Propositions of Ph.D. theses

ACCURACY ASSESSMENT OF AERIAL PHOTOGRAPHS AND SATELLITE IMAGES WITH DIFFERENT RESOLUTION BASED GEODETIC REFERENCE MEASUREMENTS

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INTRODUCTION

Geodesy and cartography are concerned with creating terrain surveys, analogue maps, photograph based maps, digital maps, digital photograph based maps, point clouds and various models. Mapworks are used by different specialist fields for different purposes. Data needed for the creation of maps may be accumulated by using geodesic methods and remote sensing. The most accurate, but also the most costly method is land measurement. Cheaper methods include preparing maps based on aerial photos and satellite images reflecting different contents and different resolutions. These have by now become mass products being available for an ever wider circle of end users. The role of remote sensing, a data capturing technique, in particular the satellite-, aerial- and land remote sensing has dramatically gained in importance due to the rapid technical improvement and an expanding scope of their potential application making these products indispensable for geodesic measurements, traffic, building industry, agriculture, forestry, environment management, and flood control.

Various specialist fields require maps of differing content, scale and resolution. Data can only be reliably provided for these clients if the accuracy of the data provided is known. These values however can be widely different as the data to be gained from maps created with the help of different data bases are also different largely due to the differences in scale and resolution. The accuracy of the information gained from the assessment does not, however, depend on scale and resolution only, but also on the content that we want to interpret. Cartographic and terrain definitions of landmarks may vary in accuracy since the identification of their centers, axes or vertical projections may also be of different accuracy.

Knowledge of the accuracy and reliability of the data gleaned is therefore simply indispensable if we want to determine whether these photos comply with the accuracy requirements and specifications of the task at hand.

In the present study I examined data defined with geodesic methods, as well as maps created using aerial and satellite remote sensing. In order to establish their accuracy and reliability I have analysed points taken by geodesic measurements, orthophotos and digital orthophotos based on aerial photos taken from aeroplanes, and maps created on the basis of satellite photos.

AIMS

I have defined the following aims for the study regarding the accuracy assessment of orthophotos and satellite images of various resolutions:

- Definition of accuracy values of methods used in the study,
- Accuracy assessment of digital orthophotos based on terrain elevation models created with different techniques,
- Accuracy assessment of orthophotos with different resolution,
- Definition of the accuracy and reliability of forest boundaries based on digital orthophotos taken in different years,
- Accuracy assessment of points and forest boundaries based on 2.5 m/pixel resolution satellite images,
- Survey of the accuracy of road centerlines in case of the resolutions 0.1, 0.4, 0.5 m/pixel and an analysis of the results of the respective resolutions,

- Accuracy assessment of road centerlines based on satellite images of 1.85 and 2.5 m/pixel.

MATERIALS AND METHODS

Four sample areas were used in the research in the counties Szabolcs-Szatmár-Bereg, Hajdú-Bihar and Bács-Kiskun. The selection of the sample areas was based on a predetermined set of criteria. The areas chosen were meant to represent flatland, sandhills, as well as outskirts and settlement centers.

The first test area (144 km^2) was the plane east of the town Hajdúböszörmény, the surface of which is covered in loes sedimentation, the second 144 km^2 test area is located in a quicksand zone with sandhills with the settlement Nyírlugos at its center. The third and fourth test areas include central parts of the towns Kecskemét and Nyíregyháza.

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Orthophotos of the study

The resolution of the orthophotos taken in the years 2000, 2005, and 2007 was 0.5 m/pixel, whereas the resolution of the orthophotos taken in 2011 was 0.4 m/pixel and all photos were obtained from FÖMI for both sample areas. The 0.5 m/pixel orthophotos of the year 2006 (taken of the first and second test area) were purchased from Mapping and Communication Servicing Non-profit Ltd., of the Ministry of Defence. The 0.1 m/pixel resolution digital orthophotos of Nyíregyháza were taken in 2011, and those of the Kecskemét area in 2013 by the Eurosense LLC.

Elevation models

For the digital orthophotos taken in 2000, 2005, 2007 and 2011 a 5x5 m grid density GRID type (consisting of points located in a regular grid network) digital elevation line model (DEM) was used that was generated from the contour lines of topographic maps (created by the vectorization of terrain reliefs) of a 1:10000 scale.

The orthorectification of the digital orthophotos taken in 2006 was done with the help of the DTM-10 model (digital terrain model, hereinafter DTM) showing contour lines of the country at 10 m intervals. The DTM-10 model was created in the Hungarian Projection System (EOV) the source of which was a 1: 50 000 scale military topographic map of a Gauss-Krüger projection type.

Three different terrain models were used for the digital orthophotos taken of the Nyíregyháza and Kecskemét sample areas. The first terrain model was the above mentioned DTM-10 model in the Hungarian Projection System, the second was prepared by stereo-photogrammetric assessment of aerial photographs consisting of a point field measured in a 3x3 grid network. The third terrain model was created from a LIDAR survey, the data structure of which was a TIN generated from a scatter point set, i.e. a triangulated irregular network with a point density of 6 points/m^2.

Satellite images

Two of the satellite images were used in the study, the QuickBird Ortho Ready Standard 4 Band Bundle satellite image in the UTM projection system purchased from Digital Globe (the resolution of the red, green, blue bands is 2.5 m/pixel), and the WorldView 2 Ortho Ready Standard 8 Band Bundle satellite image (the resolution of the red, green, blue bands is 1.85 m/pixel). The satellite images covered the sample areas in Hajdú-Bihar and in Szabolcs-Szatmár.

Geographic information system, geodesic and statistical methods used in accuracy assessments

Geospatial methods, in particular vectorization was applied in order to define cartographic coordinates of points, lines and polygons. I have checked the accuracy of vectorization by redefining them several times.

Geodesic measurements were perfomed with a network RTK method, for which I used two different instruments. On the one hand a Trimble R6 receiver and on the other a Leica GS 15 GPS receiver. The instruments were used to define the X and Y coordinates of terrain points in the Hungarian Projection System (EOV). Accuracy of the instruments was checked by redefining partial points several times.

For the mathematical-statistical analyses I used several instruments of descriptive statistics (mean, median, SD), various graphic methods (histogram, box diagram), hypothesis testing (2 sample t-test, F-test, Chi-square test, variance anaysis, normality tests) as well as interval estimation and the method of least squares. Actual deviations were computed using the CE95 method (Circle Error at a Confidence Interval of 95%). Statistical analyses were performed with the IMB SPSS statistics 22 and the MedCalc 16.2 softwares.

RESULTS

In my PhD dissertation I have presented the results of the accuracy assessments of digital orthophotos, satellite images and terrain elevation models of different resolutions, which can be summarized along the theses listed below:

1. The terrain elevation models created with different technical approaches may impair the values of horizontal coordinates in the sample areas by several pixels.

When analyzing the data it could be observed that the range, median and mean of the deviations between the cartographic and terrain points (based on the DTMs used in the study) constitute a strictly monotonically decreasing sequence demonstrating higher differences in the DTMs based on contour lines than the significantly lower differences of the LIDAR based DTMs, an observation that leads to the conclusion that the latter are more accurate than the elevation and photogrammetric DTMs. *(Figure 1.)*

Figure 1. Horizontal deviations in the DEM (yellow marking) and in the terrain model created by photogrammetrical assessment (green marking) in the Nyíregyháza area depicted with isolines at 10 cm intervals. (own edition)

The mean differences computed for the varius models yield an accuracy of 27 cm in case of the 10 cm/pixel resolution digital elevation models (DEMs) which is several times higher than the pixel value. In case of photogrammetic evaluation and LIDAR survey models these values are well below the pixel values.

The results clearly show that the most accurate orthophotos are those based on LIDAR measurement with a mean deviation of less than 50% of the geometric resolution.

Based on the results of the analysis I have noted that the difference in the horizontal deviation caused by the assessment of elevation lines and the LIDAR data generated DTMs is more than the value of 2 pixels.

2. I have proved that a LIDAR elevation model of 0.1 m/pixel resolution of the test area distorts the horizontal coordinates by less than 2 pixels with the CE95 method. Consequently it can be stated that the CE95 model lends itself for testing the accuracy of horizontal coordinates of digital orthophotos.

The actual horizontal difference of orthophotos taken in the Nyíregyháza test area, examined by the CE95 method and constructed by a LIDAR based DTM of 0.1 m/pixel resolution is 0.16 m. Upon analyzing the approximately 100 control points, it can be noted that 80% of all deviations falls in the subpixel range. Only two of the points were remarkably different, which must obviously be due to faulty map identification.

Upon processing the data it was visible that the significant deviations determined by the CE95 method demonstrate the same tendency as the absolute deviations of the models (DEM is the least accurate, the photogrammetric assessment is more accurate and the LIDAR based model is the most accurate) except that the previous method can be used for calculating deviaions in 4 directions, while the latter for unidirectional (absolute) deviations only. Results of the assessments have confirmed that the circle error method is appropriate for accuracy testing of horizontal coordinates of digital orthophotos.

3. Using the CE95 method I have been able to prove that the biggest distorsion effect on the same horizontal values was seen in the DEM under study when compared with the terrain models created by photogrammetric assessment and those based on LIDAR measurement. I have found that the horizontal accuracy of the points definable in the digital orthophotos of the sample areas increases parallel with the increase in the grid densitiy of the terrain models and with the accuracy of the height values.

The CE95 value is 0.54 m in case of the orthophotos created with the help of DTMs based on contour lines in Kecskemét considering the diameter of the circle. The actual deviations in case of the orthophotos created with the help of DTMs based on photogrammetric assessment and the LIDAR survey in the Nyíregyháza sample area were 0.23 m and 0.16 m respectively, whereby the diameter of the circle error included 95% of all points. The results confirm that there is a more than threefold difference between the most accurate and the least accurate models in the sample areas.

It has been observed that decreasing horizontal deviations correlate with height accuracy and grid density of applied models (5x5 m GRID; DEM, 3x3m GRID; fotogrammetric model, 6 point/m^2 based TIN; LIDAR model). Grid density regarding elevation was the lowest in the least accurate DEM model (the horizontal distorting effect is the highest in this model), and the highest in the LIDAR model (the most accurate regarding elevation with the least horizontal distorting effect).

4. I have proved that accuracy of forest borders definable from orthophotos taken of flatlands with forest patches (where the borders are visually identifiable) in the test areas that were created on the basis of a 5x5 m GRID elevation model with an 0.4 m/pixel resolution was 5 pixels, however, when the forest patches are broken up by reforested areas, cutblocks, and clearings, the accuracy of definition is reduced to 6 pixels.

When examining the accuracy of forest borders in the orthophotos taken in different years (2000, 2005, 2006, 2007, 2011) I found that the difference between vectorization and terrain definition includes deviations caused by changes in the terrain. These deviations are only negligible in the orthophotos taken in the year when terrain measurements were also done in the area.

It has been confirmed in the test areas that the accuracy of the orthophotos taken of forest patches with visually identifiable boundaries in the year 2011 is 2.06 m (~5 pixels), in areas however, where spots of clearings break the continuous forest, reforested areas or cutblocks are seen, interpretation of the forest boundary is much more difficult and the accuracy is reduced to 2.48 m (~6 pixels). Based on the analyses it can be concluded that the accuracy of the orthophotos under examination is increasing year by year as we advance towards the year when terrain measurements were taken.

5. Upon analysis of forest boundaries I have found that the accuracy of the orthophotos older than 6 years with a resolution of 0.4 and 0.5 m/pixel and that of the satellite image with a resolution of 2,5 m/pixel is less than 3 m in the test areas, therefore these data are not acceptable for the accuracy of definition of forest boundaries as set forth in the regulation of the forest management authorities.

The accuracy of forest borders based on the orthophhotos taken in different years range from 4.08-5.05 m in 2000, and 31.35-4.62 m in 2005 to 3.17-3.57 in 2006.

Upon analysis of forest boundaries I have found that the accuracy of the orthophotos older than 6 years with a resolution of 0.4 and 0.5 m/pixel is less than 3 m in the test areas, therefore these data are not acceptable for the definition of forest boundaries as set forth in the regulation of the forest management authorities (Paragraph 2 Section 7 of the 2 11/2010 (04 February) Regulation of the Ministry of Forestry and Regional Development).

The satellite image with a resolution of 2.5 m/pixel yields a forest border accuracy of 4.16 m (1.66 pixel) based on the mean of the sample and therefore it causes a significant error in the definition of forest patch areas based on satellite images, i.e. the error is more than 3 m and thus inappropriate for defining forest borders.

6. I have proved that the lines definable in the 0.5 m/pixel resolution digital orthophotos taken of the sample areas (with exact marking in the terrain) can be determined at an accuracy rate of about the pixel value, and in case of a higher than 0.5 m/pixel resolution the accuracy rate is below the pixel value (i.e. it is better than that).

As a result of measurements a correlation concerning all samples was found between the increase in deviations and the decrease in their frequency.

I have found that the accuracy of road centerline definitions with a resolution of 0.1 m/pixel shows a subpixel error of 7 cm.

The examination of centerlines of paved roads yields an accuracy of 25 cm in case of 0,4 m/pixel resolution orthophotos according to the result of the t-test confirming that the deviation between terrain measurement and vectorization will be less than the expected 25 cm at a confidence of 95%.

Accuracy of definition with a resolution of 0.5 m can be considered practically identical with the pixel size (0.52 m).

Based on the examinations of various resolutions I have concluded that the definition accuracy of road centerlines in the test areas in case the resolution is 0.1 m/pixel and 0.4 m/pixel shows a subpixel error, whereas in case the resoulution is 0.5 m the error value can be considered to be the same value as the pixel size.

7. Based on true color 2.5 m/pixel resolution satellite images I have proved that the accuracy of defining road centerlines in the sample areas is 1.10 pixels, whereas that of forest borders is 1.66 pixels. Due to increased accuracy of horizontal points, definition accuracy of lines and polygons is also enhanced.

Accuracy assessment of road centerlines in the first sample area in satellite images with a resolution of 2.5 m/pixel yielded a mean deviation value of 2.75 m (1.10 pixels) when 2350 points were depicted. I have noted that the accuracy data of the satellite images are reliable as the SD of the deviations cluster around the means..

Accuracy of the forest borders in the same sample area was 4.16 m which corresponds to 1.66 pixel when expressed in resolution. The definition accuracy of road centerlines in the sample areas is consequently 50% better than that of forest borders.

The more definitely the centerline and the center of a terrain object in reality and in the images can be identified the more accurately the cartographic-terrain definition of points considered to be the bases of the analyses can be done. Since points of the centerline can be identified in their respective axes of symmetry the accuracy of their definition is better than that of the vertical projections of the foliage (forest borders). Based on measurement results it can be claimed that the increase in geometric accuracy of the points leads to an increase in the accuracy of lines and polygons.

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List of publications related to the dissertation

Hungarian book chapter(s) (3)

1. **Varga Z.**, Czédli H., Kézi C., Fekete Á.: Ortofotók pontossági vizsgálata úttengelyek alapján.
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2. **Varga Z.**, Czédli H., Bíró J., Fekete Á.: Ortofotók megbízhatóságának vizsgálata erdőhatárok geodéziai felmérése alapján.
   In: Műszaki tudomány az Észak-kelet Magyarországi Régióban 2015 : konferencia előadásai : Debrecen, 2015. június 11. Szerk.: Bodzás Sándor, Debreceni Akadémiai Bizottság Műszaki Szakbizottsága, Debrecen, 348-353, 2015. ISBN: 9789637064326

3. **Varga Z.**, Bíró J.: Az Ecsedi láp területéről készült légi felvétel pontosságvizsgálata, geodéziai mérések alapján.
   In: Az elmélet és a gyakorlat találkozása a térinformatikában IV.: Térinformatika Konferencia és Szakkiállítás, Debrecen, 2013.05.23-2013.05.24. Szerk.: Lóki József, Debreceni Egyetem, Debrecen, 481-488, 2013. ISBN: 9789633183342

Foreign language Hungarian book chapter(s) (1)

4. **Varga, Z.**: Precision assessment of aerial photographs with different resolution based on geodetic measurements.
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Hungarian scientific article(s) in Hungarian journal(s) (1)

5. **Varga Z.**, Fekete Á.: Ortofotó pontossági vizsgálata geodéziai felmérés alapján. *Geodézia és Kartográfia. 66* (7-8), 11, 2014. ISSN: 0016-7118.

Foreign language scientific article(s) in international journal(s) (3)

6. **Varga, Z.**, Czédli, H., Lóki, J., Bíró, J., Fekete, Á.: Evaluating the accuracy of orthophotos in the context of forest borders in hungarian test sites. *Fresenius Environ. Bull. 24*, 2015. ISSN: 1018-4619. IF:0.378 (2014)

7. **Varga, Z.**, Czédli, H., Kézi, C., Bíró, J., Fekete, Á., Lóki, J.: Studying the accuracy of orthophotos on the example of various terrain models in study areas in Hungary. *Appl. Geophys. Epub*, 2015. ISSN: 1672-7975.

8. **Varga, Z.**, Czédli, H., Kézi, C., Lóki, J., Fekete, Á., Bíró, J.: Evaluating the Accuracy of Orthophotos and Satellite Images in the Context of Road Centerlines in Test Sites in Hungary. *Res. J Appl. Scien. 10* (10), 568-573, 2015. ISSN: 1815-932X. DOI: http://dx.doi.org/10.3923/rjasci.2015.568.573

List of other publications

Hungarian book chapter(s) (3)

9. , **Varga Z.**, Bíró J.: Az Ecsedi láp területéről készült légi felvétel pontosságvizsgálata, geodéziai mérések alapján. In: Az elmélet és a gyakorlat találkozása a térinformatikában 3. Szerk.: Lóki József, Debreceni Egyetemi Kiadó, Debrecen, 437-442, 2012. ISBN: 9789633182185

10. K. Bacsó L., **Varga Z.**: Térinformatika alkalmazása a mérnökképzésben. In: Az elmélet és gyakorlat találkozása a térinformatikában. Szerk.: Lóki József, Kapitális Nyomdaipari Kft., Debrecen, 175-178, 2011. ISBN: 9789633181164

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12. **Varga Z.**: A világ kataszteri rendszerei.
Az elmélet és gyakorlat találkozása a térinformatikában II. 2, 488, 2011.

Total IF of journals (all publications): 0,378
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