Research Journal of Applied Sciences 10 (10): 568-573, 2015
ISSN: 1815-932X

Evaluating the Accuracy of Orthophotos and Satellite Images in the Context of Road Centerlines in Test Sites in Hungary

[1]Zsolt Varga, [1]Herta Czedli, [1]Csaba Kezi, [2]Jozsef Loki, [3]Akos Fekete and [1]Janos Biro
[1]Faculty of Engineering, University of Debrecen, Otemeto u. 2-4, H-4028 Debrecen, Hungary
[2]Faculty of Sciences, University of Debrecen, Egyetem ter, H-4032 Debrecen, Hungary
[3]Geodesic and Cartographical Inc., Hunyadi utca 4, H-4028 Debrecen, Debrecen, Hungary

Abstract: Improvement and constant change in science, technology and innovation in our modern life demands knowledge of a variety of geo-information applications, thus tools of data processing, display, analysis and simulation while fulfilling an interdisciplinary role, promote decision making and analytic procedures of engineering, ecological and marketing tasks. Aerial and satellite images have been used worldwide for the purpose of conducting various projects (studies of changes in land cover, classification, defining land usage) with photos serving mostly as starting points, a basis for our analyses. Assuming that different aerial and satellite images shall yield data of varying accuracy, subject to the scale and resolution of the photos as well as the type of depicted cartographic units, it is essential to have advance knowledge of expected accuracy of the photos to be used before the evaluation is performed. The aim of our analysis was to determine the difference between the vector files obtained from digitized orthophotos and those obtained by using geodesic measurements; we examined whether accuracy was subject to varying resolutions of orthophotos or satellite images. We have analyzed aerial photos and satellite images of two chosen test sites by comparing points and lines obtained by landscape measurements with those digitalized from orthophotos. By using statistical methods we defined the expected accuracy (resolutions used were 0.4 and 0.65 m/pixel) of road centerlines digitized from photos. Our study wants to emphasize that the assessments we apply may be utilized for planning and research work and the resulting data may effectively be used for road line planning as well as determining road segments and public utility crossings.

Key words: Landscape changes, landscape metrics, environmental monitoring, orthophoto, GPS Trimble R6

INTRODUCTION

Analysis of areal and satellite photos may yield data of variable accuracy consistent with the scale and resolution used (Hohle, 1996; Greenfeld, 2001; Mena and Malpica, 2005; Mesas-Carrascosa *et al*., 2014). Options for evaluating remote sensing data sets are highly dependent on image resolution (Rau *et al*., 2002). Accuracy of information obtained from the assessment is however, not only subject to image resolution but also to the elements that to be determined. Accuracy relative to a point for example differs from that of a line or a polygon. Beyond that the interpretation of satellite images and orthophotos does have an inherent potential for mistakes and errors. Szabo analyses done on remote sensing images with inappropriate resolution for the task in hand or for the type of object in question may lead to incorrect interpretation of data.

A low resolution image might be enough for some tasks whereas in other cases even a high resolution orthophoto may not necessarily fulfill accuracy requirements of certain other tasks. In order to be able to orient ourselves among the products offered by the manufacturers we need to know both the accuracy and the reliability of the orthophotos and satellite images. (Smith *et al*., 1997).

Unless we know the accuracy of the aerial photo it is rather difficult to judge whether the aerial photo meets accuracy requirements and instructions of the given task. It is absolutely necessary to know in what professional disciplines and for what purposes the data obtained from the images and subsequent results shall be used. On account of this two sample areas of 144 km^2 each have been studied to determine accuracy of aerial photos and satellite images. The first test site is located in the Hajduhat region to the east of the town Hajduboszormeny (N47°38'11"-N47°44'52";E21°29'48"-E21°39'41"),covered in loess sedimentation. The second test site is situated in the North-East part of Hungary (Fig. 1) close

Corresponding Author: Zsolt Varga, Faculty of Engineering, University of Debrecen, Otemeto u. 2-4, H-4028 Debrecen, Hungary

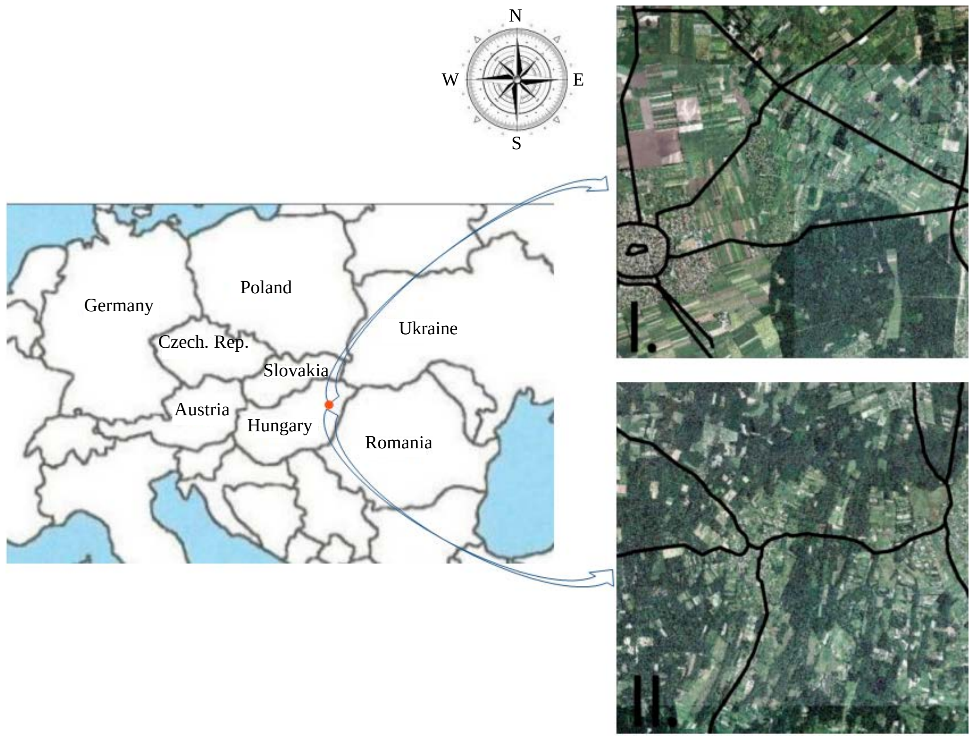

Fig. 1: Position of measured and digitized road centerlines in test sites I and II

to the settlement Nyirlugos (N47°38'01"-N47°44'44"; E21°58'33"-E22°08'30") a quicks and area with sandhills.

The study wants to investigate the nature of differences to be discerned when vectorized data originating from orthophotos and satellite images of varying resolution and those gained by geodetic measurements are compared.

MATERIALS AND METHODS

Our study compared digitized lines of terrain measurements of both test sites and those gained from orthophotos and satellite images of the same sites.

We analyzed the orthophotos of 0.4 m/pixel resolution taken in 2011 as well as satellite images taken in 2013. From among the orthophotos of 0.5 m/pixel resolution the ones taken in 2000, 2005, 2006 and 2007 were selected to be used for the study. We are presenting the evaluation of the accuracy of the above orthophotos and satellite images by comparing the road centerlines located in test areas 1 and 2. Aerial photos for the research with the exception of the year 2006 were provided by the Institute of Surveying and Remote Sensing (Foldmeresi es Taverzekelesi Intezet, FOMI) in 2013. Orthophotos of the year 2006 were obtained from the Land Information Service of the Hungarian Land Information Service of the Hungarian Defence Force. Photos used for the research were taken as follows: Spring of 2000 and Summer of 2005, 2006, 2007 and 2011 with green foliage.

The orthophoto scale was 1: 30 000 for each photo. In 2000 and 2005 RC20 and RC30 analogue cameras with a color depth of 24 bit were used for taking photos. Focal distance of these cameras was 152.866 mm. The satellite images were taken by QuickBird Ortho Ready Standard 4 band Bundle with a resolution of 0.65 m/pixel. From among the road centerlines located in the two test sites we only took measurements of surfaced roads for two reasons; on the one hand photo shots and their geodetic definition happened years apart from each other allowing for changes in dirt road alignments and their centerlines and on the other geodetic definition of surfaced roads can be performed with more precision. We decided to use the kinematic method of measurement and employed a Trimble R6 dual frequency GPS receiver, since the total length of roads measured in the test sites is 124 km the static measurement of which would have cost a lot of time and money. The necessary corrections for the GPS measurement were provided by the permanent station in Debrecen operated by FOMI. Definition of the centerlines of the roads selected for measurement with the kinematic method was done by a GPS receiver mounted on a platform at the top of a land rover's axis of symmetry. Before any measurement could be performed external reference points had to be defined as the vehicle could hardly be expected to run on the centerline but rather in its own lane following the direction of traffic during all measurements.

The distance of the receiver's axis from the axis of symmetry of the road to be measured (marked centerline) and the height of the receiver from the road surface defined the external reference points. We measured these points with the help of a tape measure and recorded them in the GPS. When the actual GPS measurement was performed, geoposition was defined relative to the temporary position of the center of the receiver (the axis of symmetry of the rover), the measured coordinates were however, continuously corrected by the instrument using the external reference data calculating simultaneously actual coordinates relative to the centerline. As measurement of the external reference points was performed and fed into the instrument once only prior to measuring each road, the corrections were only able to yield an average value owing to their constant change due to flow of traffic and other reasons (meandering motion of the car, change in road width, presence of marked centerlines or lack of them); therefore we had to prove that results of the examination are not significantly affected by errors caused by changes of external reference points. We verified accuracy of kinematic measurement by using kinematic measurement to define points that had already been measured with static measurement.

Before starting the kinematic survey either time interval of the measurement of the point or the distance between the two points to be fixed had to be recorded in the instrument. The distance of points to be measured was set to be 50 m. Storage of x and y coordinates of measured points was only permitted, if the accuracy of the coordinate calculated by the GPS did not exceed +/-8 cm. For this reason 8 cm was set as a threshold limit in our instrument. This value does not have a relevant impact on the reliability of measurement yet it is big enough to ensure continuous point capturing. Was there a higher error than the given threshold, the next value within the threshold limit was recorded, i.e., the point another 50 m away. It would then follow that the distance between any two points sometimes deviates from the value defined at the beginning of the measurement process. In order to prove accuracy of measurement results that serve as a basis for the research, the instrument used for the survey must also be checked for accuracy. Accuracy check of the instrument applied was performed on three horizontal trigonometrical points located in the sample area which allows for the determination of the magnitude of dx and dy coordinate deviations when using the RTK network. Orthophoto and satellite digitization was done along the centerlines marked on the road surface using 1:1000 scale or in case the markings were missing axes of symmetry were defined (Fig. 2). It is easy to see that digitized lines in the first photo (0.4 m/pixel) run exactly over the points measured on the terrain, in the second photo (0.5 m/pixel) inaccuracy can already be noticed while in the third photo (0.65 m/pixel) the points of the terrain measurements are almost without exception well beside the digitized lines.

Vectorization of aerial photos as well as processing and documentation of terrain measurements was performed by using ITR5, ArcGIS and Microsoft Excel softwares. To define centerlines in the satellite images ENVI+iDL 5.0 Software was used. Digitized and measured horizontal coordinates were used to compute sum of

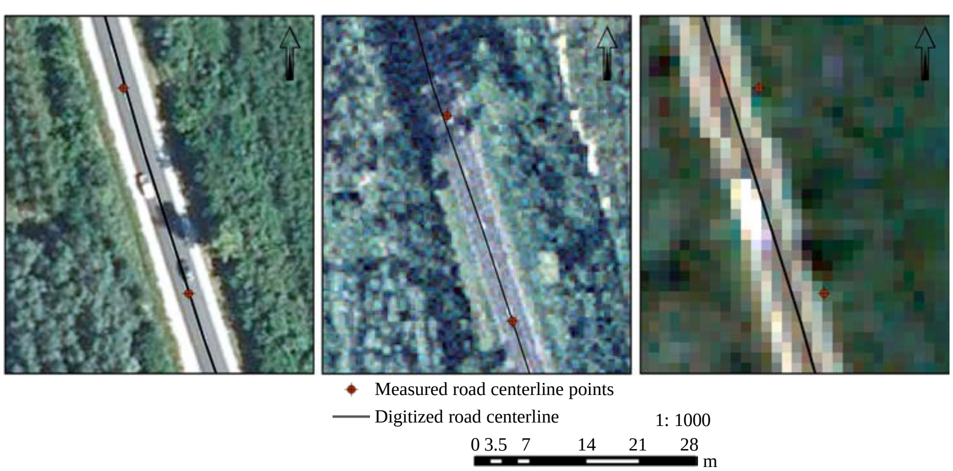

Fig. 2: Digitization of orthophotos of 0.4 m/pixel, 0.5 m/pixel resolution and satellite images of 0.5 m/pixel in a scale of 1:1000

deviations, variance, average deviation, the Gaussian squared distribution, standard deviation, median of deviation, minimum and maximum deviations and magnitude of error. We used the two-sample t-test and the F-test for our statistical analyses.

RESULTS

In order to test reliability of the instrument used control measurements were performed on 3 trigonometrical points in the test areas the results of which are shown in Table 1. Deviation of dx and dy coordinates was within ±5 cm.

Kinematic method of measurement was chosen to measure sections, on the one hand because this is one of the most cost effective landscape mapping methods and on the other because centerlines of roads without road marking or with multiple lanes are not only difficult to measure with the static method but also slow and expensive. Since, however, external reference points are constantly changing when kinematic measurement is used having a significant impact on measurement results, we verified kinematic definitions with static measurements. The typical error for the measurement of a point with the fast static method is 1-5 cm which by far exceeds the expected accuracy of both the accuracy of digitization and that of the mobile mapping system and therefore, lends itself for verification of kinematic measurement results. The 50 points along the total length of the road network were selected for our verification procedure. The discrepancies between the points of the verification process and the kinematic measurements are depicted as they were assigned to classes of 10 cm intervals. The graph shows that 88% of the deviations calculated on the basis of the control points fall into the 0-30 cm interval (Fig. 3) with the remaining 12% making out the gross errors.

Part of the discrepancies of >1 m originated from the road curves where distance between the car and the centerline (the value measured and set at the outset of the measurement) could not be consistently kept while driving, the other part, however was due to oncoming traffic that had to be avoided or road damages that had to be dodged which made keeping the distance between car and centerline impossible. Based on the differences calculated from the comparison (static vs. kinematic measurements), it can be concluded that the accuracy of the method yields appropriate data to serve as basis for the comparison in orthophoto vectorization studies as the majority of points demonstrated a deviation below 30 cm, i.e., a value well below the resolution of the orthophotos. Thus, for the purposes of the study the coordinate values measured with the kinematic method and corrected with external reference points shall be considered the measured coordinates of the centerlines.

Table 1: Computed deviation of coordinates on the basis of points of the National GPS Network (OGPSH)

OGPSH points	Y given	X given	Y measured	X measured	dy (cm)	dx (cm)
79-3451	835459.79	260606.73	835459.80	260606.75	1	2
79-4122	835684.94	269784.65	835684.89	269784.65	5	0
79-4338	846248.24	257514.30	846248.29	257514.25	5	5
Mean deviation					4	2

Deviations between vectors of points defined by orthophotos, satellite images and geodetic methods are summarized in Table 2. Deviation was defined in a point by point pattern in the study. Since, a large number of points were analyzed it would not have been reasonable to include all deviations of all points in a table, so we defined classes of 20 cm intervals to demonstrate linear deviation. Altogether 15 classes were needed to cover all terrain points (Table 2). Total number of points measured kinematically was 1340 and only a few of those demonstrated gross deviation which may be explained with digitization errors as vectorization was verified by static measurements.

The deviations in these cases fell into the 3.0-9.02 interval and thus excluded from the study data. Another 241 measured points of the terrain were also excluded from the analysis as they were outside the area covered by orthophotos or satellite images. In sum the total number of points used for and calculated with during the study was 1099.

Table 2 demonstrates that deviations below 0.6 m fall into 3 classes with a frequency of 92.06, 90.75 and 22.11% for the resolutions of 0.4, 0.5 and 0.65 m, respectively. Deviances >1 m run to 2.3 and 1.38% of all points measured in a descending order from the higher to the lower resolution photos whereas they account for 40.9% when resolution is 0.65 m. As the majority of the deviances of satellite images demonstrates an error of 1 m or more, it can be inferred that satellite images of 0.65

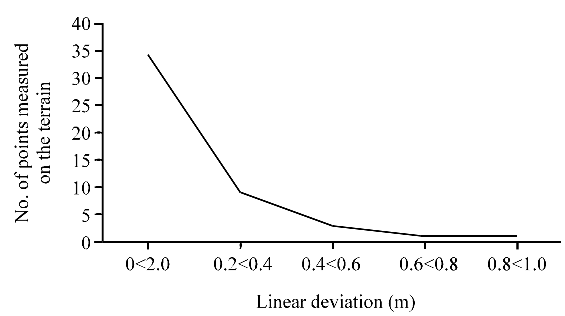

Fig. 3: Deviation of centerline points and control points

Table 2: Linear deviations of vectors from 0.4 m/pixel orthophotos of 2011, 0.5 m/pixel orthophotos of 2006 and 0.65 m/pixel, satellite image of 2013 and the terrain measurements in test site 1

Deviations assigned to classes (m)	Frequency distribution for 0.4 m resolution (%)	Frequency distribution for 0.5 m resolution (%)	Frequency distribution for 0.65 m resolution (%)
0<0.2	52.12	46.52	7.07
0.2<0.4	28.32	29.67	6.17
0.4<0.6	11.62	14.56	8.87
0.6<0.8	3.78	5.40	9.47
0.8<1.0	1.86	2.47	9.32
1.0<1.2	1.38	0.92	10.09
1.2<1.4	0.46	0.37	8.42
1.4<1.6	0.28	0.00	6.77
1.6<1.8	0.09	0.00	5.56
1.8<2.0	0.09	0.09	5.26
2.0<2.2	0.00	0.00	4.66
2.2<2.4	0.00	0.00	5.11
2.4<2.6	0.00	0.00	3.61
2.6<2.8	0.00	0.00	5.11
2.8<3.0	0.00	0.00	4.51
Total (%)	100.00	100.00	100.00

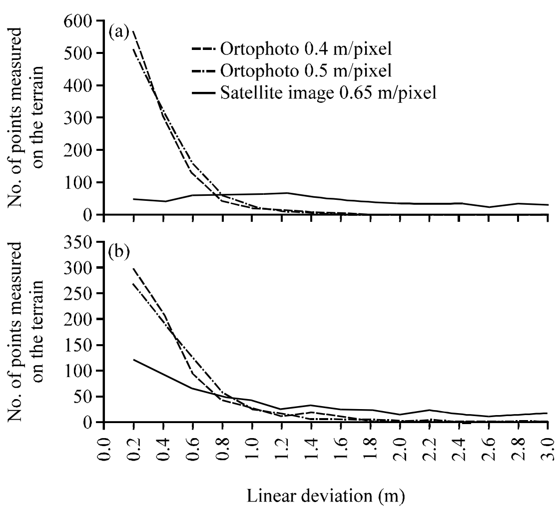

Fig. 4: Deviation of coordinates of points gained either from terrain measurements or digitized in relation to total number of points in both sample areas: a) Area 1 and b) Area 2

resolution are unsuitable for defining centerline coordinates. The 52% of all terrain points in 0.4 m/pixel resolution photos demonstrates an error below 20 cm with 62% of these under 10 cm. The 28% of the points falls into the next (0.2-0.4 m) class. In sum it can be argued that 80% of the linear deviation is below 0.4 m, i.e., an error below the pixel resolution of the aerial photos. Relative frequency that is percentual distribution of samples over classes have been depicted for each year in which orthophotos and satellite images were available for the study.

This was needed to determine distribution of the function. Consequently one look at the "shape" of the function shows that with the exception of satellite images the higher the deviations the lower their frequency (Fig. 4).

Subsequently we investigated the question whether average deviations are consistent in different samples. For this purpose we applied the two-sample t-test to compare absolute deviations of the highest resolution orthophotos of 2011 with the expected values of average absolute deviations of the other years. Since, two-sample t-test types have to be chosen dependent on whether means are equal or unequal, an F-test needed to be applied to find out whether standard deviation of the two samples could be considered equal or not. We found that deviations may be considered equal in each case with a confidence interval of 95%. Based on the results a two-sample t-test appropriate for the analysis was selected. Computing the t-statistical value in each case (2000-2011: 7.35; 2005-2011: 17.72; 2006-2011: 17.2; 2007-2011: 2.05), it was found that keeping the confidence interval 95% the null hypothesis, namely that the expected values of the two samples are equal can be rejected which means that the average absolute deviation of the 2011 sample is different from deviations of the years 2000, 2005, 2006 and 2007. Since, the averages of the two samples are different we needed to find out what the reason for this difference might be.

Analysis of variance was used to determine whether the value of average absolute deviation was varying with the resolutions of 0.4, 0.5 and 0.65 m/pixel. The one-way ANOVA used in our study is a generalization of the two-sample t-test for several independent groups; it will consequently compare the expected values with full variance matrix (A two-sample t-test cannot be applied for this job as the number of samples is not two but three.) Test statistics show that the F-values computed for the three different resolutions are significantly higher than the critical value; consequently the average absolute deviance of the three samples cannot be considered identical which leads to the conclusion that the value of the average absolute deviance varies with image resolution (Fig. 5).

Table 3: Summary data

Deviation	0.4 m/pixel orthophoto from the year 2011	0.5 m/pixel orthophoto from the year 2006	0.65 m/pixel satellite image from the year 2013
Average of sample (m)	0.25	0.52	2.75
Standard deviation (m)	0.24	0.44	2.23
Median of standard deviation (m)	0.19	0.40	2.06
Maximum deviation (m)	1.84	2.91	9.99
Minimum deviation (m)	0.00	0.00	0.00

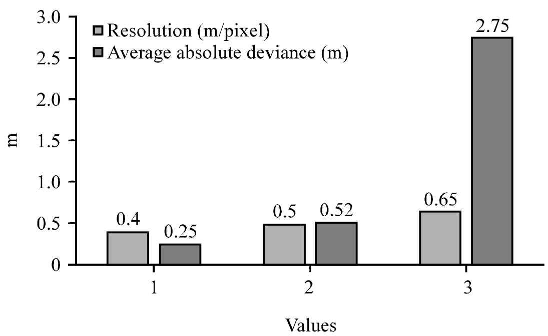

Fig. 5: Deviation between centerline points and control points

Moreover, absolute deviation depends also on the fact whether it is orthophotos or satellite images that are under examination. As a matter of fact, it is possible to define whether satellite images or orthophotos are used simply by looking at the value of deviation. It can be inferred that accuracy of centerline definition in case of 0.4 m/pixel resolution demonstrates an error below the resolution in case of 0.5 m resolution the value is considered identical with the pixel value while in case of a resolution of 0.65 m the error increases to >4 times of the pixel value (Table 3).

DISCUSSION

We studied the nature of differences seen between vectorized data originating from orthophotos and satellite images of varying resolution and those gained by geodetic measurements. Before comparing the data the method of survey applied in the study as well as accuracy of the instrument applied during measurement needed to be verified. Verification has revealed that neither the method applied nor the inaccuracies of the instrument applied have any significant effect on the result of the analysis. Based on the comparison of the digitized vectorial data and the vectorial data originating from the geodetic method it has been confirmed that higher and higher deviations are associated with lower and lower frequencies. We have proved that accuracy of digitization of lines varies with resolution. Inaccuracy is continuously increasing with lower resolution and age of photos used (earlier than the date of terrain measurement). In addition, during the study we found that accuracy of centerline definition was performed with an error below the pixel value when resolution of the photos was 0.4 m/pixel; the error can be considered equal with the pixel value when resolution of the photos was 0.5 m/pixel whereas it increased to four times the pixel value when resolution of the photo was 0.65 m/pixel. Consequently, satellite images of 0.65 m/pixel resolution are not suitable for defining centerline coordinates.

We have proved that parallel to vectorization, terrain measurements are necessary for control in each and every case as this facilitates screening out gross errors of digitization.

CONCLUSION

The results may be utilized in all professional disciplines where based on the accuracy value defined in the study the position of the centerline meets the requirements of the task in hand. Thereby significant reduction of expenses of terrain measurements can be achieved.

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