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Using Low Cost DeskTop Publishing (DTP) Scanners for Aerial Photogrammetry

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Abstract This paper emphasizes on investigating the suitability of using low cost DeskTop Publishing (DTP) scanners for aerial photogrammetric applications. The paper involves calibrating the scanner geometric errors. Mathematical and actual photogrammetric data were used during this investigation. The mathematical data shows that calibration of DTP scanners improves the root mean square error (RMSE) values of the photogrammetric solution by about 81% and 83% in horizontal and vertical directions respectively. The actual data proofs that the use of low cost DTP scanner as opposed to the use of Leica BC2 analytical plotter increases the horizontal and vertical RMSE values of about 35% and 43% respectively. The obtained accuracies allow the generation of planimetric maps at a scale of 1:500 or smaller and topographic maps with a contour interval of around 1 m or larger. This methodology is of great interest to small engineering firms for the generation of local area maps.

Keywords: *scanner, calibration, photogrammetry, GIS, mapping*

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1. Introduction

Scanners are necessary for digital photogrammetric systems. The main use of scanners is definitely in the digitization of aerial images. A distinction should be made between photogrammetric scanners and non-photogrammetric, or DTP, scanners in the market. Photogrammetric scanners typically meet very robust standards in terms of the optical alignment, throughput capability and the accuracy of analogue image conversion to digital form. DTP scanners are available at a fraction of the cost of photogrammetric units, and this has led to their periodic use in photogrammetric production. The main problem of DTP scanners regarding image scanning is that they lack high geometric accuracy (inherent or through calibration). Improvements on this topic will drastically increase the range of their application. Regarding scanning of maps, plans etc. DTP scanners provide sufficient functionality and in many cases their geometric accuracy, even without calibration, is sufficient. Since, the format of DTP scanners is not expected to increase, their use for scanning of cartographic documents is limited to A3. For these reasons the developments in the DTP scanners should be closely monitored.

The major errors of DTP scanners [3] are geometric mechanical positioning inaccuracies, lens distortions, electronic noise and small dynamic range, and color balance. Other errors can occur depending on the design, construction, and parts of each individual scanner. Some errors are slowly or frequently varying depends on the quality and stability of the scanner, for example in DTP scanners the positioning errors vary from scan to scan or even within one scan. In DTP scanners, the geometric errors in CCD (Charged Coupled Device) direction considerably increase towards the borders of the scanner stage, and in scanning direction they may increase slightly towards the end of the scan.

For testing the geometric accuracy and performing geometric calibration of DTP scanners, the author of this paper developed user-friendly software called ScanCal [7]. ScanCal was used for testing and correcting the geometric errors of low cost VUEGO Scan Brisa Acer 640U scanner with A4 scan size. It has significant effect on improving the geometric accuracy values of the tested scanner from 40-65 μm to 4-6 μm. These values of accuracy open the door-way for using low cost DTP scanners for photogrammetric applications and researches.

Little research has been performed to determine the quantitative effects of the geometric imprecision of scanned photographs using DTP scanners in a photogrammetric production setting. In addition, the practical effect of these errors upon the photogrammetric solution has not sufficient study. Therefore, the objectives of the present paper are:

1. Calibrating the geometric errors of the used low cost DTP scanner.
2. Evaluating the accuracy of the used DTP scanner for the determination of object space coordinates of points for photogrammetric applications using mathematical and actual photogrammetric data.
3. Comparing the obtained results with the mathematically generated data and with the obtained results using Leica BC2 analytical plotter.

2. Concept of ScanCal Software

ScanCal is a Windows-based software package. The software initializes and terminates the operations of five menus namely Grid Generation, Coordinates Extraction, Geometric Accuracy, Scanner Calibration and Calibrating New Scan.

Grid Generation menu was developed for:

1. Generating grids, in the form of separate crosses, according to the specified scanner size, spacing and cross size.
2. Automatic generation of the reference x, y coordinates of each cross center and storing these coordinates in specified ASCII file format for later use.
3. Saving the generated grids in DXF (AutoCAD's Drawing eXchange Format) file format to be plotted ([1-7]) using suitable DXF compatible software (e. g. AutoCAD software [11]). The grids should be plotted on high quality paper or special type transparency.

Coordinates Extraction menu reads the scanned file, extracts automatically the x and y image coordinates (in pixel) of the grid crosses, and stores the x, y image coordinates of all grid cross centers in specified ASCII file format for later use.

Geometric Accuracy menu reads the reference x, y coordinates (in mm) of the grid cross centers as generated by Grid Generation menu and the measured x, y coordinates (in pixel) as extracted by Coordinates Extraction menu and performs coordinate transformation(s). This menu enables the user to select the number and location of the control points which may be four or eight corner points (similar to the fiducial marks in aerial photographs), points of outer borderlines or all points. ScanCal software has the capability of performing the following x, y coordinate transformation [10]:

1. Affine transformation,
2. Projective transformation and
3. General two dimensional polynomial transformation (Polynomial transformation).

For all methods of coordinate transformations, the software performs Least Squares Technique [10] for getting the values of the transformation parameters and statistical data such as the residuals (v) of x, y coordinates of the grid crosses, the Root Mean Square Error (RMSE) values for the residuals of x, y coordinates, the Maximum Absolute Error (MAE) and the Mean Error. Moreover, this menu has the capability of plotting the geometric scanner errors in the form of contours, vector of residuals, or three dimensions view. This capability is useful for studying the nature, distribution and effect of errors.

Scanner Calibration menu performs automatically the steps of calibrating DTP scanners as following:

Transformation of the plate reference coordinates of the grid crosses to plate corrected pixel coordinate system: The origin of the two coordinate systems is taken as the upper left grid cross.

Transformation of the coordinates of the grid crosses from corrected pixel to corrected scanner coordinate systems: This transformation, is called linear conformal, includes simple translation and rotation of the corrected pixel coordinates system. After getting the transformation parameters, the corrected scanner coordinates of any grid cross can be obtained.

Computation of the geometric corrections for the grid crosses: The geometric corrections are the differences between the corrected scanner coordinates and the extracted scanner coordinates of the grid crosses (both in pixel). The computed geometric corrections reflect the effect of geometric errors without applying any errors minimizing or compensation method. To increase the accuracy of getting the geometric corrections, the mean corrections for each grid cross of four or five scans taking with the same scanning resolution are computed and stored in suitable files. The output of this step is the measured scanner coordinates of each grid cross with its geometric corrections.

Computation of the geometric corrections for each pixel in the scanner effective area: Interpolation method is used for computing the geometric corrections for any pixel locating between crosses. For this purpose, Surfer software [9] is interfaced. The interfacing of Surfer software is performed using Surfer Automation Model method without any interruption to the user. Out of the different methods of grid interpolation of Surfer software, Modified Shepard's method is recommended [6] and used in this research. The results of interfacing Surfer software are two files namely DataCal_X.grd and DataCal_Y.grd for specified scanning resolution. These files can be used for computing the geometric corrections in x and y extracted scanner coordinates of any pixel for new scan(s).

Calibrating New Scan menu reads the extracted coordinates of the points of interest of the scanned image, computes their geometric corrections using the generated calibration files, as explained above, and computes their corrected x and y coordinates. The menu has options to perform different methods of coordinates transformation with displaying the necessary statistical data to test the validation of the calibration method. Desired control points number and pattern can be specified by the user of this software.

3. Calibrating the Geometric Errors of the Used Scanner

ScanCal software was used to test and calibrate the geometric errors of Mustek A3 2400S flatbed scanner with A3 scan size. The software was executed to generate the test pattern. This pattern consists of 49*49 grid crosses (total of 2401 crosses) with a grid spacing of 5 mm. The AutoCAD software [11] was used to print the generated grid crosses on high quality HP transparency using inkjet printer(s). Laser printers were not used in this test to avoid their thermal effect which may damage the transparency. The testing and calibrating phases of low cost DTP scanner consisted of [7]:

1. Testing the plotting error.
2. Testing the Scan-to-Scan Error.
3. Testing the geometric accuracy.
4. Geometric calibration of the scanner.
5. Testing the geometric calibration procedure.

3.1. Testing the Plotting Error

The plotting error was tested by plotting the grid crosses using three different types of inkjet printers. The print outs were scanned using different values of scan resolution. The computer and the scanner were turned off/on after each scan. ScanCal software was used for getting the measured x and y coordinates of all crosses from the scanned files. The six parameters of affine transformation [8] were computed using the measured and reference coordinates of the grid crosses and using all grid crosses as control points. The values of RMSE in x and y directions for each scan were computed as follows:

$$RMSE = \sqrt{\sum_{i=1}^{n} (known\ or\ actual\ value - computed\ value)_i^2 / n} \quad (1)$$

Where n is the number of points.

The maximum difference in RMSE values of each scanning resolution of the three print outs is 2 μm which can be neglected. It can be concluded that the plotted grids are free off plotting error.

3.2. Testing the Scan-To-Scan Error

It was tested by taking four scans for the plotted grid crosses at scanning resolution of 300, 600, 900 and 1200 dots per inch (dpi). These scans were taking under the following conditions:

1. Taking one scan, turning off/on the scanner and taking the next scan.
2. Taking one scan, turning off/on the computer and scanner and taking the next scan.
3. Taking one scan, turning off/on the computer and taking the next scan.
4. Taking one scan followed by the next scan.

For this test, the coordinates of grid crosses were determined by ScanCal software and the six parameters of affine transformation were computed using these values and the reference values with using all grid crosses as control points. The values of RMSE for each scan were computed. The results showed that the maximum difference in the computed RMSE is 1 μm which can be neglected and hence it can be concluded that the scanner is clear off scan-to-scan error.

3.3. Testing the Geometric Accuracy of the Scanner

For this purpose, the grid crosses were scanned with scanning resolution of 300, 600, 900 and 1200 dpi.

Four scans were taking for each scanning resolution as showed above. ScanCal software was used for automatic extraction of the x and y coordinates of grid crosses for each scan.

Testing the geometric, or global, accuracy of the scanner was performed by choosing all points as control points [7] and using the polynomial coordinate transformation method [8] for its significant effect in reducing the errors in x and y directions. For each scan, the values of RMSE, MAE and Mean Errors in x and y directions for all points were computed. The mean of these values for the four scans were computed and tabulated in Table 1.

Table 1. Scanner geometric accuracy for different scanning resolutions

Scanning Resolution	Root Mean Square Error (μm)		Maximum Absolute Error (μm)		Mean Error (μm)	
	X	Y	X	Y	X	Y
300 dpi	41	32	114	90	0	0
600 dpi	38	30	108	77	0	0
900 dpi	38	30	97	73	0	0
1200 dpi	37	30	94	77	0	0

Table 2. Scanner geometric accuracy after calibration for different scanning resolutions

Scanning Resolution	Root Mean Square Error (μm)		Maximum Absolute Error (μm)		Mean Error (μm)	
	X	Y	X	Y	X	Y
300 dpi	13	11	45	34	0	0
600 dpi	3	3	11	11	0	0
900 dpi	4	4	12	11	0	0
1200 dpi	4	3	12	10	0	0

As depicted in Table 1, it can be concluded that:

1. Increasing the scanning resolution has insignificant effect on improving the accuracy because the error sources and magnitude remain the same. In fact, with a higher scanning resolution, only the accuracy of coordinates extraction could be possibly improved but this gain would be very small compared to the whole error budget.
2. The maximum absolute errors are bounded and correspond to 2.5 – 3.5 RMSE.
3. The best geometric accuracies of the scanner are 37 and 30 μm in x and y directions respectively. These RMSE values are not suitable for photogrammetric applications which need at least geometric error of 20 μm or better [4]. Furthermore, the above mentioned scanner accuracy may be sufficient for some cartographic and GIS applications [7].

3.4. Geometric Calibration of the Scanner

As was explained earlier, the corrections in x and y coordinates for each grid cross of each scan were computed. The average values of these corrections of the four scans of each scanning resolution were determined. Surfer software was interfaced to generate the calibration files, DataCal_X.grd and DataCal_Y.grd, for each scanning resolution to predicate the corrections for any pixel locating within the scanner effective area.

3.5. Testing the Geometric Calibration Procedure

To check the results of the calibration procedure, each scan was calibrated using the generated calibration files to find the corrections for each grid cross and its corrected x and y coordinates. Global accuracy of the scanner was performed by choosing all points as control points and using the polynomial coordinate transformation method, and RMSE, MAE and Mean Error values at all points were computed. The average results of the four scans for each scanning resolution were computed and tabulated in Table 2.

From Table 1 and Table 2, the following conclusions can be drawn:

1. The developed calibration procedure has significant effect on improving the accuracy of the scanner.

2. Scanning resolution more than 300 dpi has significant effect on improving the scanner accuracy. This may be due to improving the accuracy of coordinates extraction for the higher scanning resolution.

3. The best scanning resolution, for the tested scanner, is 600 dpi.

4. Investigating the Accuracy of calibrating DTP Scanners Using Mathematical Photogrammetric Data

Mathematical photogrammetric data can be advantageously used for testing of photogrammetric methodologies since in this case error free input data and end results are both known. Testing the photogrammetric methodology, therefore, was carried out by using the mathematically generated blocks of photographs of MATHP software [5]. Out of the various mathematical photogrammetric blocks generated, the block having following specifications was used (Table 3):

The block size consisted of two strips each of 3 photographs. MATHP output consisted of:

1. Camera interior orientation parameters.

2. For each photograph, photo and strip numbers, camera exterior orientation parameters, and photo coordinates of image and fiducial points.

3. Since in each photograph, several points were available, the six Gruber points distribution pattern of control points [8] was used for testing the proposed methodology. In this case, the block contained 17 and 34 control and check points respectively.

4. Ground coordinates of all points.

5. Graphical plots, in DXF file format, to show the format of each photograph depicting the location of points and their numbers. The AutoCAD software was used to print out the generated photographs on high quality HP transparency using inkjet printer.

Table 3. Specifications for the generated mathematical photogrammetric block

a. Photograph scale	: 1:1
b. Camera Format	: 230.0230.0 mm
c. Camera focal length	: 150.00 mm
d. Longitudinal and Lateral overlaps	: 65% and 30% respectively
e. Total number of points available per model	: 18
f. Terrain configuration	: hilly type with height variation of 25% of flying height.

Table 4. RMSE values for ground coordinates of points before and after scanner calibration (using mathematical photogrammetric data)

Scanning Resolution (dpi)	Root Mean Square Error Values for Ground Coordinates(μm)*											
	Before Calibration						After Calibration					
	Control Points			Check Points			Control Points			Check Points		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
300	17.4	16.6	38.8	34.3	29.9	74.7	5.7	6.9	12.8	11.7	11.0	26.5
600	16.8	17.3	35.9	33.0	30.4	72.7	2.9	2.8	3.9	3.8	4.7	8.5
900	16.9	16.7	33.4	32.3	29.6	70.1	3.0	2.6	3.7	3.8	4.2	8.2
1200	16.4	15.5	34.2	32.0	30.1	70.7	2.8	2.2	3.7	3.7	4.2	7.8

* Values at Photo Scale 1:1

Each photograph was scanned using resolutions of 300, 600, 900 and 1200 dpi. Each scanned photograph was calibrated using the previously generated calibration files of the same scanning resolution to compute the calibrated scanned x and y coordinates in pixels of each image point.

The calibrated scanned coordinates along with the available mathematical photogrammetric data, were then processed by PHOTOMAP software [5], Bundle Adjustment module, for computing the ground coordinates of the control and check points. Values of RMSE at control and check points before and after calibration were, then, obtained and tabulated in Table 4.

The following conclusions can be drawn from Table 4:

1. The developed calibration method improves the geometric accuracy of the tested scanner. It improves the RMSE values at the check points of about 81% and 83% in horizontal and vertical directions respectively.

2. Using resolution of 600 dpi improves the values of RMSE of about 62% and 68% in horizontal and vertical directions respectively than using resolution of 300 dpi.

3. The use of 1200 dpi resolution as opposed to that of 600 dpi resolution generates improvements in horizontal RMSE values of about 7% and 8% in vertical RMSE values.

5. Investigating the Accuracy of Calibrating DTP Scanners Using Actual Photogrammetric Data

A pair of stereo B/W diapositives of Canton de Vaud, Switzerland [5] was used to investigate the accuracy of DTP scanner. The height difference in the area is about 78.00 m and mean terrain altitude is 620.00 m above the mean sea level. The aerial photographs were taken by Wild Avioplot RC10 Automatic Camera System of Echallens of wide angle coverage on a 23×23 cm format at 1280.00 m height with focal length 153.18 mm lens, as a result, the average photo scale is about 1:4300. The camera calibration data such as calibrated focal length, calibrated fiducial marks and radial lens distortion are available. The area contains 16 well-distributed and identified control points. The control point numbers, ground coordinates and standard errors are also available. Seven patterns of control points [5] as shown in Figure 1 were chosen in order to compare the photogrammetrically extracted data coordinates with the corresponding ground survey values at check points.

Conventional method of the coordinates measurement of image points was carried out [5] on the stereo comparator of Aviolyt BC2, Leica, Switzerland, having a least count of 1 μm .

Each photograph of the stereo pair was scanned using resolution of 300, 600, 900 and 1200 dpi and calibrated using the previously generated calibration files as explained earlier. Computation of the corrected photo coordinates from the calibrated scanned coordinates consisted of two dimensional affine transformation and correcting camera lens distortion ([5,6,7,8]).

For each pattern of the distribution of control points, the photo coordinates of the control and check points after due corrections along with ground coordinates of control points and their a priori standard errors were processed in the PHOTOMAP, BUNDLE Adjustment module. The unknowns to be estimated were the six exterior orientation parameters of each of the two photographs and the ground coordinates of the control and check points. In order to present the results, RMSE values for ground coordinates of check points were obtained and tabulated in Table 5.

Table 5. RMSE values for ground coordinates of check points (using actual photogrammetric data)

Control Pattern	Root Mean Square Error Values for Ground Coordinates (cm)														
	Using Analytical Plotter [5]			Scanning Resolution											
				300 dpi (85 μm)			600 dpi (42 μm)			900 dpi (28 μm)			1200 dpi (21 μm)		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
3	5.6	6.3	17.2	17.2	16.7	46.7	10.6	9.9	29.1	9.7	9.1	26.4	7.7	8.1	23.4
4	6.4	5.4	11.1	16.8	14.8	46.6	9.6	8.8	19.2	8.6	8.1	17.8	7.8	7.2	15.2
5	5.8	5.4	10.6	15.5	13.5	42.8	9.2	8.8	17.8	8.4	8.2	16.6	7.5	7.2	14.1
6A	5.9	5.5	9.9	14.9	13.2	41.6	9.8	8.7	16.6	8.9	7.9	15.6	8.0	7.1	13.1
6B	5.1	5.4	9.5	14.3	13.0	40.8	8.8	8.4	15.9	8.0	7.7	14.6	7.2	6.9	12.5
9	5.0	4.6	9.0	14.0	12.9	39.7	9.4	8.3	15.6	8.7	7.6	14.1	8.0	6.8	12.2
12	4.9	4.6	8.7	13.6	13.2	39.1	7.9	8.4	14.6	7.2	7.8	13.1	6.4	6.1	11.4

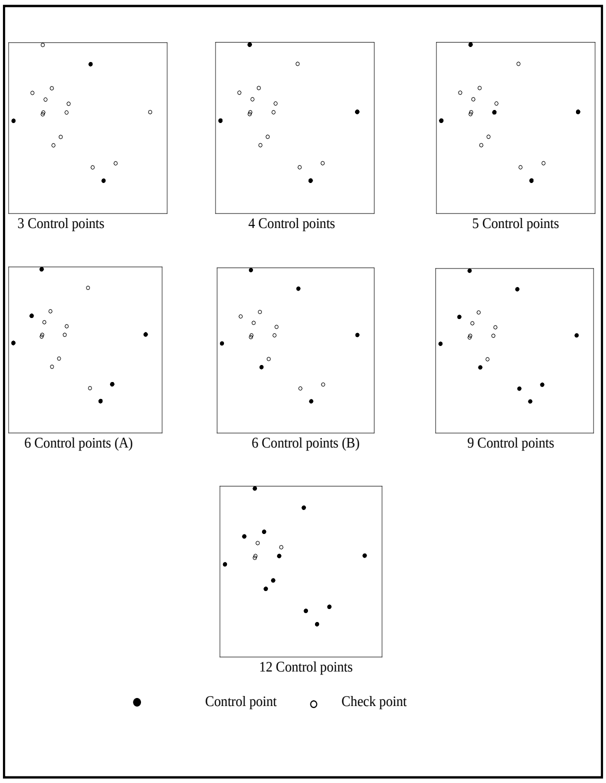

Figure 1. Control Points Patterns [5]

From Table 5, it can be concluded that:

1. Increasing the number of control points improves the obtained accuracies.

2. Using more than three control points significantly reduces the RMSE values especially for Z coordinates.

3. Using different control distribution patterns, for the same number of control points has an effect on the obtained RMSE values. This is evident from the comparison of RMSE values of 6A and 6B control distribution patterns. Furthermore, using 6B distribution pattern gives smaller RMSE values for planimetry and height than 6A distribution pattern.

4. The use of low-cost DTP scanner for conventional aerial photography as opposed to the use of Leica BC2 analytical plotter increases the horizontal RMSE values of about 35% and 43% in vertical RMSE values when using 1200 dpi scanning resolution.

5. Using 42 μm per pixel (600dpi) resolution improves the RMSE values of about 38% and 57% in horizontal and vertical directions respectively than using 85 μm per pixel (300dpi) resolution.

6. The use of 21 μm per pixel (1200dpi) resolution improves the RMSE values of about 19% and 21% in horizontal and vertical directions respectively than those of using 42 μm per pixel (600dpi) resolution.

7. Moreover, the obtained RMSE values in Table 5 were compared with the permissible limits according to the specifications of ASPRS (American Society for Photogrammetry and Remote Sensing) [2] as tabulated in Table 6 and Table 7.

From Table 5, Table 6 and Table 7 and taking into account only the specifications for the highest accuracy (Class I Maps) it can be seen for scanning resolution of more than 300 dpi that:

1. The obtained accuracies for elevations are suitable for generating contour maps of 2m or larger contour intervals.

2. Generating contour map of 1m contour interval requires using 4 control points or more.

3. All accuracies for elevations are not suitable for generating contour map of 0.5 m contour interval.

4. The Planimetric accuracy is suitable for generating maps of scale 1:500 or smaller.

Table 6. ASPRS topographic elevation accuracy requirement for well-defined points

Contour Interval in Meters	ASPRS Limiting Root Mean Square Error in Meters Spot or Digital Terrain Model Elevation Points		
	Class I*	Class II	Class III
0.5	0.08	0.16	0.25
1.0	0.17	0.33	0.5
2.0	0.33	0.67	1.0
4.0	0.67	1.33	2.0
5.0	0.83	1.67	2.5

* The maps are divided into three classes:
Class I: holds the highest accuracies. Site plans for construction fit this category.
Class II: has half the overall accuracy of Class I. Typical projects may include excavation, road grading, or disposal operations.
Class III: has one third the accuracy or three times the allowable error of Class I maps. Large area cadastral, city planning, or land classification maps are typically in this category.

Table 7. ASPRS planimetric coordinate accuracy requirement for well-defined points (Class I maps)

Planimetric (X or Y) Accuracy (limiting RMSE in Meters)	Typical Map Scale
0.0125	1:50
0.025	1:100
0.050	1:200
0.125	1:500
0.25	1: 1,000
0.50	1:2,000
1.00	1:4,00
1.25	1:5,000
2.50	1:10,000
5.00	1:20,000

6. Summary and Conclusions

Scanners are an essential part of digital photogrammetric systems for digitizing aerial images for deriving Digital Terrain Model (DTM), orthoimages, and digital maps. A new trend is the use of digital or orthoimages for generation and updating of databases, generation of orthoimages maps, integration with other raster and vector data and visualization.

Scanners can be classified as Photogrammetric Quality Scanners or Photogrammetric Scanners and Low cost DTP Scanners. Photogrammetric Scanners are able to produce a geometric accuracy of 2-5 μm (for high accuracy applications) typically at resolution up to and over 2000 dpi. These scanners start at a price of about $45,000 US. Low cost DTP Scanners is used typically for house hold use and its price is $80 - $300US. Low cost DTP scanners have been developed for applications totally different from the photogrammetric ones. However, since they constitute the largest sector in the scanner market, they are subjected to rapid development and improvements.

Low cost DTP scanners have geometric accuracy of about 40 μm and usually even higher. This accuracy may be sufficient to be used in GIS-related applications. Improvements on this topic will drastically increase the range of their applications to include photogrammetric applications.

This study emphasizes on testing the suitability of low cost DTP scanners for aerial photogrammetric applications. It involves the following:

1. Testing the geometric accuracy and performing geometric calibration of DTP scanners: The author of this paper developed user-friendly software called ScanCal which has significant effect on improving the geometric accuracy values of the tested scanner from 30-37 μm to 3-4 μm.

2. Investigating the accuracy of calibrating DTP scanners using mathematical photogrammetric data: Mathematical photogrammetric data is widely used for testing of photogrammetric methodologies since in this case error free input data and end results are both known. Testing the photogrammetric methodology, therefore, was carried out by using the mathematically generated blocks of photographs of MATHP software. Each photograph was scanned using different resolutions and calibrated to compute the calibrated scanned x and y coordinates in pixels of each image point. The calibrated scanned coordinates along with the available mathematical photogrammetric data, were then processed by PHOTOMAP software for computing the ground coordinates of the control and check points. Values of RMSE of ground coordinates at control and check points before and after calibration were, then, obtained based on the obtained and error free values of ground coordinates. The results shows that calibration of DTP scanners improves the RMSE values of the photogrammetric solution by about 81% and 83% in horizontal and vertical directions respectively. These values of RMSE open the door-way for using low cost DTP scanners for photogrammetric applications.

3. Investigating the accuracy of calibrating DTP scanners using actual photogrammetric data: The actual photogrammetric data consisted of a pair of stereo B/W diapositives of Canton de Vaud, Switzerland with the camera calibration data such as calibrated focal length, calibrated fiducial marks and radial lens distortion. The ground coordinates and standard errors of the control points in the photographed area were also available. Seven patterns of control points were chosen in order to compare the photogrammetrically extracted data coordinates with the corresponding ground survey values at check points. Conventional method of the coordinates measurement of image points was carried out on the stereo comparator of Aviolyt BC2, Leica, Switzerland, having a least count of 1 μm. Each photograph of the stereo pair was scanned using different resolutions and calibrated using the previously generated calibration files as explained earlier. For each pattern of the distribution of control points, the

scanned photo coordinates, or measured photo coordinates in case of using analytical plotter measurements, of the control and check points after due corrections along with ground coordinates of control points and their a priori standard errors were processed in the PHOTOMAP software to obtain the ground coordinates of the check points. In order to present the results, RMSE values for ground coordinates of check points were obtained based on the computed and known ground coordinate values of points.The actual photogrammetric data proofs that the use of low-cost DTP scanner for conventional aerial photography as opposed to the use of Leica BC2 analytical plotter increases the horizontal RMSE values of about 35% and 43% in vertical RMSE values when using 1200 dpi scanning resolution. The use of 42 μm per pixel resolutions improves the RMSE values of about 38% and 57% in horizontal and vertical directions respectively than using 85 μm per pixel resolution. Furthermore, the use of 21 μm per pixel (1200dpi) resolution improves the RMSE values of about 19% and 21% in horizontal and vertical directions respectively than those of using 42 μm per pixel (600dpi) resolution.

The obtained accuracies in horizontal and vertical directions allow the generation of planimetric maps at a scale of 1:500 or smaller and topographic maps with a contour interval of around 1 m or larger. This methodology is of great interest to small engineering firms for the generation of local area maps.

However, the results obtained in this study are encouraging and show the possibility of using low cost DTP scanners for photogrammetric applications especially large scale mapping. Researches have to be continued for increasing the accuracy of DTP scanners and reducing the need for costly photogrammetric scanners which may be unavailable for all academic centers, universities or firms.

This paper shows the necessity for the mathematical photogrammetric data for testing the photogrammetric methods and softwares.

References

[1] Abed, R. S., "Photogrammetric Precision of a Desktop Scanner," Al-Rafidain Engineering Journal, Vol 18, No 1, pp 43-50. 2010.

[2] American Society for Photogrammetry and Remote Sensing (ASPRS), ASPRS Accuracy Standards for Large-Scale Maps, USA, 1993.

[3] Baltsavias, E. P., and Waegli, B., "Quality Analysis and Calibration of DTP Scanners," in the 18 ISPRS Congress, 9-14 July, Vienna, Austria, In IAPRS, Vol. 31, Part B1, pp. 13-19. 1996.

[4] Baltsavias, E. P., "Photogrammetric Scanners – Survey, Technological Developments and Requirements," in the ISPRS Comm. I Symposium, 25-27 February, Bangalore, India. In IAPRS, Vol. 32, Part 1, pp. 44-52. 1998.

[5] El-Ashmawy, K., (1999). A Cost-Effective Photogrammetric System for Engineering Applications .Ph.D. Thesis, Department of Civil Engineering, University of Roorkee, Roorkee, India.

[6] El-Ashmawy, K., and Azeez, A. B., "Generation of Mathematical Digital Terrain Model (DTM) Data for Testing DTM Generation Methodologies," Eng. Res. Jour., Faculty of Eng., Matria, Helwan University, Cairo, Egypt, Vol. 95. 2005.

[7] El-Ashmawy, K., "Testing and Correcting the Geometric Errors of Low Cost Desktop Publishing (DTP) Scanners," Civil Engineering Research Magazine, Faculty of Engineering, Al-Azhar University, Egypt, Vol 28, No 1, pp 379-398. 2006.

[8] Ghosh, S. K., Fundamentals of Computational Photogrammetry, Concept Publishing Company, New Delhi, India, 2005.

[9] Golden Software, SURFER Version 11: Reference Manual, Golden Software, Inc., Golden, Colorado, U.S.A, 2012.

[10] Mikhail, E.M., Bethel, J.S., and McGlone, J.C., Introduction to Modern Photogrammetry, John Wiley & Sons, New York, U.S.A., 2001.

[11] Omura, G. and Graham, R., Mastering AutoCAD 2012 and AutoCAD LT 2012, SYPEX Inc., 1151 Marina Village Parkway, Alameda, CA 9450, 2011.