AUTOMATED QUALITY CONTROL OF DIGITAL TERRAIN MODELS

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ABSTRACT:

The paper demonstrates modified cross-correlation methods to detect height errors of DTM points based on stereo-pairs of aerial images. The usual cross-correlation method is extended using dynamic dimensioning and different structures of the correlation matrix. Also a texture coefficient is introduced which makes the auto-correlation procedure more robust. All together seven different image matching modifications are demonstrated. Before starting to check the DTM points, we should check the control points. If gross error exists among the control points and the exterior orientation elements were calculated by the control points, then we should check and revise the exterior orientation elements, as well. Since these errors cause absolute positional errors in the DTM points. These elements should be checked by recalculation. The recalculation and the gross error detection of control points are done with a direct analytical method which was demonstrated on the XXth ISPRS Congress (Jancso,2004) .The main part of the paper describes how to find gross errors based image matching using modified cross-correlation techniques. The paper distinguishes two approaches for image matching: 1. Image matching means of matching of left image points to the right image. The search area on the right image is determined by the location of the right image point calculated from the back projection by the collinear equations. After the image matching we gain a new image point on the right image. Comparing these two image point calculations the ground point is wrong if the differences are over the gross-error limit.2. At the checking of DTM points we can follow the way where the X,Y coordinates of the examined DTM point are fixed and the appropriate back-projected points are calculated at different Z coordinates. This procedure assumes to have the area based image matching several times and we will choose that Z coordinate where the cross-correlation coefficient reaches the maximal value. After this we can calculate the difference of Z coordinates comparing the original Z coordinate of the DTM point with the gained Z coordinate corresponding to the maximal cross-correlation coefficient.Also as a separate method the paper points at the importance of examination of the possibilities of the median difference filter for detection of “sensitive” areas on the digital terrain models as a method to visualize and separate the areas where more thoroughly checking procedures would be necessary. Also some experimental results are demonstrated which were produced by a software application especially developed for the checking of TDM points. Finally the paper points out the following important conclusions:- Before testing the quality of DTM points first we should check the exterior orientation elements by an independent calculation or by re-measurement of the control points on a different Digital Photogrammetric Workstation (DPWS).- The median difference filter is a very fast and effective method to detect the sensitive areas of DTM points.

1. INTRODUCTION

1.1 Aims

There is given a stereo-pair for DTM generation. We have control points covering the whole image area. The DTM is produced on a digital photogrammetric workstation in different grid sizes. Our goal is to check automatically the height error of DTM points. In other words, our aim is to detect and allocate the points where the height error is larger than 3-5 σ . To detect the height errors there have been applied a series of extended area-based image-matching techniques based on the well-known cross-correlation formula (Höhle, J., Potucková M. 2003, Jancso, T., Zavoti, J. 2006).

$$\rho = \frac{\sum_{r=1}^{R}\sum_{c=1}^{C}(g_1(r,c)-\mu_1)(g_2(r,c)-\mu_2)}{\sqrt{\sum_{r=1}^{R}\sum_{c=1}^{C}(g_1(r,c)-\mu_1)^2(g_2(r,c)-\mu_2)^2}} \qquad (1)$$

Where:

g_1 - gray value of a pixel in the template area

g_2 - gray value of a pixel in the search area

r, c - row, column

μ_1, μ_2 -arithmetic mean of the gray values in the template area

R, C - arithmetic mean of the gray values in the search area

1.2 The procedure

The whole procedure is summarized on Figure 1. On this figure we separate the input data and the procedures derived from them.

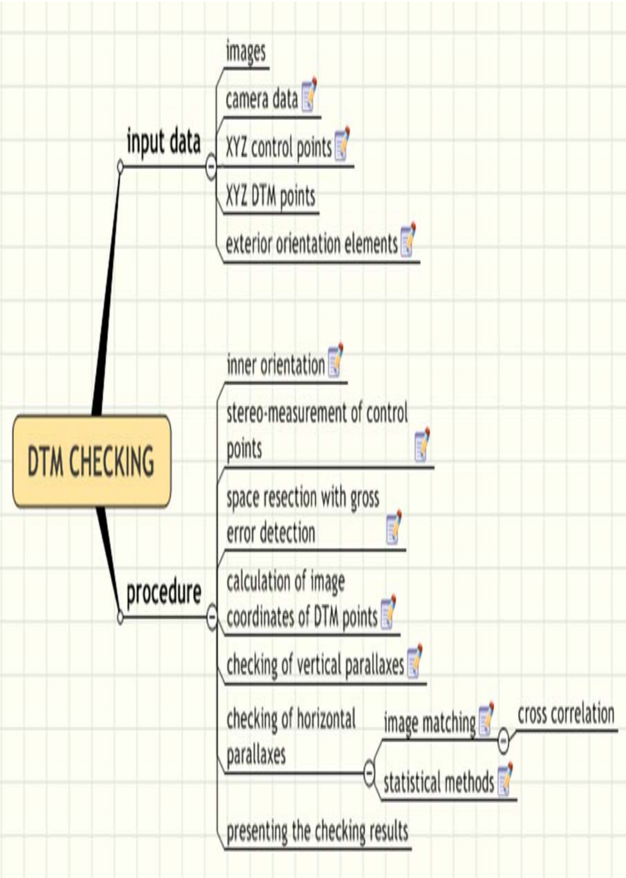

Figure 1. DTM checking procedure

The procedure steps are divided into two main parts. First the control points are measured on images and the resection is carried out with a method which includes a gross-error detection method and if necessary the given exterior orientation elements are altered. After this, seven different cross-correlation methods are used for checking the DTM points.

2. CHECKING OF THE EXTERIOR ORIENTATION ELEMENTS

2.1 Space resection with adjustment

Before starting to check the DTM points, we should check the control points. If gross error exists among the control points these errors will effect the exterior orientation elements as well. These errors can cause absolute positional errors in the DTM points. A direct adjustment and gross-error detection method can be applied on control points based on the Jacobian Mean Theorem. The main core of this theorem is that the adjusted values of exterior orientation elements can be calculated from the weighted mean values of solutions from a minimally necessary number of control points and it is done in every combination (Jancso,2004).

2.2 Gross error detection

During the adjustment we can detect the control points with gross errors. After eliminating those control points which have gross-errors, the exterior elements are recalculated and they will be used during the DTM point checking procedure.

3. IMPLEMENTATION OF THE CROSS-CORRELATION METHOD

3.1 Cross-correlation procedures

The basic cross-correlation formula was extended and experimented on seven different methods like:

1. Cross-Correlation (RGB)
2. Cross-Correlation (RGB- P)
3. Cross-Correlation (Gray)
4. Cross-Correlation (RGB – 0,1)
5. Cross-Correlation (Gray – 0,1)
6. Cross-Correlation (RGB – H,V)
7. Cross-Correlation (RGB – DTM)

Let's comment each method:

Cross-Correlation (RGB): it is a usual cross-correlation made by each color channel, than the max. correlation is chosen.

Cross-Correlation (RGB-P): This method is using the same procedure as above, but here the cross correlation coefficient is altered by a weight and a texture coefficient. The weight factor is accommodated to the threshold correlation of 0.7:

$$P = \frac{(c_m + 2)^2 - (c_m)^2}{(c_m + 4)^2 - (c_m + 2)^2},$$

$$corr_P = corr \cdot P \quad \text{(for R,G,B)} \tag{2}$$

Then the correlation coefficient is calculated as the weighted mean from the texture coefficients altered by the calculate weight of P:

$$corr = P \cdot \frac{corr_R \cdot tu_R + corr_G \cdot tu_G + corr_B \cdot tu_B}{tu_R + tu_G + tu_B} \tag{3}$$

It is possible to calculate the minimally acceptable correlation coefficients for each correlation matrix:

$$corr_{\min} = \frac{0.4666669}{P} \tag{4}$$

The Table 1. shows the weights and the acceptable correlation coefficients for different correlation matrices of c_m :

cm	weight	corr_min
3	0.666667	0.7
5	0.75	0.622223
7	0.8	0.583334
9	0.833333	0.56
11	0.857143	0.544445
13	0.875	0.533334
15	0.888889	0.525
17	0.9	0.518519
19	0.909091	0.513334
21	0.916667	0.509091
23	0.923077	0.505556
25	0.928571	0.502564
27	0.933333	0.5

Table 1. The weights and the acceptable correlation coefficients for different cm correlation matrices

The calculation of the texture coefficient t_u is made by the following formula:

$$t_u = q \cdot \frac{n_c}{c_m^2} \tag{5}$$

where

n_c : number of different colors (gray values) in the correlation matrix

c_m^2 : number of pixels in the correlation matrix

$$q = 1 \text{ if } c_m \leq 15 \text{ else } q = \frac{c_m^2}{256}$$

Cross Correlation (GRAY): Here the RGB values are changed to gray values as an average and after this a usual cross correlation is made on pixel level.

Cross Correlation (RGB)-(0,1): Here each RGB value is changed to 0 or 1 depending on the mean value. So, we will have 3 correlation matrices (for each color channel). If the gray value is larger than the mean value, it is converted to 1, If the gray value is smaller than the mean value, it is converted to 0 (see Figure 2.). Then a usual cross correlation is made by the first method.

Cross Correlation (GRAY)-(0,1): Here each gray value is changed to 0 or 1 depending on the mean value. If the gray value is larger than the mean value, it is converted to 1, If the gray value is smaller than the mean value, it is converted to 0 (see Figure 2.). Then a usual cross correlation is made by the first method.

126	234	101	45	230
98	99	102	65	210
4	230	56	45	212
34	255	87	34	189
176	20	145	21	173

0	1	0	0	1
0	0	0	0	1
0	1	0	0	1
0	1	0	0	1
1	0	1	0	1

Figure 2. Conversion of the correlation matrix into a binary matrix

Cross Correlation (RGB)-(H,V): Here two correlation matrices are derived from the original one. The first one consists only every second horizontal rows, the second one consists only every second vertical columns, which means some „polarization" of data (see Figure 3.). Then a usual cross correlation is made by the first method.

126	234	101	45	230
98	99	102	65	210
4	230	56	45	212
34	255	87	34	189
176	20	145	21	173

126	234	101	45	230
4	230	56	45	212
176	20	145	21	173

126		101		230
98		102		210
4		56		212
34		87		189
176		145		173

Figure 3. Polarization of the correlation matrix

In this case the mean values are calculated differently:

$$\mu_H = \frac{\sum_{r=1}^{c_m, step2} \sum_{c=1}^{c_m} g_{r,c}}{c_m^2 - ((c_m - 1)/2) \cdot c_m}$$

$$\mu_V = \frac{\sum_{r=1}^{c_m} \sum_{c=1}^{c_m, step2} g_{r,c}}{c_m^2 - ((c_m - 1)/2) \cdot c_m} \qquad (6)$$

Cross Correlation (DTM): Here the vertical locus method is used (Schenk T., Seo S., Csathó B., 2001), which means that the DTM X,Y coordinates are fixed and the cross correlation is calculated for different Z values. The Z value is incremented each time by 0.1 m until the Max. H error value is reached in both directions.

Mainly the procedure steps are same for the methods 1-6. (see Figure 4.) , only the algorithm of the last method (RGB-DTM) is different (see Figure 5.).

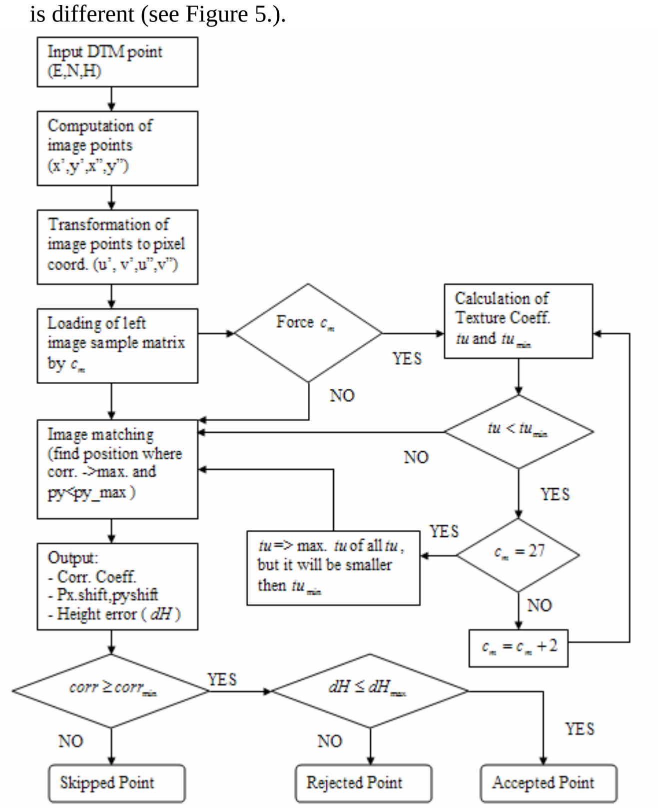

Figure 4. Algorithm for methods 1-6.

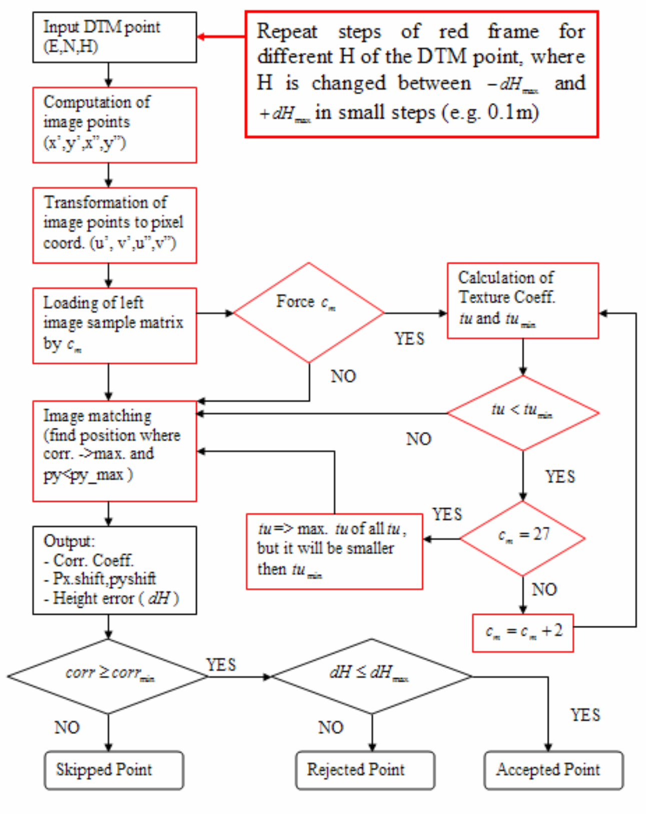

Figure 5. Algorithm for method RGB-DTM

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3.2 Experimental results

To experiment the different cross-correlation methods a software application was developed (Figure 6.)

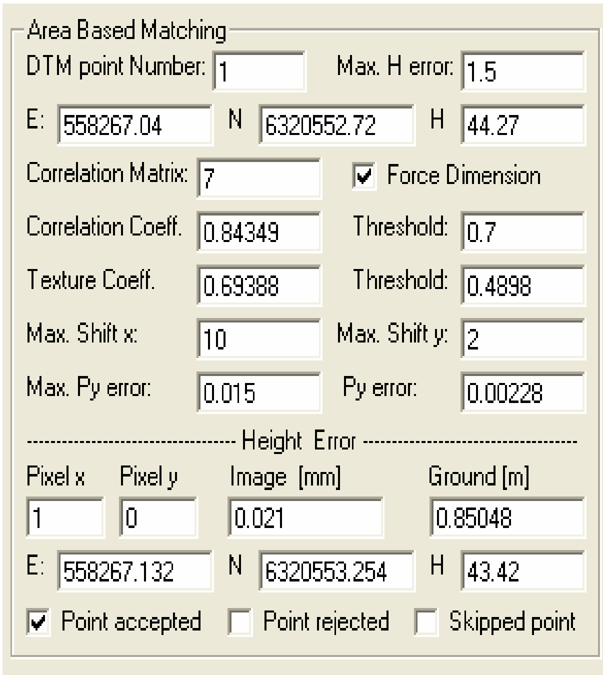

Figure 6. Area based matching application – setup window

The software calculates the following parameters:

- Correlation coefficient
- Height errors in pixels (Pixel x, Pixel y)
- Height error on the image in mm.
- Height error on the ground in m.
- Recalculated coordinated of the DTM point. (If you chose the „Cross Correlation (DTM)" method, the horizontal coordinates are not changed, only the height.

The program indicates whether the DTM point can be accepted, rejected or it's just skipped. The DTM point is accepted if the correlation coefficient is larger then the threshold, otherwise it is rejected. The point is skipped if the achieved correlation coefficient is smaller than the threshold. In Appendix A. some experimental results are summarized for one test area.

4. MEDIAN DIFFERENCE FILTER

For indicating the sensitive parts inside a DTM we can produce a median difference image and table. The median difference filter means that for each grid node (r,c) we identify the set of non-blank, neighboring input grid values, then we compute the median of these neighboring values. If B represents this median value then the output grid node value is set to $Z_{out}(r,c) = Z(r,c) - B$. The effect of this filter is to emphasize the sudden height changes in the grid. Before applying the median difference filter, a Kriging interpolation method is applied with 1/10 grid size of the original DTM grid size. The median difference filter was applied on a sample interpolated grid and the result can be seen on Figure 7.

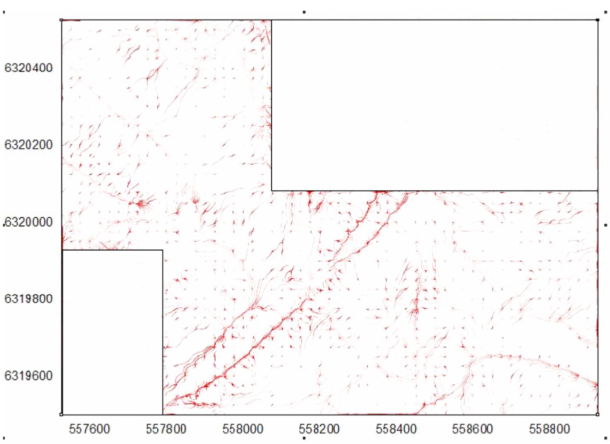

Figure 7. Resulting image of the median difference filter

From the image we can distinguish the main geo-morphological elements, and the small dots and lines mean smaller or larger height changes in the grid. By this method we can allocate the sensitive areas where we need more detailed investigation and quality checking of DTM points.

5. CONCLUSIONS

5.1 Space resection

Before testing the quality of DTM points first we should check the exterior orientation elements by an independent calculation or by re-measurement of the control points on a different Digital Photogrammetric Workstations.

5.2 DTM error detection

The median difference filter is a very fast and effective method to detect the sensitive areas of DTM points.
It is necessary to experiment and investigate the proposed extended and modified cross-correlation methods. By the first experiments an order of effectiveness can be listed as follows:

- M7 (RGB-DTM)
- M6 (RGB – H,V)
- M1 (RGB)
- M3 (GRAY)
- M4 (RGB -0,1)
- M5 (Gray -0,1)
- M2 (RGB-P)

It is necessary to experiment and investigate the proposed extended and modified cross-correlation methods.

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APPENDIX A. ERROR DETECTION ON SAMPLE DTM

Comparison of methods was applied for a test area and the results are summarized in Tables 2 and 3. The highlighted values indicate the best results if we omit the results which were gained at the correlation matrix dimension of 5x5.

Number of accepted points

CM	M1 (RGB)	M2 (RGB-P)	M3 (GRAY)	M4 (RGB-0,1)	M5 (GRAY-0,1)	M6 (RGB-H,V)	M7 (RGB-DTM)
5	433	139	421	193	228	540	704
7	477	287	475	188	258	570	675
9	520	396	517	213	281	566	689
11	591	479	570	237	305	626	751
13	633	557	628	272	322	669	762
15	670	624	673	287	335	704	805

Number of rejected points

CM	M1 (RGB)	M2 (RGB-P)	M3 (GRAY)	M4 (RGB-0,1)	M5 (GRAY-0,1)	M6 (RGB-H,V)	M7 (RGB-DTM)
5	404	75	304	211	261	605	108
7	285	128	243	178	190	335	112
9	257	167	228	166	172	302	110
11	237	181	212	161	144	259	97
13	229	196	204	149	146	244	112
15	219	204	197	142	142	234	96

Number of skipped points

CM	M1 (RGB)	M2 (RGB-P)	M3 (GRAY)	M4 (RGB-0,1)	M5 (GRAY-0,1)	M6 (RGB-H,V)	M7 (RGB-DTM)
5	732	1355	844	1165	1080	424	714
7	807	1154	851	1203	1121	664	782
9	792	1006	824	1190	1116	701	770
11	741	909	787	1171	1120	684	721
13	707	816	737	1148	1101	656	695
15	680	741	699	1140	1092	631	668

Table 2. Number of accepted, rejected and skipped points at each method

Dynamic CM methods

St. Error	M1 (RGB)	M2 (RGB-P)	M3 (GRAY)	M4 (RGB-0,1)	M5 (GRAY-0,1)	M6 (RGB-H,V)	M7 (RGB-DTM)
All	1.96	1.939	1.912	2.316	2.131	1.934	0.928
Accepted	0.654	0.628	0.648	0.617	0.645	0.648	0.794
Rejected	2.919	2.927	2.968	3.006	3.213	2.958	1.506

Dynamic CM methods

Point	M1 (RGB)	M2 (RGB-P)	M3 (GRAY)	M4 (RGB-0,1)	M5 (GRAY-0,1)	M6 (RGB-H,V)	M7 (RGB-DTM)
Accepted	572	416	585	208	273	658	780
Rejected	304	156	259	187	193	337	121
Skipped	693	997	725	1174	1103	574	668

Table 3. The standard errors and the number of accepted, rejected and skipped points at each method but with dynamic handling of the correlation matrix dimension

Standard height error for all points

CM	M1 (RGB)	M2 (RGB-P)	M3 (GRAY)	M4 (RGB-0,1)	M5 (GRAY-0,1)	M6 (RGB-H,V)	M7 (RGB-DTM)
5	2.454	2.41	2.35	2.615	2.552	2.458	0.953
7	2.187	2.176	2.118	2.535	2.334	2.179	0.956
9	2.015	2.006	1.969	2.368	2.187	2.014	0.952
11	1.878	1.87	1.835	2.24	1.998	1.862	0.92
13	1.767	1.753	1.721	2.123	1.906	1.768	0.927
15	1.701	1.688	1.649	2.071	1.862	1.669	0.918

Standard height error for accepted points

CM	M1 (RGB)	M2 (RGB-P)	M3 (GRAY)	M4 (RGB-0,1)	M5 (GRAY-0,1)	M6 (RGB-H,V)	M7 (RGB-DTM)
5	0.653	0.61	0.643	0.662	0.656	0.652	0.827
7	0.659	0.651	0.647	0.612	0.636	0.64	0.808
9	0.66	0.64	0.634	0.643	0.652	0.659	0.803
11	0.643	0.627	0.626	0.64	0.64	0.646	0.803
13	0.642	0.622	0.631	0.63	0.646	0.65	0.796
15	0.652	0.608	0.629	0.644	0.644	0.644	0.799

Standard height error of rejected points

CM	M1 (RGB)	M2 (RGB-P)	M3 (GRAY)	M4 (RGB-0,1)	M5 (GRAY-0,1)	M6 (RGB-H,V)	M7 (RGB-DTM)
5	3.145	3.094	3.127	3.115	3.217	3.192	1.507
7	2.967	3.016	3.009	3.036	3.183	3.008	1.507
9	2.857	2.841	2.878	3.009	2.935	2.856	1.507
11	2.842	2.94	2.883	2.865	3.018	2.841	1.508
13	2.903	2.916	2.858	2.913	2.89	2.874	1.507
15	2.95	2.921	2.897	2.865	2.876	2.913	1.507

Table 4. Standard errors at each method

From the Table 4. we can see that the standard height error for the accepted points is around 0.6 m. The standard errors of the rejected points are around 3 m, and finally if we don't filter the DTM points it means that the height error is varying between 0.918 m and 2.615 m depending on the correlation method and the correlation matrix dimension.