CALIBRATION OF DIGITAL IMAGES PRODUCED WITH THE USE OF UMAX 1200 SE SCANNER

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ABSTRACT

As a result of the analysis of geometric deformations of digital images acquired using low cost scanner UMAX 1200 SE, the correction method is proposed which reduces scanning geometric errors from $m_p = \pm 5$ pixels to $m_p = \pm 0.15$ pixels = ± 3 μm. The correction is executed in two stages. In the first stage are determined I-order corrections d_x, d_y, being steady for each point of the scanner plate and determined during precalibration process. Next are determined d_y correction of II-order, being variable for each scanner run, but on certain digital image being constant along the sensor line and changeable for different sensor line position.

1. INTRODUCTION

Digital photogrammetry deals with processing of photogrammetric photos, as well as semi-metric and non-metric images given in a digital form. One of the method of gaining the digital images is scanning the original photo using different scanner type. Scanner which are used to gain the digital image for digital photogrammetry purposes should be characterised by the following feature:

- high optical resolution,
- scanning in passing light,
- sufficient scanning field size (min.23x23 cm - typical aerial photo size),
- scanning black and white as well as colour photos,
- possibility of scanning of a photo made on glass plate, and
- high geometrical similarity of a digital image to a original photo.

The scanners which fulfil all above mentioned conditions are very expensive. On market there are also available scanners used in printing (designed for printing purposes), which are more cheaper. Some technical parameters like: resolution and size meet the requirements of digital photogrammetry but the geometrical quality is significantly lower. The UMAX 1200 SE is such type of scanner, which is in possession of Department of Photogrammetry and Remote Sensing Informatics, University of Mining and Metallurgy, Cracow.

The goal of this paper is to describe the methodology of scanner accuracy testing, to present the results achieved and to propose method of geometric calibration of scanned images with their accuracy description.

2. RECORDING AND MEASUREMENT OF TESTED DIGITAL IMAGES

The UMAX 1200 SE scanner, used to gain digital images for testing it's geometric accuracy, is a flat type scanner. The scanning in a reflected light is possible for a size 210x300 mm (A4), while in a passing light (for negatives and diapositives) is possible for a size 150x220 mm. The maximal optical resolution along Y axis (according with movement direction of a bar composed of CCD elements) equals 1200 dpi while in X direction 600 dpi (5000 CCD elements located on a bar, 210 mm long).

Thus a smallest optical pixel size in Y direction equals 0,02mm, while in X direction 0,04mm. The maximal software scanner resolution is 2400x2400 dpi. It means that if decreasing of the pixel size take place, the pixel value is interpolated from values of recorded optical pixels. Testing the scanning errors was performed for the full scanner size (150x220mm) in a passing light. Such size make possible to scan 70% of typical air photo size 23x23 cm. For stereoscoping processing, when only 60% of area of each stereo-pair photo is used, such area of a scanned photo is sufficient.

To conduct a geometric calibration of the scanner a special pattern was designed and made. The pattern is composed of 368 main crosses of size 5x5x0,1mm regularly distributed in 10mm intervals and grouped in 16 columns and 23 rows. Between the crosses located in columns 1,2, 8,15 and 16, for further grid densification, additional 110 small crosses (size 1x1x0,1mm) were located. For the pattern design a programme COREL was used. Then the pattern was visualised with resolution 2400 dpi on LINOTRONIC. The fragment of the pattern is shown on Fig.1.

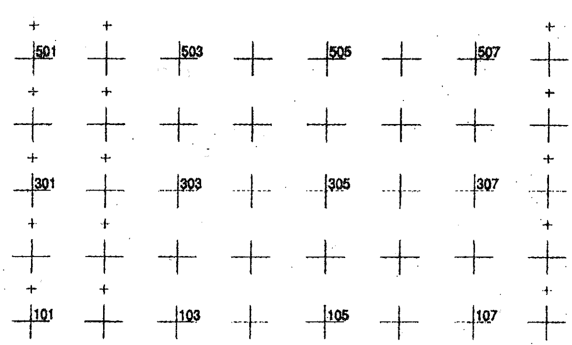

Fig.1. Fragment of the ideal pattern

The pattern made on film was then measured on precise stereocomparator Stecometer with accuracy $m_x = m_y = \pm 3\mu m$. The results of this measurement were treated as a ideal set (pattern) against results achieved by measuring digital form of the pattern.
The pattern was scanned with resolution 1200 dpi (pixel size 0,02x0,02 mm). Such resolution was admitted as optimal for digital photogrammetry measurement using Video Stereo Digitizer AGH (VSD) [Jachimski 1995]. The pattern of size 15x22 cm scanned with above mentioned resolution has a capacity above 70 Mb.
Scanning of such an image takes approximately 20 minutes. The method of the scanner accuracy testing described in [Boroń,1994] and [Boroń,1995] assumed scanning of the pattern in two sessions, one by one, without switching off the scanner. Such a procedure allowed for smaller scanner errors but unfortunately caused deformation of pattern (marked on the transparent film) under high temperature of the scanner being heated.
To eliminate that disadvantageous phenomenon there were applied at least one hour brakes between pattern scanning sessions, to cool the scanner completely. The pattern was so placed on the scanner plate that the 352 pattern crosses were equally covering the scanner working surface, and the lines of crosses were parallel to respectively X and Y scanner axis. In such position pattern film was fixed with the tape to the scanner plate. The steady pattern position allowed for the analysis of repeatability of scanner errors.
During the testing program 22 pattern images were scanned, and they were named successively from A to Z. During 4 days there were registered: in the first day A...I images, second day J to N, in the third day O...S, and in the fourth day T to Z.
The received digital images of the pattern were to be measured to register coordinates of crosses (some 8 thousand crosses) in the digital image coordinate system (pixels matrix). For that purpose a devoted program for automatic crosses position recognition was prepared by W.Trocha (described in [Trocha,1995]). As the above program requires the approximate crosses position as the entrance data, there was performed with the use of VSD a hand survey of 4 corner crosses on each digital image. A next step it was transformation of pattern coordinates (surveyed with the use of Stecometer) to the digital image coordinates (pixel system) using the 4 corner points as a pass-points for the bilinear transformation.
For each digital image of the pattern there were surveyed 352 crosses (22 rows, 16 crosses each) which created an entrance file for the program of automatic crosses position recognition.

3.THE TRUE ACCURACY OF THE UMAX 1200 SE SCANNER

To determine to what accuracy level the digital images of the scanned pattern reflect the true geometry of the pattern the Helmert transformation (similarity transformation) for the full set of the pattern coordinates (in mm) and full set of the cross coordinates in image system (in pixels) was used. The results of these transformation are given in the Table 1 while an example of geometrical deformations of an one digital image against the ideal pattern is shown on Fig.2. As can be seen in Table 1, fitting errors of points for both sets for particular images are similar and vary from $m_p = \pm 4{,}8$ pixels to $m_p = \pm 5{,}3$ pixels.

Table 1. The results of the Helmert transformation

Image number	Helmert transformation (352 reference points)				
(1200 dpi)	m_x pixels	m_y pixels	m_p pixels	$(d_x)_{max}$ pixels	$(d_y)_{max}$ pixels
a	3.72	3.71	5.25	11.1	10.2
b	3.67	3.36	4.98	11.0	9.0
c	3.67	3.38	4.99	11.5	8.7
d	3.68	3.26	4.92	11.3	8.2
e	3.55	3.24	4.81	10.7	8.5
f	3.50	3.22	4.76	10.7	8.4
g	3.55	3.18	4.76	11.0	8.0
h	3.56	3.23	4.81	10.9	8.4
i	3.57	3.24	4.82	10.7	8.5
j	3.67	3.52	5.09	10.7	9.4
k	3.55	3.30	4.84	10.6	8.5
l	3.56	3.54	5.03	10.4	9.7
m	3.72	3.41	5.04	10.7	9.1
n	3.67	3.33	4.95	10.7	8.8
o	3.80	3.59	5.22	11.2	9.6
p	3.64	3.34	4.94	10.9	8.7
r	3.60	3.22	4.83	11.0	8.1
s	3.61	3.22	4.84	11.0	8.1
t	3.77	3.44	5.10	11.1	8.9
u	3.68	3.30	4.94	11.0	8.4
w	3.65	3.26	4.89	11.1	8.1
z	3.68	3.29	4.94	11.2	8.5
[m]/n	**3.64**	**3.34**	**4.94**		
σ	**±0.08**	**±0.14**	**±0.14**		

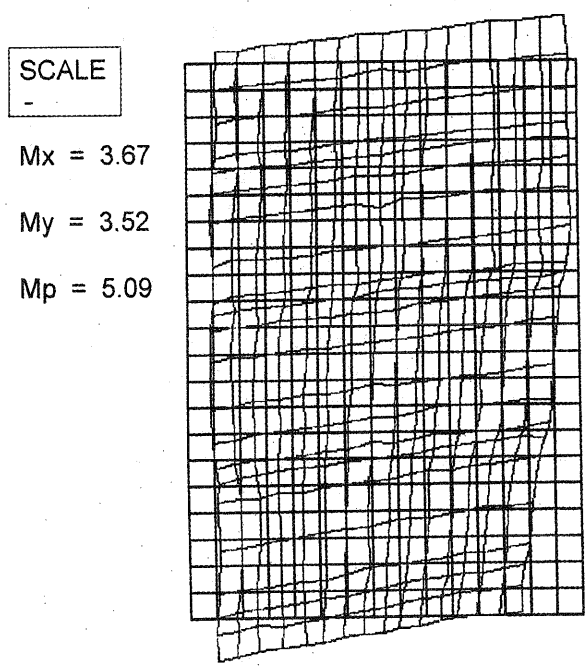

Fig.2. Deformations of the image J after the Helmert's transformation

The maximal discrepancies d_x and d_y can reach 12 pixels that represents 0,25 mm in real pattern scale. Average mean errors for 22 images are equal $m_p = \pm 4,9$ of pixels, what in reality equals $m_p = \pm 0,10$mm.
The achieved results show, that the errors of restitution of geometry by scanner UMAX are so high, that it makes impossible to use scanned and non-corrected images for photogrammetric processing.
It can be observed on Fig.2, that the scale for direction X and Y differ for both sets, and that the scale in direction X very causing change in pattern shape from a rectangle to a trapezium.

4. THE SCANNER SYSTEMATIC ERRORS

While analysing the scanner errors there is important to learn a type of errors appearing. Are they steady for each scanning results, or they change ? An answer to such question allows to choose the proper method of scanned images calibration. In case of steady discrepancies, the calibrations of each digital image will mean just taking those discrepancies into consideration in geometrical image evaluation. In case of non-steady discrepancies the corrections for each digital image would be different, and would have to be determined for each scanning session individually; that would require additional survey of many scanner reseau crosses, and would not be economical. There is also another third possibility: the errors of each scanned image are strictly systematic; in such situation a steady part of discrepancies creates a set of steady corrections, and a method should be determined for calculation of variable part of correction with the use of small number of control-points.
To determine the type of scanning geometrical discrepancies, there were analysed all digital images of the pattern which were obtained at the same pattern-film position on the scanner plate. The beginning of pixel coordinate system was slightly different for each digital image of pattern. Considering that shift of coordinate systems the values of discrepancies were calculated, and mean errors determined. The average mean error, which characterises repeatability, was $m_x = \pm 0.25$, $m_y = \pm 0.36$ and $m_p = \pm 0.44$ of pixels. Those repeatability errors are over 10-times smaller than the raw image error (see Tab.1) and gave a hope that after geometrical correction the results will be at least such.

To select the best systematic errors elimination function the 3 transformation were considered: affine, projective and bilinear.
The best results were obtained by transforming pattern coordinates to it's digital image using bilinear transformation, which eliminates affine and trapezium-like deformations. With the use of that transformation all the 22 digital images were tested and transformation coefficient were calculated with the use of all the 352 crosses. The transformation results are shown in Tab.2.

The received average mean error was: $m_x = \pm 0.7$, $m_y = \pm 1.3$ and $m_p = \pm 1.4$ of pixels. The greatest discrepancies are: max.d_x = 2.5pix = 50μm, max.d_y = 3.5pix =70μm. The bilinear transformation residual mean square errors m_x are equal for all images (the standard deviation is only 3% of the average error). The residual mean square errors m_y are in average case twice bigger than d_x, in spite of the fact that the scanner optical resolution is, in opposite, twice better in Y direction. On the Fig.3 can be noticed that the d_y discrepancies of crosses in each line Y=const are equal, but they are different for various lines.

Table 2. The results of the bilinear transformation

Image number (1200 dpi)	Bilinear transformation (352 reference points)				
	m_x pixels	m_y pixels	m_p pixels	$(d_x)_{max}$ pixels	$(d_y)_{max}$ pixels
A	0.68	1.92	2.04	2.1	3.6
B	0.66	1.30	1.46	2.1	3.0
C	0.74	1.41	1.60	2.4	3.2
D	0.74	1.02	1.26	2.5	2.4
E	0.69	1.16	1.36	2.2	2.7
F	0.69	1.19	1.38	2.2	2.7
G	0.70	0.99	1.21	2.3	2.4
H	0.69	1.12	1.32	2.2	2.7
I	0.68	1.13	1.32	2.2	2.6
J	0.70	1.61	1.76	2.2	3.2
K	0.66	1.28	1.44	2.1	2.8
L	0.69	1.78	1.90	2.1	3.5
M	0.70	1.36	1.52	2.1	2.7
N	0.70	1.23	1.41	2.1	2.4
O	0.68	1.58	1.72	2.2	3.2
P	0.66	1.26	1.42	2.0	2.7
R	0.68	0.96	1.17	2.1	2.3
S	0.68	0.97	1.18	2.1	2.3
T	0.67	1.31	1.48	2.3	2.7
U	0.66	1.08	1.27	2.1	2.4
W	0.67	1.04	1.23	2.1	2.4
Z	0.68	1.08	1.28	2.1	2.4
[m]/n	0.69	1.26	1.44		
σ	±0.02	±0.26	±0.23		

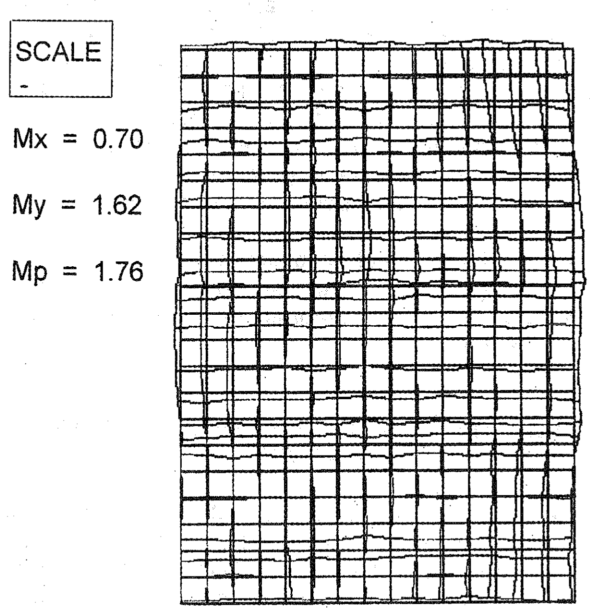

Fig.3. Deformations of the image J after the bilinear transformation

In [Boroń, 1995] the sinusoidality of $d_y(Y)$ discrepancies was presented for UMAX 1200. That phenomena can be a result of non proper synchronisation of the sensor-line position with the registration frequency. Comparison of sinusoidal discrepancies function for various digital images [Boroń,1995] show that they are similar, but not identical (see Tab.3: standard deviation of the average error m_y is great, and equals to over 20%).

5. THE METHOD OF GEOMETRICAL CORRECTION OF DIGITAL IMAGES

The correction is executed in two stages. In the first stage are determined I-order corrections d_x, d_y, being steady for each point of the scanner plate and determined during pre-calibration process. Next are determi-ned d_y corrections of II-order, being variable for each scanner run, but on certain digital image being constant along the sensor line and changeable for different sensor line positions.

To connect the surface of I-order correction to the currently scanned digital image it is enough to register and survey one pass-point targeted on the scanner plate. To actually determine the II-order corrections the perpendicular to sensors row a line of targeted points is needed. The II-order corrections are being calculated individually for selected rows of pixels (Y=const) and than interpolated for the other rows. The value of the II-order correction is constant for all pixels located in one row Y=const.

To get average correction function d_x, d_y the residual errors after Helmert transformation were analysed for the 14 pattern images (A...N). By averaging 14 values of discrepancies for each of 352 surveyed points of reseau pattern the table of average correction function values was created. Using SURFER program a graphical representation of average correction values was created for d_x (Fig. 4) and for d_y (Fig. 5). The image of the d_y functions shows clearly the sinusoida-like shape of that function surface.

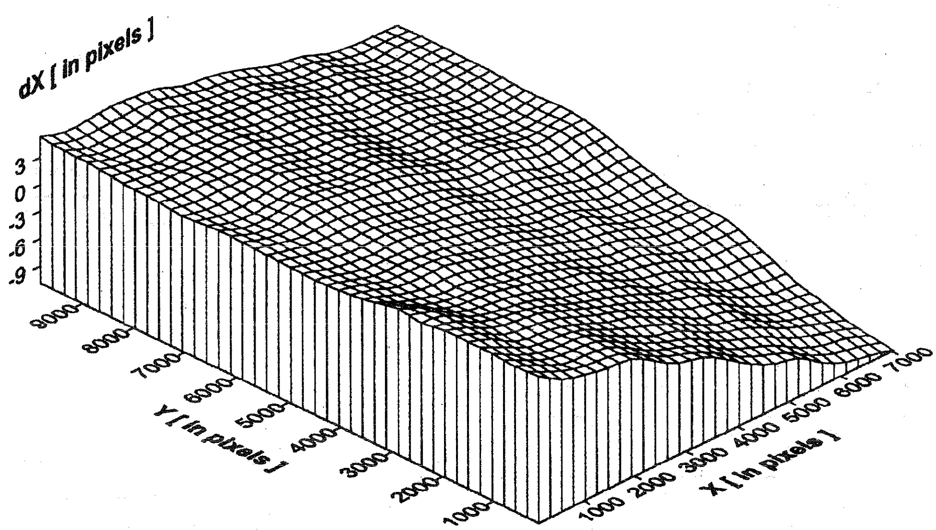

Fig.4. Surface of d_x errors after the Helmert transformation (images A...N)

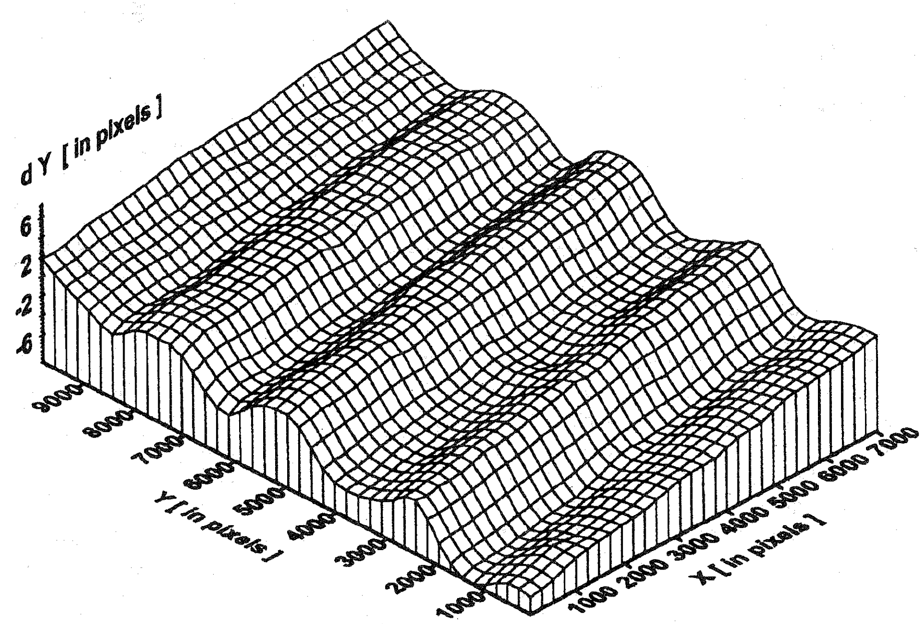

Fig.5. Surface of d_y errors after the Helmert transformation (images A...N)

To verify the I-order correction efficacy, the source files for digital images (A...N) were corrected, and additionally also 8 images (O...Z) which did not participate in average correction function construction.

The calculation results are shown in the Table 3. They confirm the basic idea that the d_x-average-correction function is steady and well determined as the average mean error is very small and equal $m_x = \pm 0.15$ pixels = $\pm 3\mu m$. On the contrary the d_y -average-correction function is less steady, and the respective average mean error equal to $m_x = \pm 0.33$ pixels = ± 70 μm, what is twice bigger than for X-axis. In spite of the above, the result of I-order correction are good enough for many applications.

Tab.3. The results of of the I-order correction

Image number (1200 dpi)	Helmert transformation (352 reference points)		
	m_x pixels	m_y pixels	m_p pixels
A	0.19	0.70	0.72
B	0.14	0.13	0.20
C	0.17	0.39	0.43
D	0.22	0.38	0.44
E	0.14	0.22	0.26
F	0.16	0.22	0.27
G	0.15	0.42	0.45
H	0.10	0.25	0.27
I	0.08	0.26	0.27
J	0.17	0.38	0.42
K	0.12	0.17	0.20
L	0.15	0.56	0.58
M	0.20	0.23	0.31
N	0.14	0.16	0.21
O	0.26	0.49	0.56
P	0.12	0.24	0.27
R	0.12	0.40	0.41
S	0.11	0.38	0.40
T	0.28	0.30	0.41
U	0.14	0.31	0.34
W	0.11	0.38	0.39
Z	0.12	0.33	0.35
[m]/n	**0.15**	**0.33**	**0.37**
σ	**±0.05**	**±0.14**	**±0.13**

The graphic representation of digital image deformation after it was corrected using I-order correction are shown on Fig.6.

To rise the efficacy of the correcting procedure one is to find the way of determining a II-order corrections, namely the current value of residuals dd_y for each currently scanned image. Considering Fig.3 and Fig.6 we can assume that the dd_y=const for all the points on certain y=const line. It means that it is enough to register one set of control points distributed along the line parallel to Y-axis of the scanner to determine the residuals dd_y for all the points of currant image. That assumption was verified twice: using one line of control points or two lines of control points along the scanner plate edges. The results of analysis are given in Table 4. A digital image corrected with the use of one line of control points only has a little lower accuracy than that corrected with the use of two lines.

For one line of control points method the $m_x = \pm 0.15$ pixels and did not change comparing with the I-order correction, but $m_y = \pm 0.09$ pixels, what is 4 times less than at I-order correction. In case of two simultaneously used lines of control points placed at two opposite edges of the scanner plate the residuals are still smaller: $m_x = \pm 0.13$ pixels= $\pm 2.7\mu m$ and $m_y = \pm 0.07$ pixels=± 1.5 μm.

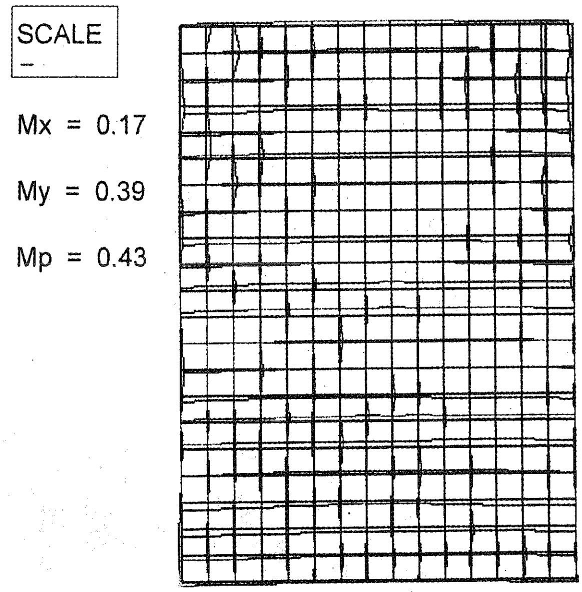

Fig.6. Deformations for the image J after the I-order correction

Tab.4. The result of the II-order correction

image number 1200 dpi	Helmert transformation (352 reference points)					
	one line of control points (22 points)			two lines of control points (44 points)		
	m_x pixels	m_y pixels	m_p pixels	m_x pixels	m_y pixels	m_p pixels
A	0.19	0.15	0.24	0.15	0.12	0.19
B	0.15	0.08	0.17	0.14	0.05	0.15
C	0.17	0.09	0.19	0.17	0.07	0.19
D	0.22	0.08	0.23	0.22	0.08	0.23
E	0.14	0.09	0.16	0.12	0.07	0.14
F	0.16	0.12	0.20	0.10	0.07	0.13
G	0.15	0.10	0.18	0.12	0.07	0.14
H	0.10	0.06	0.12	0.09	0.05	0.10
I	0.08	0.06	0.10	0.07	0.05	0.09
J	0.17	0.11	0.20	0.16	0.09	0.18
K	0.12	0.08	0.15	0.10	0.06	0.11
L	0.15	0.09	0.17	0.15	0.08	0.17
M	0.20	0.12	0.23	0.15	0.07	0.17
N	0.14	0.08	0.16	0.12	0.05	0.13
O	0.26	0.18	0.32	0.17	0.12	0.20
P	0.12	0.05	0.13	0.12	0.04	0.12
R	0.12	0.07	0.14	0.12	0.06	0.13
S	0.11	0.07	0.13	0.11	0.06	0.13
T	0.29	0.17	0.33	0.21	0.09	0.23
U	0.14	0.07	0.16	0.13	0.05	0.14
W	0.11	0.06	0.12	0.11	0.05	0.12
Z	0.12	0.08	0.15	0.09	0.06	0.11
[m]/n	**0.17**	**0.09**	**0.18**	**0.13**	**0.07**	**0.15**
σ	**±0.10**	**±0.04**	**±0.06**	**±0.04**	**±0.02**	**±0.04**

Such accuracies are already on the reseau pattern level of precision. After the correction of residuals dd_y the proportions between errors in X and Y directions correspond to the optical resolution of scanner.

6. CLOSING REMARKS

1. The UMAX 1200 SE scanner which belongs to the group of low cost equipment, produces digital images of rather low geometrical accuracy on the level of twelve pixels, which can not be used directly (without calibrations) in digital analytical photogrammetry.
2. That scanner errors are of systematic errors type.
3. After the average systematic errors correction function (the I-order correction), has been determined there is possible to reduce the digital image errors to the level $m_x = \pm 0.15$ pixels = ± 3 μm, $m_y = \pm 0.33$ pixels = ± 7 μm
4. The I-order image calibration with the use of the steady surface of mean discrepancies requires only 1 control target on the scanner plate.
5. To introduce to a digital image the II-order corrections, which concern residual scanning errors of known rules of variation, but which must be determined for each scanner run separately, one must use at least one row of control targets at the side of the scanner plate, which can be registered together with the scanned picture at its side. More reliable corrections are received with the use of two rows of control targets embracing the scanned picture on its both sides.
6. The highest accuracy of correction of geometric scanning errors was received with the use of the I-order correction and the II-order d_y corrections determined at the presence of two target rows. At that case the following corrected image residual mean square errors were noticed: $m_x = \pm 0.13$ pixels = ± 2.7 μm, $m_y = \pm 0.07$pixels = ± 1.5 μm. Such an accuracy is already on the level of the measurement accuracy of the scanner reseau control grid used for the accuracy evaluation.

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