PROCEDURES AND EXPERIENCES ON USING DESKTOP SCANNER FOR ORTHOPHOTO PRODUCTION

M. Mitrovic , Z. Cvijetinovic , D. Mihajlovic

Faculty of Civil Engineering, Belgrade University, Bulevar Kralja Aleksandra 73, 11000 Belgrade, Serbia and Montenegro, - (mitrovic, zeljkoc, draganm)@grf.bg.ac.yu

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ABSTRACT:

Paper presents procedures and experiences on using low cost desktop scanner Epson Expression 1640XL for orthophoto production. Complete process of scanning, scanner calibration and removal of systematic distortions of scanned images caused by scanner is developed and tested on several large projects of orthophoto production. Special, user-friendly software is developed for these purposes. The software includes algorithm for scanner calibration and estimation of distortions based on statistical analysis by using collocation (linear prediction). It is not expected and required from user to have any idea on the structure and distribution of scanner errors. These will be determined by the statistical analysis. Therefore, the software usage is not limited to any particular scanner or the type and nature of image distortions it introduces. Batch processing of scanned images is also supported with options for saving images in various formats and using several resampling types.

The results presented in paper shows that the procedure is very fast and reliable when geometric accuracy of scanning is concerned. The potentials of the developed software and procedure are high. Total costs for the software and the scanner are approximately ten times lower than costs for the professional photogrammetric scanner. The geometric accuracy achieved is between 5 and 10μm, which is less than one pixel size in highest scanning resolution (1600 DPI). The aspects of the scanner usage at a high production rate are also analysed. Finally, recommendations for further improvements of the developed procedures are given.

1. INTRODUCTION

The idea of low cost softcopy photogrammetry is present for a long time in photogrammetric theory and practice. However, for those who wants to start a completely digital photogrammetric production there are still large initial investments to be expected, especially when software and hardware is concerned. If aerial photogrammetry and orthophoto production are concerned, one of the most expensive components for those who want to cover the whole production line from the very beginning is the acquirement of either digital photogrammetric sensor or standard photogrammetric camera and a high quality photogrammetric scanner. Both of these options require high investments. These investments can be reduced substantially by choosing another approach. This involves acquirement of standard photogrammetric aerial camera and a low cost desktop scanner and suitable software and procedures for scanning, calibration and rectification of scanned images. The major problem that has to be solved is rather poor geometric accuracy of most of the desktop scanners available on the market.

Desktop scanners are basically intended for quite different type of users than typical digital photogrammetry users are. So, this type of scanners must be somehow checked before using in photogrammetry. Several important features define the level of desktop scanner exploitation in photogrammetry:
- scanner type (flatbed or drum),
- scanning format - minimum 25 cm*25 cm,
- geometric resolution - 800-1600 dpi,
- radiometric resolution 10 or more bytes per pixel,
- geometric accuracy 2-15 μm,
- density range from 2.5 D for panchromatic and from 3.5 for color,
- capability of scanning transparent materials.

Simple review of technical features of many new A3 desktop scanners might lead to the following conclusion: they can satisfy many mentioned features except geometric accuracy (very often without information about it).

Radiometric resolution, quality and scanning speed of desktop scanners is similar to photogrammetric scanners. Due to the strong competition between manufacturers, desktop scanners are built on new sensors, electronic devices and scanning software with much improved quality. This is the reason why the emphasis in this paper was given to the geometric accuracy, that is the most sensitive features for desktop scanners.

Geometric calibration procedure that is usually provided by all desktop scanner manufacturers is incomplete or insufficiently accurate for digital photogrammetry needs. Supplied technical features rarely represent relevant technical features in terms of geometric accuracy through tolerance of RMSE or maximal positional error. This is the reason why user of desktop scanner has to determine the nature of scanner errors by calibration process and afterwards to eliminate the most of them.

It is possible to determine the law of geometric errors spreading by multiple scanning and analysis of results of scanning glass plate with dense grid points (coordinates of these points are of high accuracy in plate's coordinate system).

2. GEOMETRIC CALIBRATION OF DESKTOP SCANNERS

2.1 Sources of geometric errors at desktop scanners

In order to objectively evaluate geometric accuracy it is necessary to know the most important error sources and their nature. In general, these errors can be divided to slowly and frequently varying errors.

Slowly varying errors are:
- lens distortion
- misalignments of CCD sensors
- imperfection of transport mechanism

Frequently varying errors are:
- vibration
- electronic noises
- mechanical positioning

It is important to mention that only effects caused by slowly varying errors can be removed. Stability of error sources during longer period of scanning is therefore very important. This is prerequisite that these errors could be removed efficiently.

2.2 Mathematical model

Geometrical calibration of desktop scanners can be seen as interpolation problem. This problem, in most of the cases, can be solved by some method of approximation - law on error propagation is supposed by some mathematical function. Due to the several error sources with unknown error propagation, the most suitable interpolation method fir geometric calibration is some of prediction methods. Linear prediction by least squares method was chosen as the most appropriate method in this research.

2.2.1 Linear prediction by least squares method

This method is also known as least-squares collocation, with remark that linear prediction represents special case of collocation. Moritz introduced the method in geodesy for the first time, for determination of gravitation anomalies and vertical deviations. This method starts with the assumption that interpolating function could be considered as stationary random function of two variables. In order to start with this assumption, it is necessary to remove the trend influence from referent point values so the points will have small absolute values and arithmetical mean will be close to zero. Then, the assumption is that these values are composed of correlated (systematic, also known as signal) and uncorrelated (random, known as noise) part. The task of prediction is to determine correlation component at interpolated point, based on known referent values. Interpolated value is sum of previously eliminated trend value and this systematic part. Random part is treated as measurement error at referent point or as noise, which should be filtrated i.e. removed.

Trend removal can be done by calculation of trend surface and subtracting it from measured surface. Trend surface is usually represented by low order polynomials. Optionally, preliminary interpolation with relatively high level of smoothing could be performed.

For the final interpolation of unknown values at arbitrary points it is necessary to know stochastic characteristics of both components (correlated and uncorrelated) participating in known values. These characteristics can be determined empirically based on known values in referent points, or based on several previously accepted assumptions.

These characteristics are represented by covariance function, with beforehand assumption that function depends just on mutual distance of observed points and not on their position. Gaussian bell function is often used as covariance function (eq.1):

$$C(d) = Ce^{-K^2 d^2} \qquad (1)$$

Unknown parameters of covariance function (C and K for Gaussian function; d is the distance between samples) can be determined empirically if one has enough referent points (over 30). Based on known values, variance is calculated and considered the same for all referent points, as well as covariance for different intervals between referent points. Unknown parameters of covariance function can be determined based on empirically calculated covariance. The case of "clean" prediction means that C value of Gaussian function is equal to covariance of correlated components. Decrease in this value leads to increase in data filtering, i.e. interpolated values will differ from known values at referent points.

During the process of scanner geometric calibration measurements are pertaining to two-dimensional coordinate system. Since scanning errors are usually considered in directions of two coordinate axes, the task of prediction is conducted independently for each of them and covariance function is determined for each coordinate direction.

2.3 Software for the geometric calibration

Software called *DigiScan 2000* is adapted for the needs of desktop scanner calibration. Software is generally intended for the calibration and georeferencing of scanned maps, but some additional functions for image analysis and processing are also provided. Batch resampling is also supported and this is very important for photogrammetric scanning. DigiScan 2000 has built-in mathematical models for Helmert, affine, polynomial second order transformation, as well as mathematical models for linear prediction by least squares, with or without filtering. All the processing and calibration result analysis, as well as the process of scanned image resampling was done by using this software.

2.4 Process of calibration and image scanning

Nature of scanning errors, as well as their stability and repeatability during the scanning, have to be determined during the calibration process. Several objectives were set for the process of geometric scanner calibration:
- determination of overall scanner error and value of systematic part in this error,
- determination of global stability of systematic errors,
- determination of local stability of systematic errors

Influence of changing spatial and radiometrical resolution of scanning as well as influence of scanner warming on scanning errors has to be considered.

The calibration process itself has several steps:
1. multiple glass grid plate scanning,
2. measurements of the grid plates and processing of the results,
3. analysis of achieved results and acceptance of transformation parameters

If the results confirm that scanner satisfies the accuracy standards, then every scanned image is resampled in batch procedure based on accepted transformation/calibration parameters.

3. CALIBRATION OF *EPSON EXPRESSION 1640XL* SCANNER FOR THE PHOTOGRAMMETRIC REQUIREMENTS

3.1 Epson Expression 1640XL

This scanner (Figure 1) is selected because it belongs to the higher class of desktop scanners and it comes from very well known manufacturer. The market price varies from 2000$ to 3000$.

Figure 1: Scanner Epson Expression 1640XL

The basic technical features are given in the Table 2.

SCANNER TYPE	Flatbed color image scanner
SUB SCANNING METHOD	Movement of the mirror
PHOTOELECTRIC DEVICE	Color CCD line sensor
SCANNING AREA	
Scanning Platen	310 x 437 mm (A3+)
Transparency Unit	290 x 420 mm
LIGHT SOURCE	Xenon fluorescent lamp
OPTICAL RESOLUTION	1,600 x 3,200 dpi with Micro Step Drive
OPTICAL DENSITY	3.6 D
PIXELS/LINE	58,560 pixels
OUTPUT RESOLUTION	
GREYSCALE	14-bit (16,384 grayscale levels)
COLOUR	42-bit (4,398 billion colors)
SCANNING SPEED	
MONOCHROME (Draft Mode)	A4 300 dpi - 14 sec[1]

Table 2: Technical features of *EPSON Expression 1640XL* scanner

3.2 Grid plate scanning

Glass plate (25.5cm x 25.5cm) has been used for the geometric calibration of desktop scanner. The plate has 625 grid points with 1cm grid spacing. Geometric accuracy of the grid is checked by measurements using analytical photogrammetric plotter.

Scanning of grid plate is performed for several spatial scanning resolutions (1000 dpi, 1200 dpi and 1600 dpi) and for two radiometric resolutions (grayscale and RGB). Grid plate scanning was performed regularly on every hour, with scanning of other images between these scans. In total, it was 24 scanning of grid plate, with different scanning parameters.

3.3 Processing and result analysis

After grid plate scanning, grid points are measured in DigiScan 2000. The result of the measurement are the pairs of grid points coordinates, that is pixel coordinates of grid points and appropriate theoretical coordinates in plate coordinate system, based on point position in the grid. The pairs of coordinates are subject of further analysis on scanner geometric accuracy.

3.3.1 Assessment of overall scanner error and systematic part

The first mathematical model applied on measurements is Helmert transformation (eq. 2). This provides simple transformation of coordinates from raster to plate coordinate system.

$$X = a1 + a*x - b*y$$
$$Y = b1 + a*y + b*x$$
$$(2)$$

where: X,Y – grid point coordinates in plate coordinate system (in μm)
x,y - pixel coordinate of grid points
a,b,a1,b1 - coefficients

Achieved RMSE based on residuals after transformation is 130 μm. Overview of errors vectors after applied Helmert transformation is given at Figure 3.
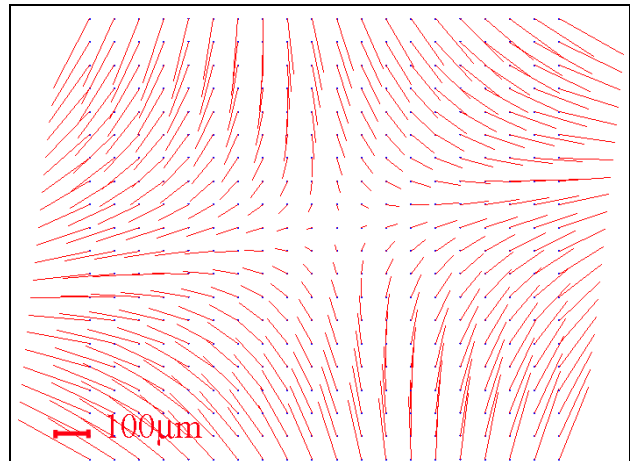

Figure 3: Error vectors after Helmert transformation.

Figure 3 shows the nature of scanning errors obtained with EPSON Expression 1640XL scanner. It can be concluded just by visual inspection that there is a huge systematic influence, which couldn't be modeled and removed Helmert transformation. Also, obtained RMSE leads to the conclusion

that this scanner cannot be used for photogrammetric tasks without additional geometric correction of images.

Affine transformation was used as the second transformation model (eq. 3)

$$X = a1 + a2 * y + a3 * x$$
$$Y = b1 + b2 * y + b3 * x$$
(3)

where: X,Y - grid point coordinate in plate coordinate system (in μm)
      x,y - pixel coordinate of grid points
      ai,bi - coefficients

Achieved RMSE based on residuals after affine transformation is about 30 μm for each axis, with maximum errors up to 70 μm. Overview of error vectors after applied affine transformation is given at Figure 4.
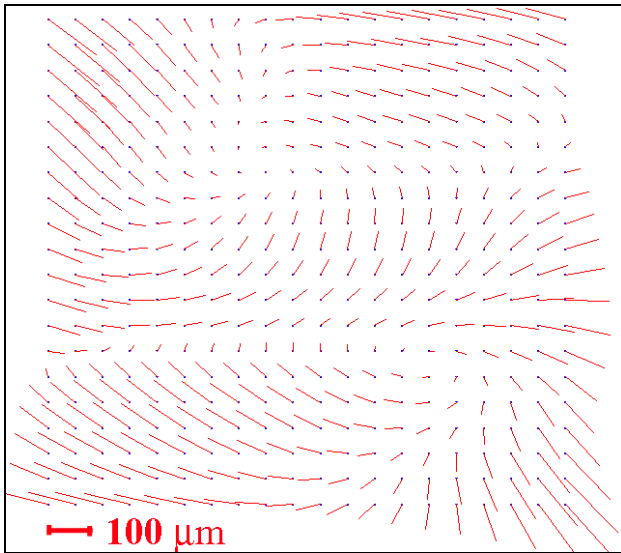

Figure 4: Error vectors after affine transformation.

As for the previous case, it can be concluded that errors still contain systematic part, but much smaller in magnitude comparing to the one after Helmert transformation. Also it is clear that this systematic influence is locally changing. Still, overall geometrical accuracy is insufficient for digital photogrammetric tasks.

The third mathematical model used is previously described linear prediction by least square (collocation). Achieved RMSE based on residuals after collocation with filtering is about 4.2 μm for the first and 8.5 μm for the second axis. Maximum error for any grid plate was not exceeding triple value of RMSE for that plate.

Figure 5 represents error vectors after collocation with filtering. Random arrangement of error vectors might lead to conclusion that systematic part of an overall error is mostly eliminated.
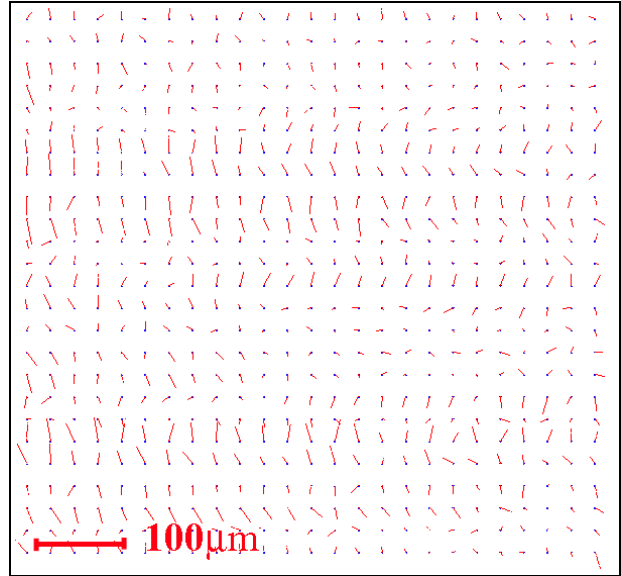

Figure 5: Error vectors after collocation with filtering was applied.

Affine transformation (eq. 3) has been used before collocation in order to remove trend.

Scanning parameters	Affine		Collocation		Empirical covariance	
	My (μm)	Mx (μm)	My (μm)	Mx (μm)	CovY	CovX
1200 dpi grayscale	36.51	32.14	4.14	9.76	0.90	0.84
	35.73	29.99	3.92	9.70	0.90	0.85
	35.61	28.85	3.80	9.35	0.90	0.84
	35.40	30.26	3.61	9.28	0.90	0.85
	35.47	29.80	3.54	9.24	0.91	0.85
	34.70	27.31	3.81	8.76	0.90	0.84
	36.26	31.69	3.59	8.78	0.91	0.86
	35.04	28.85	3.61	8.72	0.91	0.86
	35.18	29.32	3.69	8.91	0.91	0.85
	35.31	29.97	3.98	8.70	0.91	0.84
	35.04	29.78	3.80	8.50	0.91	0.85
	35.24	29.14	3.55	8.39	0.90	0.84
1000 dpi Grayscale	33.91	29.71	4.69	8.45	0.86	0.83
	34.33	29.62	4.48	8.63	0.87	0.82
	34.29	29.97	4.96	8.92	0.86	0.81
1600 dpi Grayscale	34.16	28.06	4.30	7.98	0.86	0.83
	33.87	27.77	4.01	7.95	0.86	0.84
	33.71	27.70	3.90	7.46	0.87	0.84
1000 dpi RGB	33.67	27.81	5.53	7.64	0.85	0.82
	33.96	27.41	5.04	7.37	0.86	0.83
	33.81	27.01	5.26	7.73	0.85	0.81
1600 dpi RGB	33.35	27.66	4.14	7.75	0.86	0.83
	33.92	28.29	4.48	8.40	0.86	0.81
	33.37	28.04	4.28	8.65	0.86	0.81
$M_{AVERAGE}$	34.67	29.01	4.17	8.54		
Mmax	36.51	32.14	5.23	9.76		
Mmin	33.35	27.01	3.54	7.37		
Range	3.16	5.13	1.99	2.38		

Table 6: Parameters of the scanner geometric accuracy

Table 6 shows the results of the scanner global geometric accuracy. RMSE values based on residuals after affine transformation and collocation with filtering are given. My shows RMSE based on residuals after coordinate transformation

in the direction of scanner transport mechanism. Mx shows RMSE based on residuals after coordinate transformation in the direction of CCD sensor moving.

High level of correlation of errors on grid points is shown at Figure 7. This figure represents covariance functions in the directions of transport mechanism (Y axis) and CCD sensors moving (X axis). Red dots at the diagram represent empirically calculated covariance, depending on the point distance from adjacent grid point. Covariance function (in blue) is obtained as adjusted Gaussian curve, passing as halfway line between empirical covariances. Conclusion coming out from the diagram is that errors are highly correlated for both axis. This correlation is significant even for grid points with distance of 4-5 times grid interval.
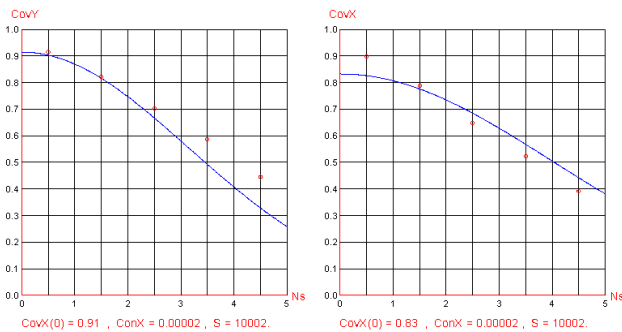

Figure 7: Covariance functions by coordinate axis

Since the accuracy of the glass plate grid is higher by the order of magnitude than scanner errors one can say that residuals after Helmert transformation represent overall scanner's errors. It comes out that positional RMSE of 130 μm, after Helmert transformation, is overall RMSE scanner. It can be also concluded that major part of this error comes from systematic part - from 130 μm RMSE decreases to 4.2 and 8.5 μm after collocation with filtering. The difference in RMSE between these transformations represents systematic part of positional error.

3.3.2   Assessment of global stability of systematic errors

In order to assess stability of systematic errors during the time and their dependence on change of scanning parameters, multiple scanning of grid plate has been performed. Grid plate was scanned 24 times, which can be seen from Table 6.

RMSE based on residuals after affine transformation and collocation with filtering has been selected as the estimate of global stability of systematic errors. As it can be seen from table 6, the difference between maximum and minimum RMSE after affine transformation is 3.2 μm (Y axis) and 5.1 μm (X axis). After collocation with filtering these differences are 2.0 μm and 2.4 μm (Y and X axis, respectively).

It can be concluded that systematic errors are very stable, at least on a global level. They are independent from the scanning time duration and changes of spatial and radiometric resolution.

3.3.3   Assessment of local stability of systematic errors

In order to determine the local stability of scanning errors the differences of residuals are compared after affine transformation and collocation with filtering in 9 distinctive grid points (Figure 8).
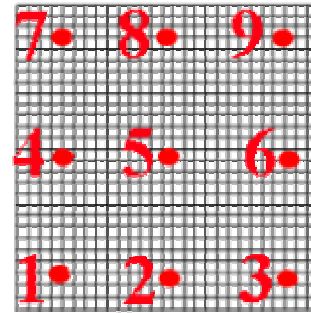

Figure 8: Points for local stability test

Figure 9 and Figure 10 show the differences of residuals in 9 distinctive grid points (for Y and X axis).
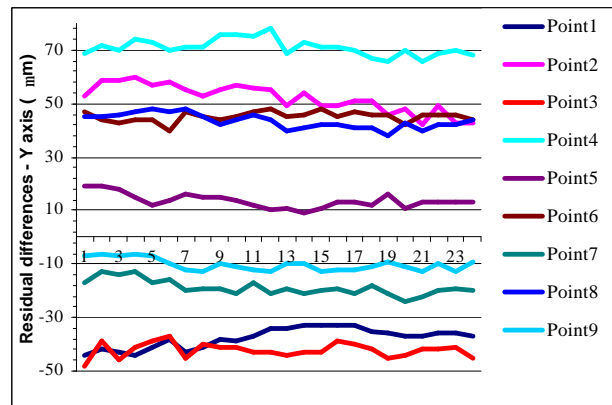

Figure 9: Residual differences at 24 plates after affine transformation and collocation with filtering (Y axis)
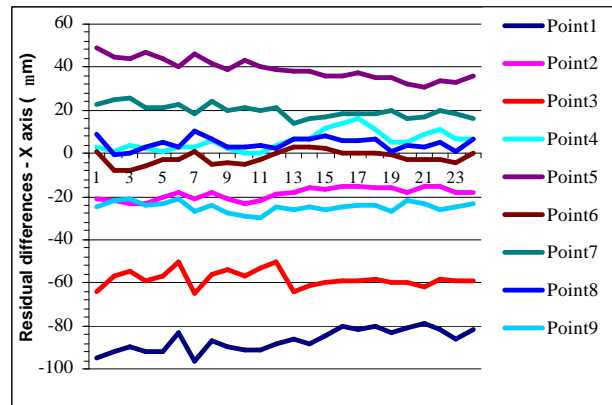

Figure 10: Residual differences at 24 plates after affine transformation and collocation with filtering (X axis)

Differences of residuals, shown at Figure 9 and Figure 10, ranges from 8 to 15 μm.

It can be concluded that systematic errors in distinctive points are very stable, regardless of the scanning time duration and changes of spatial and radiometric resolution.

3.4 Test of calibration results

Obtained calibration parameters of scanner are tested by resampling of grid plate using these parameters in exactly the same way as it would be done for scanned images. Providing that previous conclusions were correct, only random parts of overall errors should remain on rectified grid plate. Transformation results after rectification are given in following table.

	Affine		Collocation	
	My (μm)	Mx (μm)	My (μm)	Mx (μm)
plate1	10.48	11.51	3.25	3.67
plate2	11.10	12.77	3.12	2.87
$M_{AVERAGE}$	10.79	12.14	3.18	3.27
Mmax	11.10	12.77	3.25	3.67
Mmin	10.48	11.51	3.11	2.87
Range	0.62	1.26	0.13	0.80

Table 10. RMSE after plate rectification

It is visible from table 10 that after rectification of plate according to obtained calibration parameters remaining part of mean positional error is 11 μm to 12 μm. This means that remaining errors for images scanned and in this way rectified would be the same.

3.5 Practical experience

In addition to experimental research based on described technology, about 3000 aerial images were processed for the requirements of digital orthophoto production in Serbia during the last 3 years.

Interior orientation and aerial triangulation, procedures which also provides good check of geometrical quality of scanned images, has confirmed conclusions stated so far in the paper. In the process of automatic interior orientation RMSE of the affine transformation is around 0.9 pixels, with maximum error of 1.2 pixels. Aerial triangulations with bundle adjustment for several projects with 100-400 images resulted in RMSE about 1 pixel, for GCPs and tie points.

Since mentioned scanner has no system for film alignment, it is necessary to press film negative by glass plate during scanning process. Also, the there are scanning problems related to appearance of Newton rings. This problem can be removed by using AntiNewton glass plates or by applying some other known method.

4. CONCLUSION

The high price of professional photogrammetric scanners at one side, and the requirements of market for various products of digital photogrammetry at the other side, calls for very careful approach when one is trying to start autonomous digital photogrammetric production.

The major drawback with desktop scanners when used for digital photogrammetry is geometric accuracy. Nevertheless, testing and calibration of EPSON Expression 1640XL showed that with additional calibration this type of scanner can be used in photogrammetry.

By multiple scanning of glass grid plate, and by using linear prediction by least squares method the following conclusions can be made:

- there are large geometrical scanning errors (RMSE=130 μm), so this scanner can not be used without proper calibration
- after removal of systematic part scanning RMSE is reduced to 4.2 μm and 8.5 μm
- systematic errors are very stable, regardless of duration of scanning procedure and changes in geometrical and radiometric resolution. It has been estimated that variations of RMSE after affine transformation is 3.2 μm (Y axis) and 5.1 μm (X axis).
- it was proved that systematic errors in 9 distinctive points are very stabile, regardless ofo duration of scanning procedure and spatial and radiometric resolution changes
- it was estimated that remaining RMSE after image calibration/rectification by using presented procedure is about 12 μm

Three years of using described procedures and scanner EPSON Expression 1640XL, confirmed all the conclusions stated above.

However, drawback for using desktop scanners in digital photogrammetry lies in the fact that they are still not suitable for high precision tasks, because estimated accuracy limit of 12 μm is insufficient for many photogrammetric procedures. Also, it is very difficult, if not impossible, to automate the whole scanning procedure by using desktop scanner. It makes scanning rather slow compared to professional photogrammetric scanners.

Although desktop scanners cannot be recommended for large and high precision projects in digital photogrammetry, they could be used for smaller projects and where highest accuracy is not required. With additional calibration these scanners could be optimal solution considering cost-effectiveness.

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