ACCURACY OF DIGITAL TERRAIN MODELS GENERATED BY IMAGE MATCHING

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***Abstract**: The paper deals with the problem, how to optimize the image matching process after the aerial triangulation. The image matching algorithms are well developed and they give an effective method to generate tie points on the adjacent photos. On the other hand the recent autocorrelation implementations cannot offer or suggest the optimal parameters for a certain task. Therefore there is a need to investigate the whole automatic image matching process for the given photogrammetric block. In this research the results of 3D modeling including the accuracy requirements for the ground coordinates and exterior orientation elements are demonstrated. For testing some large scale (1:8000) scanned aerial photos were used in different pixels sizes between 7-52 microns. With comparison of the effectiveness and accuracy of the software this assessment is useful also for the solution providers acting on the photogrammetric market.*

***Keywords:** image matching, scanning resolution, ground resolution, error assessment*

1. Theoreitical considerations

1.1. Minimal scanning resolution without loss of information

If we use normal analogue aerial photos for photogrammetric evaluation, then we need to decide the scanning resolution. There is a theoretical minimal scanning resolution noted in equation (1) [1].

$$R_{\min} = k \cdot \frac{1}{2 \cdot VA_a}; \frac{1}{VA_a} = \frac{1}{VA_o} + \frac{1}{VA_p} \tag{1}$$

Where

$R_{\min}$: minimal scanning resolution (mm),

$\mathrm{k} = 0.7$: optimizing factor,

VA_a, VA_o, VA_p : resolution - aggregated, optical, photographic (line pairs per mm).

Let’s suppose $\mathrm{VA_a} = 60\,\text{line pairs/mm}$, then $R_{\min} = 5.8\,\mu\text{m}$. This scanning resolution is not used in practice and the other problem is that the equation (1) doesn’t consider the image noise, the loss of accuracy at small scanning resolution.

1.2. Height accuracy of natural points

After the aerial triangulation we get the adjusted exterior orientation elements and also the $\sigma_{Z(sig)}$ as an RMS error is calculated from the residuals of control points. If we would like to calculate the height accuracy of natural points, we need to consider the height uncertainty during the measurement as it is shown in equation (2).

$$\sigma_Z = \sqrt{\sigma^2_{Z(sig)} + \sigma^2_{Z(def)}} = 5 \cdot \sigma_{Z(sig)} \tag{2}$$

Where

σ_Z : height accuracy of natural points,

$\sigma_{Z(sig)} = 0.07\text{‰} \cdot H$: height accuracy of marked points,

$\sigma_{Z(def)} = 5 \cdot \sigma_{Z(sig)}$: height uncertainty of natural points.

Our plan was to generate a digital terrain model on a photogrammetric workstation by image matching of digital stereo-pairs; in this case we can estimate the height accuracy by equation (2).

1.3. Scanning resolution and height accuracy

The other way to estimate the height accuracy is to compile the relation between the height accuracy and the resolution by equation (3) [3].

$$dZ = p \cdot R \cdot \frac{H}{f} \cdot \frac{H}{B} \tag{3}$$

dZ : height accuracy

p : pointing error factor

R : pixel size

H : flight height

f : focal length

B : flight base

As an example if we take the values of $p = 2.5$, $H = 1224$ m, $f = 153.0$ mm, $B = 731.7$ m, we can get a diagram for several scanning resolutions (Figure 1).

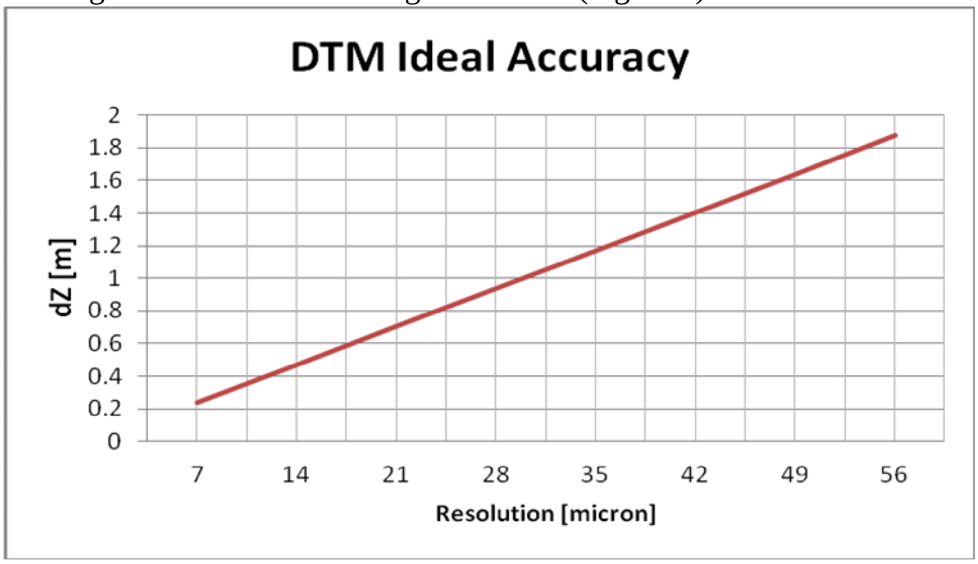

Figure 1 DTM ideal accuracy

2. Data Sources

2.1. Reference data

The test area is located in Hungary, near the village Iszkaszentgyorgy (Figure 2). The area has a mix of patterns of residential area, quarry, forest, meadow and hilly fields. A LIDAR mission was carried out in 2008 and the aerial photos were produced in 2011 [2]. On this test area a smaller window of 1780x1000 m was cut out.

Figure 2 Test Area

For reference a 5m GRID was interpolated from the LIDAR point cloud, where the vertical accuracy is about +/- 0.15m (Figure 3). Examining visually the DTM we can discover a smaller and a larger quarry. A block of forest area is located north to the larger quarry.

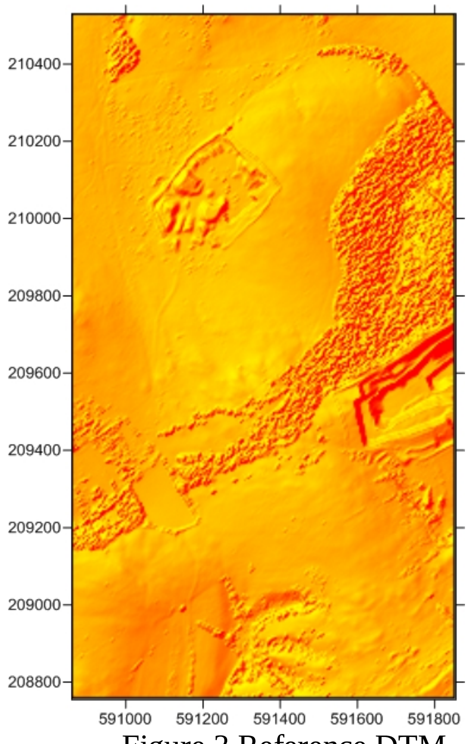

Figure 3 Reference DTM

2.2. Arial images

A series of 5 m GRID models were interpolated from the point cloud gained by image matching using a Leica LPS 2011 workstation (Table 1).

Table 1 Image matching conditions

Year	2011
Photo Scale	1:8000
Model Area	1780x1000 m
Flight Height	1224 m
Photo Base	731.6 m
Focal Length	153.0 mm
Image Pair	9643-9644
Height accuracy (control points)	0.0869 m
Scanning Resolution (micron)	7,14,21,28
Interpolated Resolutions (micron)	32,42, 49,56
GRID Dimension	5x5 m
GRID Interpolation Method	Kriging

The image matching process was done with pixel steps between 1-4 as it is shown on Table 2.

Table 2 Image matching parameters

Scanning resolution	Step	Ground step (cm)
7 micron image	By 4 pixels	22.4
14 micron image	By 4 pixels	44.8
21 micron image	By 2 pixels	33.6
28 micron image	By 2 pixels	44.8
35 micron image	By 2 pixels	56.0
42 micron image	By 1 pixel	33.6
49 micron image	By 1 pixel	39.2
56 micron image	By 1 pixel	44.8

2.3. Gained DTMs and residuals

For each scanning resolution a 5m GRID model was generated by Kriging interpolation and the resulting DTM was compared to the reference DTM. The residual image and the list of residuals are produced by Surfer ver. 9. On Figure 4 the colour scale is showing the height errors in meters. Similar residual images were produced for each scanning resolution.

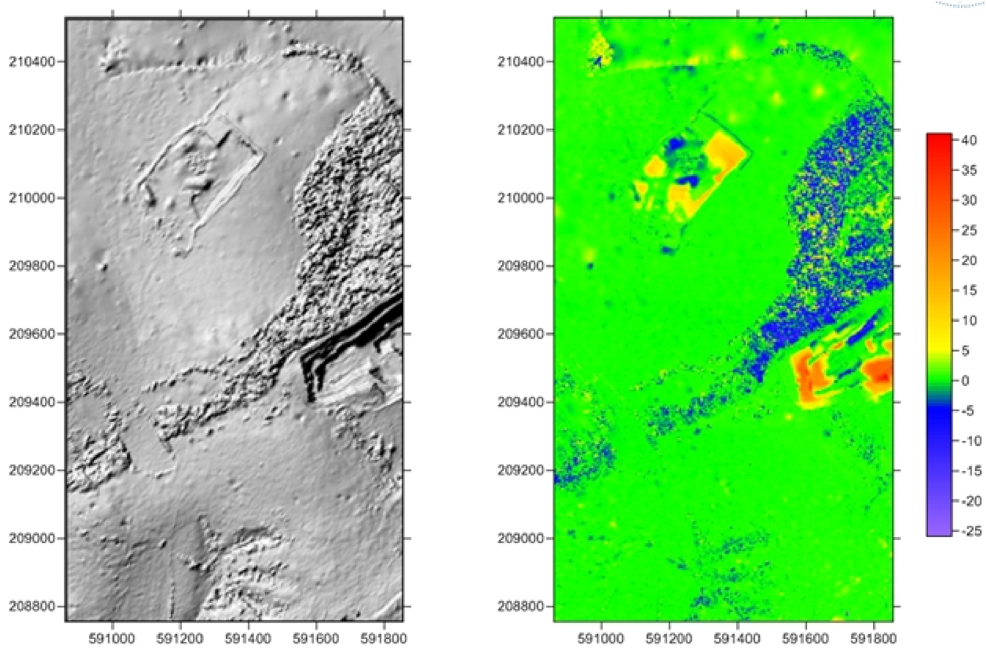

Figure 4 DTM and residual image based on image of 7 micron

3. Conclusions

3.1. Average RMS errors Statistics

After having the tables of residuals the RMS error is calculated for each scanning resolution (Figure 5). We can see for the diagram that the ideal resolution is around 14 micron. The 7 microns image gave a worse result than it was expected. The probable reason for that is the image noise effect.

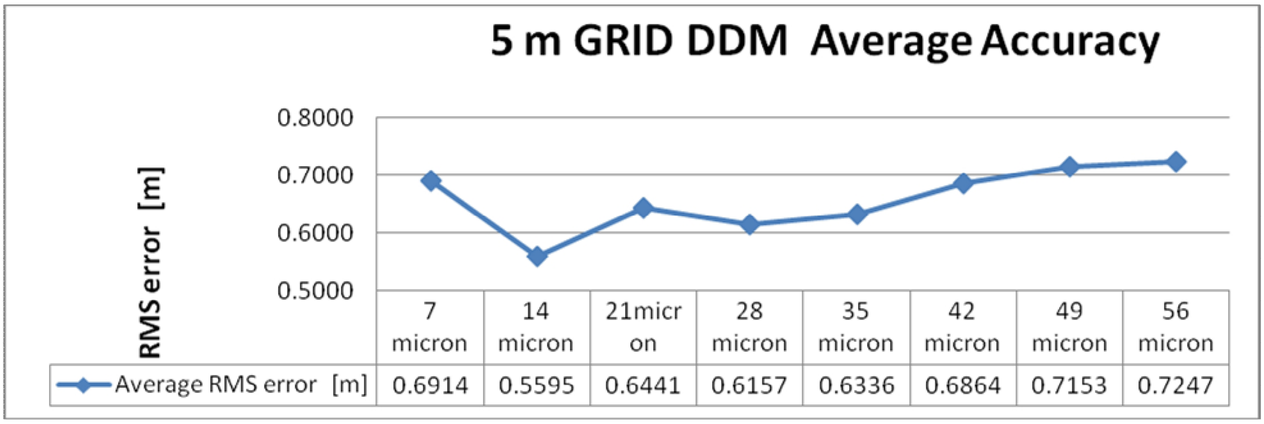

Figure 5 Average accuracy of all DTMs

2.6. Optimal resolution

To determine more accurately an optimal resolution we can return to equation (3) with a small modification.

$$R_{op} = k \cdot \frac{1}{2 \cdot VA_a} \tag{4}$$

Where

R_{op} : optimal scanning resolution (mm),

$k = 2.5$: optimizing factor,

VA_a : aggregated film resolution (line pairs per mm).

In equation (4) the optimizing factor can be derived from Figure 6, where the ideal and the experimental accuracy are compared and the two curves are crossed. The ideal and satisfactory resolution is around 21 microns.

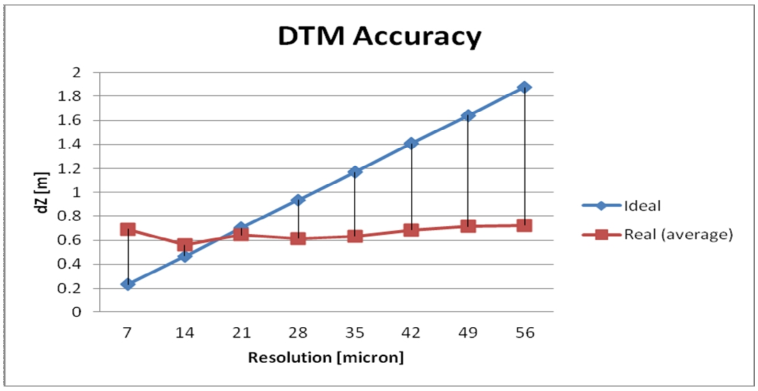

Figure 6 Comparison of ideal and real DTM accuracy

Using the 7 microns resolution givers a worse result than the matching with14 microns. It means the 7 microns image generates higher noise, which weakens the matching accuracy. If the scanning resolution is higher than 14 microns, the matching error doesn't grow fast. Ideal scanning resolution is somewhere between 14-35 microns. There are no big differences in accuracy; therefore a good compromise can be a 28 microns image, which is very economical in storage of images.

4. References

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