they are shown in a box plot as well (Fig. 4). They properly illustrate that the size, the median and the average of all examined terrain models form a strictly, monotonously decreasing sequence, which all indicate that the differences that arouse were bigger in the case of terrain model I, and significantly smaller in the case of model III, i.e. model III is more precise than II and I, so in terms of this, model III is the "best" terrain model.

In order to study whether mean differences are the same in the different samples or not, two-sample t-test was applied and in the case of the Nyíregyháza area. The absolute mean differences from the digital contour line model were compared to the expected values of the absolute mean differences of the terrain model prepared by photogrammetric survey. According to the equality of standard deviations, different types of two-sample t-test have to be applied if the number of investigated elements are the same. Therefore, prior to the examination it is necessary to determine by F-test, whether the standard deviations of the two samples are the same or not. In the case of Nyíregyháza results show that standard deviations cannot be regarded the same at 95% certainty level.

Based on the results, the suitable two-sample t-test was selected for the analysis. Calculating the value of t-statistics, the null hypothesis as the expected value of the two samples are the same, was rejected at 95% certainty level. This means that the absolute mean difference related to the DCM is different from the mean absolute differences of the terrain model based on photogrammetric evaluation.

During the analysis of study area at Kecskemét, a very similar procedure was applied, considering that the comparison of more than two samples was performed. Therefore, standard deviation analysis was carried out to investigate the magnitude of absolute mean differences depends on the digital contour line model, the photogrammetric model or the model generated from the LIDAR survey. In our study

Fig. 5. Horizontal differences in the DCM (yellow), and on the digital terrain model based on photogrammetric survey (green) in Nyíregyháza

the single factor variance analysis is applied as the generalization of the two-sampled t-test in case of several independent groups. Expected values are compared as the of the total variance dissociation (application of the two-sample t-test was not possible since three samples have to be analysed). F values calculated for three different resolutions with test statistics, are significantly higher than the critical value, so the absolute mean differences of the three samples cannot be regarded similar. The magnitude of absolute differences apparently depends on the applied terrain model (Table 1).

With two-sample t-test it was proved that there is no significant difference between the means of first and second class points in the two study areas. Minimum of the mean differences between first and second class points is 0 cm, while the maximum is 5 cm.

Therefore, the error vectors of the orthophotos were displayed by isolines with 10 cm interval. The horizontal differences of first and second class points are represented together, and the linear errors were interpreted by every height (Fig. 5). Since errors are located randomly, the smoothing

of isolines (making them plastic) was not necessary.

It can be stated that in the case of DCM (Yellow), the differences are higher by orders of magnitude with maximum values along the edge of the images. Differences in the case of DTMs prepared with photogrammetric survey (green) are only of a few cm. In the latter case, it cannot be stated that the maximum values occur along the edge of the images.

Based on the mean differences of different models, it can be stated that the accuracy of the studied orthophotos with 10 cm/pixel resolution, is 27 cm in case of digital contour line model, which is multiple of the pixel size (27/10 pixel). In case of models made with photogrammetric survey, this value does not reach the value of resolution; it is 7 cm (7/10 pixel). Most accurate value characterises the orthophoto composed on the basis of the model generated from the LIDAR survey. In this case the mean difference is only 4 cm, which is less than 50% of the pixel value (4/10 pixel).

4. Conclusion

There are significant differences between the position of reference points digitized from orthophotos, which generated from different terrain models and determined with geodesic methods. Prior to comparing the data, the accuracy of both the survey method and the reference points applied in the study were controlled. In the course of the control it was determined that neither the applied method nor the inaccuracy of the applied reference points influenced the results of the study. Based on the comparison of the reference points digitized from orthophotos and determined with geodesic methods, it was stated that every sample can be characterised by smaller-and-smaller frequencies for greater-and-greater differences. Dependence of the accuracy of orthophotos from the accuracy of height data and resolution of the terrain model was proved. The smaller the resolution of the terrain model and the smaller the class of the points used for height determination, the greater the inaccuracy. Based on the results, the expected horizontal accuracy of orthophotos with 0.1 m/pixel resolution is 27 cm in the case of terrain models with 10x10 metres GRID data structure generated from the contour lines of 1:50000 scale topographic maps. The horizontal accuracy of orthophotos composed of aerial photos with resolution of 0.1 m/pixel based on photogrammetric survey with 3x3 m GRID is 7 cm. Finally, in the case of TIN obtained from LIDAR survey, the accuracy is 4 cm.

The analysis of the terrain models is also shown, that it is required to digitize the height value of relevant objects, with special regard to relief changes, anthropogenic forms (bridges, embankments) which can be missing from the applied model. In order to ensure the above, average value filtering, gross errors of the terrain models and the completion with subsequent interpretations are essential.

Results can be applied in scientific fields, where the accuracy of orthophotos meets the requirements of a given task based on the average values determined in this study. In this way the evaluation of extended areas can be performed cost effectively and even reaching almost the accuracy of a field survey.

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