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REQUIREMENTS OF A SYSTEM TO ANALYZE FILM SCANNERS

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ABSTRACT

This paper proposes a system to analyze scanners, in particular high performance film scanners. We describe the requirements and present tools consisting of test targets, algorithms and procedures for objective operator independent and comparable scanner evaluation. The applicability of the suggested tools for scanner evaluation has been tested on different scanners; however, in the interest of brevity we illustrate only a few of the proposed concepts.

1. INTRODUCTION

We discuss the different properties of a film scanner which need to be considered in an assessment of quality. Geometric resolution, geometric accuracy, radiometric resolution, color reproduction and sustained throughput and scanning speed are topics which one has to take into account.

Our goal was to create a portable system for scanner evaluation based on test targets (e.g. Simonis,1991), algorithms and procedures which give us adequate tools for testing the performance of various types of scanners, but in particular high performance film scanners (e.g. photogrammetric scanners) in an objective manner which is independent of the operator of the device.

We begin with a discussion of scanner characteristics of interest in work with photogrammetric materials. As we review these characteristics we point to useful test material which is customarily being used in an assessment.

We propose certain measurements and analysis methods by which specific elements of a scanner's performance can be quantified. Specific algorithms for scanner evaluation have been implemented, but only a few are beeing illustrated here. We believe that we can demonstrate that our proposed process satisfies the requirements one may pose on a useful and reliable scanner performance test.

2. GEOMETRIC RESOLUTION

2.1 Background

The geometric resolution of a scanner refers to its ability to reproduce fine details from the scanned original document in the digital file. The geometric imaging resolution of analog film usually is specified in lp/mm (linepairs/mm), whereas a digital image's resolution is given in dpi (dots per inch) or micrometer per pixel. Resolutions between 100 dpi (low level) and 3000 dpi (high performance) are commonly used in photogrammetry, and may go to 5000 dpi in the graphic arts.

The geometric resolution can be measured by use of resolution targets under specific test conditions. For our tests we propose to use the United States Air Force (USAF) resolution target (Figure 1). While this resolution target is a standard to assess geometric resolution of analog photography, it lends itself also to determine scanner resolutions.

To investigate the scanner the USAF target needs to be scanned with a set of desired geometric resolutions at given pixel sizes. The digitized image can be evaluated visually on a computer screen or by help of image processing algorithms. One element from the test target is resolved if every three lines of the two patterns at right angles to each other can be resolved unambiguously. Since the target contains two right-angled patterns of every element one can determine geometric resolutions separately in two different directions.

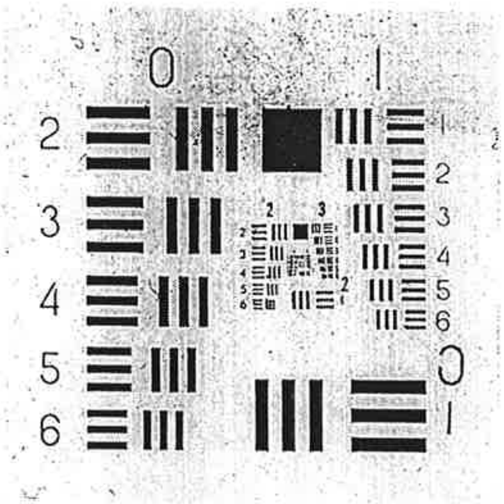

Figure 1: The USAF Target.

The use of line patterns for the determination of geometric resolutions has shown that one line-pair generally cannot be resolved by two pixels (Kell, 1940, Doyle, 1982, Trinder, 1987). It depends on the phasing of the sampling points whether it is possible to resolve the lines or not. Practical investigations by various authors show that 2.5 - 3.2 pixels are necessary to resolve one line-pair. The factor proposed by Kell (1940) suggests that 2.8 pixel/lp are needed; this is the factor often employed in the photogrammetric literature.

When using a resolution target the results depend on its contrast. Therefore it is necessary to use a high contrast test target for determining the maximum resolution; a separate issue is of course the effect on geometric resolution obtained from a reduced contrast, and of using pixels with various radiometric resolutions (Bits per pixel).

2.2 Visual Inspection

Visual inspection of the digitized target image on a computer screen can provide an estimate of the maximum geometric resolution of a scanner. It is useful to employ a zoom function and to create a gray-value profile across the digital pixel array. However, the visual analysis of magnified bars on a computer monitor, as well as the study of the gray-value profile is rather subjective and different observers may come to different conclusions (see Figure 2).

2.3 Resolution Determination by Algorithm

To guarantee full observer independence resolution needs to be determined by standardized image processing algorithms. These used to deliver the maximum geometric resolution of a scan. Such algorithms need to rely on suitable test targets which can be meaningfully processed.

2.3.1 Detection of resolved resolution

A possible procedure consists of the following elements:

(i) Scanning of the USAF target with the maximum (or desired other) scanner resolution.

(ii) Determine the position of the USAF target in the scanned image for further investigations.

(iii) The exact position of every USAF target resolving element is given by the well known geometric proportions of the elements to each other.

(iv) Evaluation of the gray value profile through each resolving element; to consider a 3 line pattern as "resolved" the profile must consist of exactly 3 significant local minima (3 lines) and 2 local maxima (spaces of equal width) between them. Two 3 line patterns, at right angles to each other have to be resolved for every resolving element.

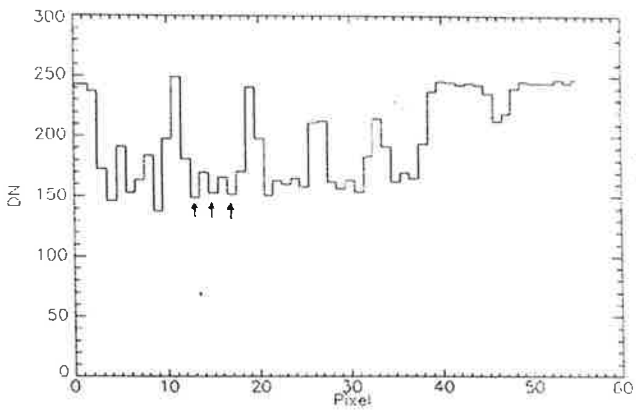

Figure 2: Example of a gray-value profile through 5 resolution elements in the USAF target obtained with a pixel size of 21 mm (1200 dpi). Visual inspection may suggest that 18.3 lp/mm are still being resolved, leading to a relationship of 2.6 pixels per lp.

2.3.2 Modulation Transfer Function

When discretely sampling analog materials one traditionally has presented the geometric effects by means of modulation transfer functions (MTF). We compute the MTF by investigating the response of the scanned USAF target at increasing frequencies by help of the gray value profiles belonging to the different 3 line resolution elements. Bethel (1994) recently investigated the MTF of a photogrammetric scanner.

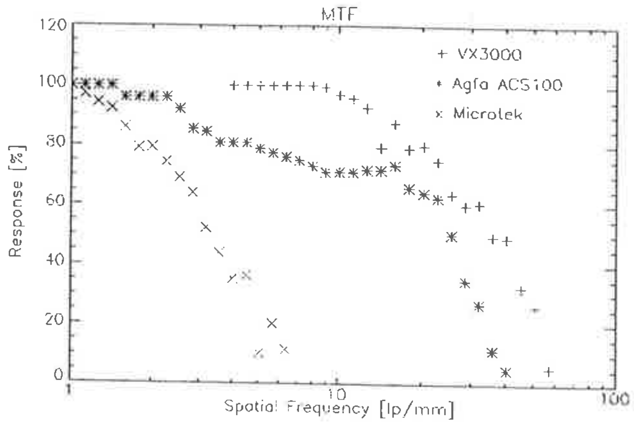

Figure 3: MTF illustrated for 3 different scanners: Vexcel VX 3000 at 3000 dpi, Agfa ACS100 at 2400 dpi, Microtek ScanMaker at 600 dpi scanning resolution

3. Geometric Accuracy

3.1 Background

The assessment of the point-to-point global and local geometric accuracy of a scanner requires use of a large geometric accuracy target. (e.g. 23 cm x 23 cm) The geometric accuracy target contains symmetric measuring marks distributed over the whole area with well-defined center positions and distances between any two targets.

Measuring the marks in a digitized version of the image produces an estimate of local and global geometric performance of the scanning system.

"Local" geometric accuracy is that which is measured by means of marks in a relatively small area (e.g. 2 cm x 2 cm). "Global" geometric accuracy is measured across the entire scanning area (e.g. 23 cm x 23 cm). The absolute error is expressed in pixels or mm. Relative accuracy is obtained by relating the error of a distance between 2 marks to the distance itself.

Repeatability can be assessed by rescanning the same target.

3.2 Design of the Target

The target may have different densities of the marks: the entire area may be covered by marks at a spacing of 1 cm, and one or more of the 1 cm x 1 cm meshes may include additional marks at a spacing of 2 mm.

Preferably the target would be available on a glass plate to avoid sensitivity to changes in temperature. However, many scanners are unable to cope with glass plates. Therefore a film-based target will need to be available. A five degree change in temperature can cause a change in length of 12 μm over a distance of 25.4 cm (Wolber, 1991). The marks ought to be symmetric (circles, squares, cross-hair) and their coordinates need to be measured on a precision instrument, e.g. an analytical photogrammetric plotter.

Generally, however, the shape of a measuring mark should depend on the type of evaluation process. The circular mark is better suited when the evaluation is by matching using a centering algorithm. The more common cross-hair is perhaps desired for manual assessments. Circular dots can be easily produced, for example in a photogrammetric point transfer device. It is important for evaluation by an algorithm to ensure high contrast so that the measuring marks are distinct from the background.

3.3 Visual Analysis

The center of a digitized mark has to be found visually by placing a cursor at the desired location of the mark. This requires the availability of a zooming function to find the mark with sub-pixel accuracy. The geometric accuracy of the scanner is then obtained from computations comparing the measured positions of digitized marks with those known on the analog original.

3.4 Analysis by Algorithm

The center of circular digital dots can be found with subpixel accuracy by means of simple center finding algorithms (e.g. Trinder, 1989). Manual centering can lead to an error in the center position depending on the target's diameter (e. g. Trinder 1984). Machine-centering will be accurate as a function of pixel size, not as a function of the target's diameter (Förstner, 1982). Therefore we will prefer machine centering since it is of higher accuracy, independent of the operator's skill and of the exact diameter of the targets. Finally, of course, it will also be faster to center by machine than to accomplish this by hand.

3.5 Comparing the Accuracy

The coordinates on the analog medium present a 2-d point cloud(') with index, and the measurements on the digital file are a second point cloud (") with index. The two sets of points need to be compared.

This invariably follows a linear conformal transformation of points (") into the system of points ('). Residual differences Δx and Δy in x- and y-directions will be found in the transformed points and can now be used to calculate absolute, relative, local and global values of accuracy.

One may encounter difficulties in dealing with large data quantities at very high resolution, say at 3000 x 5000 dpi, over large formats of 25 cm x 25 cm, or 25 cm x 50 cm. These can be overcome by studying geometric errors along profiles in x- or y-direction only. Instead of assessing the geometry across the entire format in one single effort, such assessment is in many separate steps.

4. RADIOMETRIC RESOLUTION AND RANGE

4.1 Background

Manufacturers usually report a scanner's radiometric capabilities by means of using either 8 or 12 bits per pixel, and by statements about the density range. But the real radiometric resolution is limited by the noise produced by the scanner system. Noise produces an uncertainty in the digitized gray value for a particular gray value of the original analog image. Noise can be expressed as the standard deviation of the fluctuation of the gray values. For a scanner system using CCD technology sources of noise are the CCD (Janesick, 1987), the CCD's readout electronics, the A/D converter and the light source.

When scanning photographic film the noise caused by the graininess of the film has also to be taken into account. In the digitization process noise of the photographic film can affect both the geometric and radiometric resolution (Almroth, 1985).

Noise and density range are very important factors in digitizing images, particularly when high quality photography is an issue, as is the case in the graphic arts. Information theory leads one to conclude that the measurement of a certain quantity (gray value) makes only sense if the quantization steps with which the measurements are taken are larger than the noise in the "quantity", i.e. the noise produced by the scanner and film.

4.4 Evaluation of a Scanner's Density Range

The resolved density range (dynamic range) of a scanner can be evaluated by means of a standardized gray wedge. It features progressively denser regions. Optical density increases in defined steps from a minimum to a maximum density. The different density steps of the gray wedge correspond to gray levels that can be found in real images. For our purposes it would be suitable to use a gray wedge with a linear scale but most of the currently available wedges use a logarithmic scale.

We use the Kodak SR37 (Q61) gray wedge (0.0 D - 1.8 D, opaque) and the Kodak ST 34 (Q59) gray wedge (0.0 D - 3.4 D, transparent).

4.5 Noise Evaluation

An investigation of noise produced by the scanning process can rely on a gray wedge to study noise at different levels between minimum and maximum density. Of course if we use a gray wedge for noise evaluation we have to consider that the gray wedge itself contributes to the noise measured in the scanning system. This noise part can be neglected if the granularity of the gray wedge is very small.

The following describes two different methods for scanner system noise evaluation.

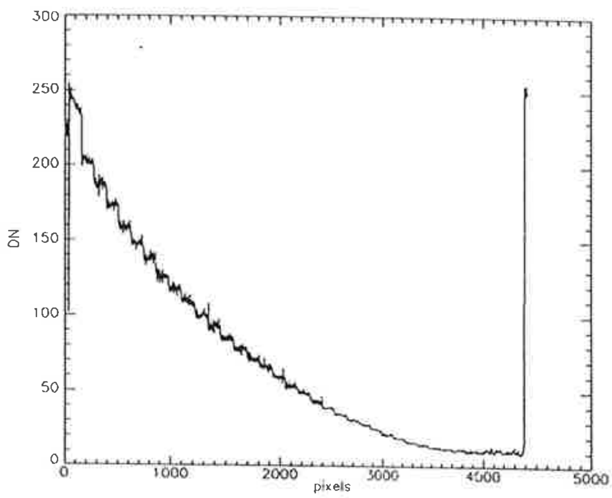

Figure 4: Gray value profile through the Q61 gray wedge obtained from the Agfa ACS 100 scanner. One gray wedge step corresponds to a change in density of 0.1D.

4.5.1 Scanning the Gray Wedge Once

The gray wedge is digitized at a specified geometric resolution. When digitizing a specific density step of the gray wedge we obtain a gray zone with the corresponding digital numbers. Noise can be computed as a standard deviation within a pixel matrix (e.g. 60 x 60 pixels) in every gray zone. We expect that the noise in light areas produced by the CCD (shot noise + read noise) be larger than at dark areas.

For scanners using CCD technology this method does not reveal the source of certain noise in the pixels which may be non-uniform; lens properties (zoom lens) and ligthing inhomogeneties may cause an effect perceived as "noise". The advantage of this method is, however, that only one scan of the gray wedge is needed, and it certainly is sufficient for a system test of a scanner. If a scanner operator is interested in calibrating a device, then the sources of noise may need to be separately investigated.

4.5.2 Multiple Scans of the Gray Wedge

The gray wedge is digitized at a specified resolution on the same position multiple times (at least 20 times) for good statistical results. For computation of a standard deviation and mean value we have to look at exactly the same pixel in every scanned gray wedge image. The noise now is expressed as a standard deviation for one pixel computed from the multiple images. The standard deviations at every pixel position are stored in an array which has the same dimensions as the gray wedge image has. Additional statistical results may be obtained over the matrix of standard deviations for the different gray zones. So every mean value delivers the measured noise at the specified gray value.

This method produces noise values at each pixel clean of effects due to lens properties, lighting inhomogeneties or variations in adjacent pixels.

4.6 Density, Intensity, Digital Numbers

Noise computations deliver the results in DN (digital numbers). Conversions between density levels D, intensities I and digital numbers DN are provided by the scanner's manufacturer. Some scanners produce densities, other intensities, some let the user decide what the output should be.

However, the exact relationship between the scanner's output (in DN) and the physically meaningful values can be established by means of a look-up table or curve created with the gray wedge (Figure 5).

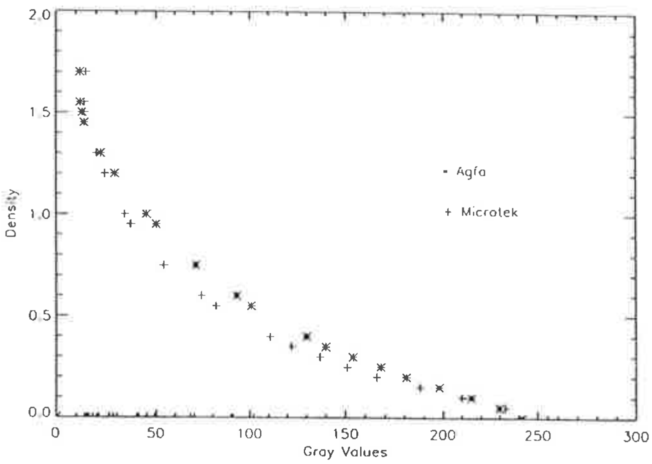

Figure 5: Relationship between 8-bit DN and a gray wedge's density. It is evident that in dark areas, gray value differences are no longer being resolved.

4.7 Analysis versus Use of Algorithms

Assessment of the density range and differentation between elements of a gray wedge can of course be accomplished manually on a display monitor. However, this subjects the outcome to the judgement of an operator. Therefore it is advisable to employ the computer to compute density ranges and noise levels at various densities, thereby considering the limitations imposed by properties of photographic materials.

4.8 Colour Reproduction

When working with 3-colour images (e.g. r, g, b) an accurate colour reproduction becomes important. In order to achieve feasible colour separation results the scanner has to deliver a good compression of the original colour gamut (e.g. Suzuki et al, 1990).

To measure the colour reproduction of a scanner, colour test targets can be used. A colour test target should be designed to present the whole colour space from full saturation through near naturals at highlight.

It has to be considered that visual colour investigations on a computer screen can only be made if the screen is well calibrated.

5. SPEED AND THROUGHPUT

5.1 Background

Digitizing large format photogrammetric film produces unusually large data files, easily exceeding 100 MBytes per photograph, and dealing with many such photographs a day.

It is therefore advisable to clearly separate the speed of a scanner from the sustained throughput of a scanning system. The latter is a result of careful systems investigation, network management, disk storage, operation and quality control. The former is simply a value obtained by looking at the potential pixel collection if no other limits existed in a routine operation with digital images.

5.2 Maximum Speed and Sustained Throughput

We propose to assess scanner speed by two values: one being the maximum possible speed at a selected geometric resolution and radiometric performance; the second being a value for the sustained production rate with image set-up, short term and long term storage, quality control, network traffic, etc.

The "maximum speed" is being assessed by producing a small digital file from a single photograph. It would be expressed in "pixels per second" or MBytes per second.

The sustained production rate would be tested by means of scanning many photographs, perhaps 20 or more, over an extended period of time and will be expressed in "photographs per day".

Of course the "maximum speed" and "sustained throughput" measure different quantities, even if they can be expressed in the same dimension (MB per second). However, "sustained throughput" assesses qualities of a scanner dealing with system configuration, functionality, user interface, integrability, etc., whereas "maximum speed" merely measures a small subset of throughput-related characteristics.

6. CONCLUSIONS AND OUTLOOK

We present a system for the evaluation of scanners, in particular photogrammetric scanners, and report about the experience with our system.

Issues of concern are geometric resolution, geometric accuracy, radiometric resolution and range, colour reproduction, speed and sustained throughput. It is proposed to employ specific test targets to assess each element of a scanner's performance.

The analysis of digitized image data is possible by manual, visual methods. However, they may result in a bias by a specific human analyst. Therefore, and for reasons of economy, one should employ automated algorithms to produce test results.

Of course visual analysis will continue as an important part of a scanner's evaluation because visual analysis is the only way to detect visual artifacts.

A corollary issue is the assessment of the information content in a given analog image. Any "system test" of a scanner needs to verify the qualities of the test data. However, the assessment of that quality is an important topic in its own right so that digital data get produced that are commensurate with the analog original in terms of information content, geometric accuracy and the intended applications of the data.

7. ACKNOWLEDGMENT

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8. REFERENCES

Almroth, U., 1985. Digital photogrammetry :pixel size, image quality , noise considerations, Fotogrammetriska Meddelandan, No. 51, pp. 1-15, Royal Institute of Technology, Stockholm

Bethel, J., 1994. Calibration of a photogrammetric Imaging Scanner. Proc. ASPRS, Reno, Nevada, pp 81-88

Doyle, F.J., 1982. Satellite Systems for Photogrammetry, ISPRS Comission I Symposium Proceedings. Canberra, pp. 180-185

Foerstner, W., 1982. On the Geometric Precision of Digital Correlation, IAP, Arch. Int. Soc. Photogramm. and Remote Sensing, Vol. 24-III, Helsinki.

Janesick, James R. et al, 1987. Scientific charge-coupled devices, Optical Engineering, Vol. 26(8), pp. 692-714

Kell, R.D., Bedford, A.V., Fredenhall, G.L.,1940. A Determination of the Optimum Number of Lines in a Television System. RCA-Rev. No. 1, pp. 8-30

Simonis, Roland,1991. Scanner analyzer target, Proceedings SPIE,"Beam Deflection and Scanning Technologies, Vol. 1454, pp. 364-369

Suzuki, Shoji et al, 1990. Color characteristic design for color scanners, Applied Optics. Vol. 29, No. 34, pp. 5187-5192

Trinder, J.C.,1984. Pointing Precisions on Aerial Photography, Photogrammetric Engineering and Remote Sensing. Vol. 50, pp. 1449-1462

Trinder, J.C.,1987. Measurements to Digitized Hardcopy Images, Photogrammetric Engineering and Remote Sensing. Vol. 53, pp. 315-321

Trinder, J.C., 1989. Precision of Digital Target Location, Photogrammetric Engineering and Remote Sensing. Vol. 55, pp. 883-886

Wolber, John W., 1991. Measuring the geometric accuracy of a very accurate, large, drum type scanner, Proceedings SPIE, "Camera and Input Scanner Systems", Vol. 1448, pp. 175-180