GEOMETRIC PRECISION OF SCANNED IMAGERY FOR PRODUCTION PHOTOGRAMMETRY

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ABSTRACT:

Little research has been performed to determine the quantitative effects of the geometric imprecision of scanned photographs in a photogrammetric production setting. While photogrammetric scanners are most commonly used to scan aerial photographs, desktop and graphic design scanners have also been applied. It is recognized that the precision of non-photogrammetric scanners is highly variable and their errors larger than those of photogrammetric units, but these values have seldom been quantified. In addition, the practical effect of these errors upon the photogrammetric solution has not received much study.

A precision calibration plate was repeatedly scanned on photogrammetric and non-photogrammetric scanners to determine the variability and magnitude of errors. These errors were plotted spatially to illustrate the inherent instability of non-photogrammetric scanners. These models of scan accuracy were then used to determine the effects of the random scan errors in a photogrammetric production environment. While appropriate for qualitative uses, ultimately it was observed that the characteristic unpredictability of the errors rendered this imagery unsuitable for quantitative applications.

During the investigation a significant degree of consistency was observed in the non-photogrammetric scanners, i.e. the errors, though large, included a systematic component that did not vary through time and changing conditions. Therefore a small block was scanned in such a scanner and the imagery re-sampled using the calibration parameters. The results were compared with those obtained from the same block scanned in a photogrammetric scanner.

1 INTRODUCTION

With the introduction of airborne digital sensors, much attention has shifted away from traditional means of image capture. However, at this point only a very small percentage of airborne imagery is collected from digital sensors with the overwhelming majority of images being subjected to the conventional softcopy methods of data processing. Images are collected with a metric aerial camera, processed, and converted to digital format on a film transparency scanner for use in photogrammetric production.

The choice of film scanner is critical since any errors introduced during scanning will be carried through the photogrammetric workflow and can negatively influence the results obtained during aerial triangulation, Digital Terrain Model (DTM) extraction and registration of the rectified imagery to existing datasets.

1.1 Justification of Study

A distinction should be made between photogrammetric (PG) scanners and non-photogrammetric (NPG) scanners in the market. PG scanners typically meet very robust standards in terms of the optical alignment, throughput capability and the accuracy of analog image conversion to digital form. NPG scanners are available at a fraction of the cost of PG units, and this has led to their periodic use in photogrammetric production. While NPG scanners are typically able to produce imagery of high radiometric quality, uncertainty remains regarding the ability to consistency produce digital imagery of high reliability. There is no mechanism to calibrate the movement of the scanner stage / sensor line and therefore no quantitative values exist to the appropriateness of the imagery for photogrammetric measurement.

The purpose of this paper is to explore and compare the achievable precision of imagery scanned on PG and NPG film scanners. Should the results show markedly different results between the units tested, the quantification of attainable precision may serve to preclude the use of NPG scanners in photogrammetric work. In an effort to establish the precision of both PG and NPG scanners, a fixed methodology was established.

1.2 Research Design

There are three types of error: systematic, random and egregious. Of the three, only the distinction between systematic and random errors was focused upon.
Due the nature of systematic errors, they are less problematic since they can be compensated for through calibration. A

consistent pattern and magnitude of error can be modelled into a spatially reference calibration applied to each image collected on the scanner.

Random errors are those that do not follow any discernable pattern and therefore may not be removed through a traditional calibration procedure. If the magnitude of the random error is small, it should not affect the reliability of the imagery for photogrammetric use, however, should this error be large and show a high variability it may not be suitable.

2 METHODS

2.1 Data Collection

The analysis began through repeated scans of a precision grid plate. The plate was constructed of BK-7 optical glass and was etched with eighteen horizontal and vertical lines at a spacing of twenty millimetres covering an area 260 mm squared. This created a grid pattern with 324 grid intersections. The plate was scanned ten times on both a PG (Leica Geosystems DSW600 Photogrammetric scanner) and a NPG scanner ($10,000 US high performance graphic arts scanner – manufacturer name withheld), with no wait period or delay between scans. This was performed to establish the precision of scans collected in quick succession. The images were collected at 12.5 µm (2032 DPI) and consisted of only one image band. Once completed, the intersections in each scanned image were compared to the expected calibrated intersection locations and X and Y-axis error values calculated.

2.2 Data Analysis

In an effort to determine whether a systematic pattern of error or one that was largely random existed, both global summary and local analyses of error were performed.

Summary statistics were calculated, including average error, standard deviation, minimum error, maximum error, skewness and kurtosis. The first four metrics provide an indication of the magnitude and variability of error. The latter two offer a sense of how well the errors follow the predicted normal distribution of random errors. To further test for a systematic pattern in error, a more detailed analysis was performed. The errors within the first scan from each scanner were used as an empirical calibration. The X and Y-axis errors from this scan were subtracted from the corollary intersection error in each subsequent scan. If the residual values showed a significant reduction in magnitude, this would imply that the film scanner in question is capable of supporting some degree of calibration to control error.

In addition to summary statistics, the X and Y-axis errors were plotted spatially to identify any regional trends in the error patterns. For each dataset, a standard deviation value based upon the ten scans, was determined for both X and Y-axis error at each grid intersection. These values were interpolated to model a contiguous surface for visualization of error variability

3 RESULTS

3.1 Results of Global Error Analysis

Summary error information is presented in Table 1. While the mean error for both NPG and PG scanners deviates little from zero, there are clear distinctions between the standard deviation (sigma) values. The PG scanners produced sigma values that were less than 0.07 pixels showing a strong central tendency. The NPG units showed much higher sigma, with 0.77 and 1.13 pixels respectively for the X and Y-axes. The large sigma values demonstrate a strong variability of error in the NPG scans.

	NPG X Axis Error	NPG Y Axis Error	PG X Axis Error	PG Y Axis Error
Mean	-2.70261E-08	-3.78701E-09	3.00821E-09	-1.67563E-09
Std Dev	0.774339714	1.138940972	0.06837934	0.066504326
Skew	-0.343904154	-0.515024721	0.019562816	-0.045172838
Kurt	0.46377147	-0.187309652	0.900246728	0.782021849
Min	-2.66069	-3.68723	-0.24816	-0.242151
Max	2.22324	2.72777	0.31695	0.280056
Range	4.88393	6.415	0.56511	0.522207

Table 1 – Summary Error Statistics (in pixels) for PG and NPG scanners

The absolute range of values was also markedly higher on the NPG scanner than the PG unit, showing a higher degree of variance in both magnitude and algebraic sign of error. As mentioned earlier, in an effort to quantify how much of the error was due to systematic sources, an empirical calibration was used. The errors from the first scan performed on each scanner tested were subtracted from each of the nine remaining scans. The results are presented in Table 2.

	NPG X Axis Error	NPG Y Axis Error	PG X Axis Error	PG Y Axis Error
Mean	-3.68627E-08	2.61438E-10	7.32449E-10	-9.59827E-10
Std Dev	0.375661004	1.042602416	0.040442633	0.040098813
Skew	2.314461622	-0.368984042	0.051477459	0.192260271
Kurt	7.936765987	0.174791663	0.305202294	1.145695749
Min	-0.690781	-3.68723	-0.1398593	-0.140139405
Max	2.22324	2.5712	0.1503055	0.193613
Range	2.914021	6.25843	0.2901648	0.333752405

Table 2 – Summary Error Statistics (in pixels) following calibration, for PG and NPG scanners

Following calibration, the scans from the NPG unit showed only modest reduction in errors and still maintained an unacceptably high overall error. Interestingly, the NPG X axis errors appear to have been affected to a greater degree than the Y-axis errors. The Kurtosis value for NPG X axis rose dramatically, indicating a very strong peaked distribution, where before calibration the kurtosis was only very moderately positive. It would appear that calibration was effective at removing some systematic error from NPG scanners but the magnitude of the remaining error continues to preclude their use in photogrammetric production. The photogrammetric unit also saw a reduction in error following calibration, indicating that some of the error was systematic in nature. Consistently before and after calibration, the PG unit performed at precision levels approximately ten times better than the NPG unit.

3.2 Results of Spatial Error Analysis

A global error analysis provided an indication of the overall pattern of error and the errors were also plotted to identify any spatially influence on the error. A sigma surface for the ten scans from each scanner was generated and presented in Figures 1 and 2.

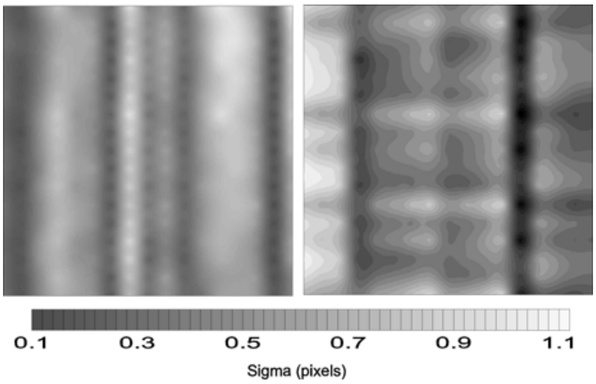

Figure 1 – Spatially plotted Standard Deviation from NPG X axis (left) and NPG Y axis (right) errors

The error sigma surfaces for the NPG scanner show strong linear spatial patterns for both X and Y. Within very short distances in the scan, a high variability of error is seen in both axes.

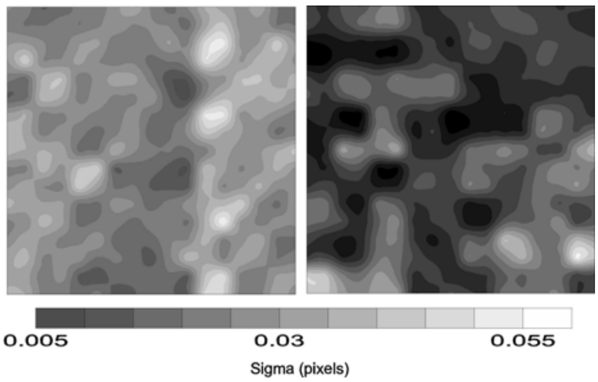

Figure 2 – Spatially plotted Standard Deviation from PG X axis (left) and PG Y axis (right) errors

In contrast, the spatially plotted standard deviation values from the PG scanner show a largely random pattern. On interest is the difference in scale between Figure 1 and Figure 2. The PG scanner produces scans with error sigma values approximately ten percent of the magnitude of those from the NPG scanner. There does not appear to be a systematic pattern to the error, qualitatively indicating that the errors are random in nature.

After applying the empirical calibration, another set of spatial sigma surfaces were produced. Figure 3 shows the effects of the calibration upon the NPG scanned imagery. Similar systematic patterns remain, indicating that the pattern is not a simple linear one and is not consistent between captures from the NPG scanner.

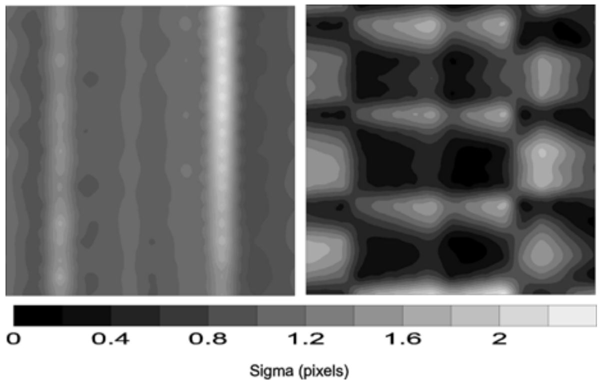

Figure 3 – Spatially plotted Standard Deviation from NPG X axis (left) and NPG Y axis (right) errors after empirical calibration

After calibration of the PG imagery (Figure 4), the pattern remains very similar and largely unchanged. This implies that little similarity of error exists from one frame to the next for correction. Again, it is seen that the magnitude of errors is approximately one tenth of those from the NPG scanner.

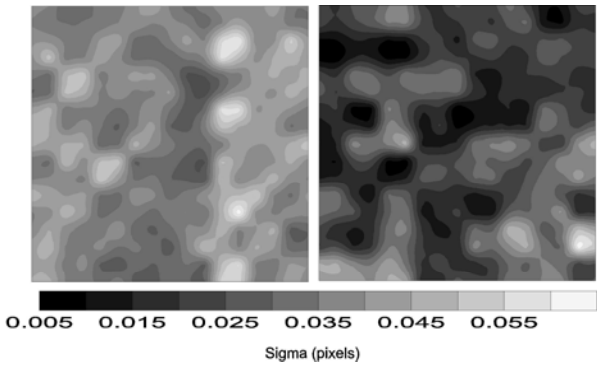

Figure 4 – Spatially plotted Standard Deviation from PG X axis (left) and PG Y axis (right) errors after empirical calibration

4 SUMMARY

Following analysis of the global and spatial error patterns, it is clearly not appropriate for NPG imagery to be used in photogrammetric mensuration. The summary of statistics provided information regarding the large magnitude of error variation as well as the large absolute range of errors. Deviations of one pixel or larger are routinely seen and these errors would propagate through the photogrammetric workflow. Individual error spikes were seen up to 3.5 pixels and would not only influence interior orientation but would also lead to unacceptably high RMSE values during aerial triangulation and negatively affect the accuracy of any photogrammetrically derived product.

Attempts to calibrate the NPG data empirically only saw limited success with a modest reduction in the range of errors. Large, multi-pixel errors still remain, as evidenced by the high sigma values.

Conversely, the PG data habitually only produced small, random errors with a range of approximately 0.5 pixels. The resulting small sigma value is typical of a tightly clustered error pattern and one that is predictable and may be calibrated.

It is therefore advisable that any use of NPG scanners, including high performance graphic arts units, be limited to work only requiring qualitative products. There use in producing photogrammetric products is strongly cautioned and quantified in this paper.