On the use of DTP scanners for cartographic applications

Conference Paper

Author(s):
Baltsavias, Emmanuel P.; Patias, Petros

Publication date:
1995

Permanent link:
https://doi.org/10.3929/ethz-a-004335977

ON THE USE OF DTP SCANNERS FOR CARTOGRAPHIC APPLICATIONS

Emmanuel P. Baltsavias [1], Petros Patias [2]
[1] Institute of Geodesy and Photogrammetry, ETH-Hoenggerberg, CH-8093 Zurich, Switzerland
tel. +41-1-6333042, fax +41-1-6331101, email manos@p.igp.ethz.ch
[2] Dept. of Cadastre, Photogrammetry and Cartography, Aristotle University of Thessaloniki
University Box 473, GR-54006 Thessaloniki, Greece
tel. and fax +30-31-996116, email patias@olymp.ccf.auth.gr

Abstract

Scanners have been used as input devices in cartographic applications mainly for digitisation and eventually subsequent vectorisation of existing hardcopy maps. Other applications that can increasingly be found, particularly in relation to cartographic work within a GIS, make use of scanned images, especially aerial imagery, which are usually transformed into orthoimages and are subsequently used for generation or update of cartographic databases, and creation of different visual products in digital or analogue form like orthoimage maps and 3D perspective views. This paper deals with the use and applicability of DeskTop Publishing (DTP) scanners for cartographic applications. The motivation of the paper is the investigation as to what extent lower-priced DTP scanners, which are rapidly improving during the few last years, can be used for such applications.

DTP scanners can be roughly divided into two groups: (a) flatbed scanners that are generally low-cost and up to A3 format, and (b) drum scanners that are generally more expensive and geometrically less accurate than flatbed ones, but with better radiometric performance and larger scan size. The paper will mainly concentrate on flatbed scanners with aim the scanning of aerial images. However, many of the topics mentioned in the paper are also valid for drum scanners and applications involving scanning of maps or layers thereof. The paper gives a review of recent technological developments with respect to these scanners, describes advantages and disadvantages, presents characteristics, tests and problems of such scanners, and investigations on their geometric accuracy. For certain applications, e.g. production of analogue orthoimages or orthoimage maps, the geometric accuracy of such scanners may suffice, while for others like updating of digital databases it is generally insufficient. Thus, test patterns for calibration of such scanners and some first results will also be presented.

1. Introduction

Scanners are an essential component in cartographic applications. They have been used for digitisation of maps, topographic and thematic, plans, charts, as well as scanning of aerial and satellite images. Scanned topographic maps have been used as a central base layer within GIS, as a backdrop in different applications, e.g. navigation systems, for visualisation, or for subsequent vectorisation of digital map data. The latter case is an attractive alternative to the cumbersome and expensive manual digitisation of the analogue maps. This raster to vector conversion can proceed in a manual, semiautomatic or automatic mode. In semiautomatic and automatic procedures usually the original map layers are scanned, so that the resulting scan data are less, better structured and of higher quality. Aerial and satellite imagery has been used to derive Digital Terrain Models (DTM), orthoimages, and for digital mapping (new generation or update of existing map data). A trend is the use of digital orthoimages for generation and update of cartographic databases, generation of orthoimage maps, integration with other raster and vector data and visualisation. Although the developments in direct digital data acquisition have been enormous in the last decade, film-based systems are used in all fields of photogrammetry. In aerial photogrammetry film-based systems will provide the main data input for many years to come. Film-based satellite images are provided by many Russian sensors.

Scanners of documents (reflective and/or transparent) can be classified according to their function in the following categories:

1. Photogrammetric scanners
2. Modified analytical plotters or monocomparators
3. Drum scanners or scanner/plotters of large documents (excl. the less accurate engineering document scanners)
4. Microdensitometers

5. DeskTop Publishing (DTP) scanners
6. Other scanners such as scanners of documents and 3D objects, slide scanners, text document scanners, multiple purpose scanners (e.g. scanner/copier/colour printer, scan/edit/fax scanners), specialised scanners (e.g. hand-held scanners, engineering document scanners, roentgen-image scanners, microfiche digitisers, barcode scanners, motion picture film scanners)

A detailed survey of scanners is given in [1].

The scanning requirements of maps and aerial images differ. Maps/plans are black and white or colour, can be transparent or opaque, require a large scanning format (e.g. A1), a geometric resolution of 400 - 1000 dpi, a geometric accuracy that is below the map accuracy (usually 0.2 - 0.3 mm), and a radiometric resolution of 1 - 4 bit (2 - 16 grey values). Aerial images are scanned in grey levels or colour, require a format of 25 x 25 cm, a geometric resolution of at least 600 - 1200 dpi, a geometric accuracy of 2 - 5 µm (for high accuracy applications), a radiometric resolution of 10 - 12 bit and a density range of 2.5 D (panchromatic images) to 3.5 D (colour images). Satellite images have the same scanning requirements as aerial images with the exception of the scan format (up to 30 x 45 cm). There is no single scanner, as far as the authors know, that can fulfil all these requirements. The scanners that come closer to fulfilling these requirements are: (i) high-end DeskTop Publishing (DTP) scanners, which have up to A3 format and a geometric accuracy of more than 50 µm, and (ii) expensive scanner/plotters (e.g. Intergraph's Mapsetter Series, Ektron Model 6447, Kirstol ZED HRC-1000) which cannot scan in transmissive mode, mostly can not scan images without dot screening, and have a geometric accuracy that does not suffice for scanning images. This paper concentrates on DTP scanners.

2. DTP Scanners

2.1. Overview

DTP scanners have been developed for applications totally different than the cartographic/photogrammetric ones. However, since they constitute the largest sector in the scanner market, they are subject to rapid developments and improvements. The consultancy BIS Strategic Decisions (Norwell, MA) forecasted in 1993 that the colour flatbed DTP scanner market will grow 39 % annually over the next five years. While DTP scanners include both flatbed and drum ones, only flatbed scanners will be considered here. Although drum scanners (Howtek D4000, Optronics ColorGetter Plus, Kirstol/Dainippon ISC-2010, ScanView's ScanMate magic) have a high geometric resolution (2000 - 4000 dpi), and high density range (3D - 4D), they are more expensive than their flatbed counterparts (starting at ca. 50,000 $ for formats larger than A4), and most importantly they have low geometric accuracy due to drum inaccuracies, unflatness of film on drum etc. and because of the same problems an accurate geometric calibration is not feasible. Flatbed scanners typically employ one or more linear CCDs, and move in direction vertical to the CCD to scan a document. They can scan binary, halftone, grey level and colour data (with one or three passes), may have good and cheap software for setting the scanner parameters, image processing and editing, and can be connected to many computer platforms (mainly Macs and PCs, but also Unix workstations) via standard interfaces. They can usually scan A4 format, but some can scan up to A3 or even more. Some do not scan transparencies, others do so but only of smaller format (typically with a 8´´- 8.5´´ width). There exist a handful of scanners which can scan aerial images (characteristic representatives are the 1200 dpi Agfa Horizon Plus and Horizon, and the 600 x 1200 dpi Sharp JX 610 and 600).

Flatbed scanners have a resolution of up to 1200 dpi (21 µm pixel size) over the whole scan width. Few scanners offer the option to increase the resolution (e.g. up to 2400 dpi) by projecting a document portion (smaller than the full width) on the CCD. Their price range, with few exceptions, is 1,000 - 30,000 $. The big price jump occurs when going from A4 to A3 format. The transition from 600 dpi to 1200 dpi costs less. A3 scanners with 600 x 1200 dpi start at ca. 12,000 $. A4 scanners with 600 x 1200 dpi and transparency options cost much less (2,000 - 4,000 $). Their radiometric resolution and quality, and scanning speed can be comparable to or even exceed that of the more expensive photogrammetric film scanners. DTP scanners with automatic density control and user definable tone curves that can be applied during scanning need for the setting of the scan parameters a few minutes as compared to more time (even one hour) required by some photogrammetric scanners. In particular, the sensor chip and the electronics of DTP scanners are updated faster and are in most cases more modern that the respective parts of photogrammetric scanners. New generation DTP scanners employ 10 - 12 bit digitisation and have a density range of up to 3.4D. Some employ modern 3-colour linear CCDs (like the 2,000 - 8,000 pixels KODAK linear CCDs) and scan colour documents in one pass. Functions that can be encountered in DTP scanners include sharpening, noise removal, automatic brightness and contrast adjustment, manual and automatic thresholding, white and colour balancing, black/white point setting, negative scanning, automatic colour calibration, self-defined screens for scanning halftone documents and printing images, multiple self-defined thresholding for each colour channel to scan multi-colour documents, preview (sometimes with variable zoom) and scan area selection, CMYK scanning, colour correction, integrated JPEG compression, and batch processing. The scanners can be bundled with other packages for image processing, editing, and retouching, colour management and calibration, image management etc. Their quality is rising while their price drops (especially for the A4 format scanners). The main disadvantage of DTP scanners are the small format and the insufficient geometric accuracy and stability, caused mainly by mechanical positioning errors and instabilities, large lens distortions, and lack of geometric calibration software. For scanning maps the geometric accuracy may be sufficient but the format is limited to A3. Thus, DTP scanners can be employed in scanning maps, plans, charts, guidebooks and atlases of such format. Table 1 shows the major features of flatbed DTP scanners that can scan aerial images with a resolution of at least 600 dpi. Scanners of A4 format with resolution of 600 x 1200 dpi and transparency options include: UMAX's PowerLook, Tamarack's Artiscan 12000C, Ricoh FS2, Microtek ScanMaker III, Agfa Arcus, Sharp JX-325, Spectrum Scan III (other models are produced by the companies Howtek, Dextra, Mustek and Relisys). Other A3 scanners include: Howtek Scanmaster 3+ (400 x 1200 dpi, A3 transparencies), Imapro QCS-2400 (600 x 1200 dpi, 5´´ x 7´´ transparencies), Pixelcraft's ProImager 8000 (400 x 4000 dpi, no transparencies).

Brand	Agfa	Sharp	Scitex	Intergraph
Model	Horizon Plus	JX-610	Smart 340 L	ANA Tech Eagle 1760
Mechanical movement	flatbed, stationary stage	flatbed, moving stage	flatbed	flatbed
Sensor type	3 linear CCDs, 3 x 5,000 pels	linear CCD, 7500 pels	linear CCD	2 linear CCDs, 2 x 5,000 pels
Scanning format (mm)	A3 (reflective) 240 x 340 (transp.)	305 x 432	A3	419 x 610
Geometric resolution (mm)	21.2 - 1270	21.2 (v) x 42.3 (h)[a]	21.2	42.3 - 25400
Radiometric resolution (bits) (internal/output)	12/10 or 8	12/8	8	8
Illumination	halogen, 400 W	3 RGB strobing fluorescent lamps		quartz halogen, fiber optic
Colour passes	3	1		
Geometric accuracy (mm)	50 - 100 (without calibration)[b]			460 (in x) 0.1% (in y)
Scanning throughput and/or speed	0.35 Mb/s (1200 dpi)[b] 5 - 100 mm/s	0.62 Mb/sec (A3, 600 dpi)	0.48 Mb/s (A4) 0.68 Mb/s (A3)	
Host computer/ interface	Mac, PC, Unix workstations/ SCSI-2	Mac, PC, Unix workstations/ GPIB, SCSI-2	Mac	PC. PS-2, Mac
Price (SFr.)	45,000	22,000		48,000

Table 1: Flatbed DTP scanners

a. Horizontal is in CCD direction, vertical in scanning direction

b. Values estimated by the first author for Agfa Horizon (32 Mb internal image buffer) connected to a Sparc 2

3. Scanner aspects and requirements

Different scanner aspects and necessary requirements will be discussed below. Knowledge on these topics allows users to better understand and evaluate scanners or appropriately set the scanning paremeters. Different implementation options and technological alternatives will be presented.

3.1. Illumination

The illumination must be high in order to achieve a better radiometric quality and higher SNR. This is due to the high scanning speed and the light intensity loss in the parts of the optical path. The higher the scanning speed, the higher the illumination should be since the dwelling time (integration time for CCD sensors) is reduced. Different parts of the optical path (filters, beam splitter) lead to intensity losses (for the Agfa Horizon with 400 W halogen lamps only the equivalent of 100 mW light reaches the CCD surface). Particularly in blue the power of the illumination is dramatically reduced. On the other hand, high power light sources generate heat, which must be treated appropriately in order to minimise the influence on the mechanical parts and the electronics (cooling, use of cold light, placement of the light source away from the sensitive scanner parts and use of fiber optics for light transfer). The spectral properties of the light source and its temporal stability (related also to the power supply stability) are important factors. In some scanners the light source has variable intensity in order to obtain balanced colour scanning (highest intensity used for blue channel, lowest for red). The illumination should be uniform over the whole field of view of the sensor and preferably diffuse (not directed). Diffuse illumination can be accomplished by use of fluorescent lamps, diffuser plates in front of the light source, diffuse reflectors, and integrating spheres/cylinders. Light sources usually include halogen and fluorescent lamps (often over 100 W), as well as laser beams.

3.2. Dynamic range and quantisation bits

The dynamic range of films can be in extreme cases very high (e.g. 16,000:1). To capture this information a quantisation up to 16-bit would be necessary. For aerial images 10 to 12 bit quantisation suffices to capture the information even in difficult scenes containing very bright and dark regions. This dynamic range can be supplied by point sensors and linear CCDs, and by special purpose area CCDs which are however not used in DTP scanners. New generation scanners often have A/D converters with 10 - 12 bit quantisation, but since almost all software and hardware supports only 8-bit/pixel and to avoid problems with excessive amount of data and image display, the data is reduced to 8-bit. The user often has no influence and no information on how this reduction is made. If this is done properly, then the result will be a radiometrically better image with higher SNR. However, 10 or 12 bit quantisation can lead to an improvement only for low noise levels (a fine quantisation does not make sense, if the noise level is much higher than one grey level). This is not always the case, particularly with CCD based scanners. Parameters like control of heat generation to reduce thermal noise, maximum charge storage capacity, integration time, smearing etc. are not always optimised to allow a truly beneficial 10 or 12-bit quantisation. Thus, the 10/12 bits are sometimes used as a selling argument but often they do not reflect an essential quality difference to 8-bit scanning. The scanner should be able to accommodate densities in the range 0.0 - 3.5 D. Density close to 0 is necessary when scanning glass plates (films start at 0.1 - 0.2 D), while a density over 3D is required for B/W images with very high dynamic range and many colour images.

3.3. Colour scanning

Colour scanning can be implemented by:

- primary or complementary colour filters spatially multiplexed on the sensor elements (1-chip colour linear or area CCD)
- use of 3-chip CCDs (linear or area arrays)
- rapidly strobing fluorescent lamp and dichroic filters, halogen ray and rapidly rotating filter wheel, flashing 3-colour fluorescent lamps (scan at each sensor position sequentially the R, G, B channels)
- use of filters before the sensor (RGB and neutral filters) or rotating lamps (scan whole document sequentially in R, G, B)

The first three approaches require one scan, while the last one three. The first approach leads to reduced spatial resolution and sometimes pattern noise in the image, and it lacks the ability to colour balance (blue in particular). The second is the best approach but also most expensive. Although many claim that the third approach is faster than the fourth, the scanning time is similar, if the same integration time for each colour is required. Another general belief that, the third approach often leads to smearing, while the fourth might suffer from misregistration of the three channels, is also not always correct. Misregistration between the colour channels can occur not only due to positioning errors in scanners that perform three passes but also due to the lens and other optical parts (mirrors, filters on glass plates). A problem with colour balancing will occur, if the sensitivity of the sensor is nonuniform (particularly CCDs have a lower sensitivity in the blue region as compared to green and red region of the spectrum). To avoid or reduce the problem of unbalanced colours each channel can be treated differently using one of the following approaches: variable light intensity, variable integration time, individual exposure control, individual gain factors.

3.4. Linear CCDs

Among the sensors, the most promising and widely used are linear CCDs. Today there are various linear CCDs with 5,000 to 10,000 elements. With current technology multiple linear CCDs can be optically butted with high precision to result in a line with sufficient elements for a high resolution scan of 10 μm or less. An interesting technology is also Time Delay and Integration (TDI) scanning (i.e. scanning of the same object with multiple lines - called stages - and signal averaging) which permits a higher scanning speed, lower light and a higher SNR (such a technique is employed e.g. in the 10 x 15 cm format Polaroid CS 500 scanner).

Linear CCDs provide a better radiometric quality, have higher charge transfer efficiency, and suffer less from electronic noise (smearing etc.) than area CCDs. They have high dynamic range (10,000:1 is possible). Linear CCDs have small noise and therefore respond to low input light and due to the high dynamic range they respond to high light levels as well. They have adjustable integration time and high speed (pixel rates of up to 120 MHz). Since a line contains a single row of pixels, the uniformity can be held tight and the geometric centring of the sensor elements is precise.

Linear CCDs also have some disadvantages. Normal operation of linear CCDs results in short integration times (typically 1 ms), and therefore a much higher light intensity is required. Linear CCDs due to their long length place special demands upon lenses and associated optics. When applying subsampling, linear CCDs lead to a slight image degradation of horizontal lines (parallel to the CCD) as compared to vertical ones due to image smear caused by the high scanning speed. Linear CCDs can lead to stripes in the scanning direction due to illumination nonuniformities, defect or noncalibrated sensor elements, or dust.

3.5. Scanning speed

Many users are fascinated by high speed, and vendors of high speed scanners use this as a selling argument. First of all, the total time for a successful scan should be taken into a account. As an example, the Agfa Horizon needs ca. 2 min (for 1200 dpi) to scan, transfer to swap disk space of the host computer and display in a window, a 30 Mb image, whereby the time for the mechanical scanning is just 3.3 sec. The majority of the required 2 min is for transfer of the data via the SCSI interface to the host and for saving the data on disk. That means that the physical scanning process could be much slower without increasing considerably the overall time, i.e. with a 18 times slower scanning rate the overall time would be 3 instead of 2 min. This is still not the total time needed for a successful scan. The time needed to set and optimise the scanning parameters can be more than the time required to do the final scan. In certain cases, as with the Agfa Horizon, a successfully scanned image must be transferred from the swap disk space to the disk space allocated to the users. For the Agfa Horizon this procedure needs 5 min for a 30 Mb image, so it is 2.5 times more than the time required for a successful scan. The digitisation of the image is just one part in the processing chain. Usually other processes follow, like orthoimage and DTM generation, mapping etc., i.e. procedures that require more time than the scanning itself.

As a conclusion, the physical scanning speed could be slower without any significant reduction in production throughput. The reduction of the scanning speed would have several advantages: the scanning mechanism (mechanical, optical, etc.) could be slower which means simpler, cheaper and stabler components ; the integration time could be increased which means higher signal to noise ratio, and no need for powerful illumination which is expensive and generates a lot of heat, influencing the optomechanical and electronic parts, and requiring mechanisms for controlling the heat dissipation ; vibrations in the scanning direction could be avoided or reduced ; the smear in the moving direction depends on the product (scanning speed x integration time), so it could be decreased if the integration time is increased less than the scanning speed is decreased; noise like lag which is typical of high speed imagers could be decreased ; the bandwidth and the price of the electronics could be decreased while more operations could be applied in “real-time” using hardware processing capabilities ; large image buffers in the scanner that are sometimes required to store the data before transferring it to the host would not be necessary since the low data rate could be accommodated by the host/scanner interface or a small image buffer.

3.6. Geometric and radiometric problems and tests

Geometric and radiometric calibration procedures are usually applied by all DTP scanner vendors but in all cases they are incomplete, or not accurate enough. In DTP scanners geometric calibration is not implemented, or if it is, patterns and procedures of low geometric accuracy are used.

Calibration and test procedures can and should also be applied by the user periodically. For such calibration procedures software and test patterns should ideally be supplied by the scanner vendors but this is unfortunately a rare case. In addition, the scanner vendors rarely provide the users with all relevant technical specifications of the scanner and with error specifications, e.g. tolerances for the RMS and maximum error that can occur in different cases.

4. Error types and scanner problems

Error types can be classified according to different criteria, e.g. geometric and radiometric errors, or slowly and frequently varying errors. In the following the second classification will be used. Some errors refer only to linear CCDs, others to multiple optically butted linear CCDs. Reference to these specific sensors in the text will be made using the acronyms L-CCD, ML-CCD respectively. Here only the major errors will be mentioned. Other errors can occur depending on the design, construction, and parts of each individual scanner. Whether some errors are slowly or frequently varying depends on the quality and stability of the scanner, e.g. in DTP scanners the positioning errors vary from scan to scan or even within one scan. For linear CCDs the following convention will be used. Horizontal direction is the direction of the linear CCD, vertical the direction of the scanning movement.

A. Slowly varying errors

1. Distortions due to lens or other optical parts
   This refers mainly to geometric errors like symmetric radial and tangential distortion. Radiometric errors like vignetting, shading, and secondary reflections can also be introduced by the optics.
2. CCD misalignment and overlap (ML-CCD)
   The multiple CCDs may have different direction or not be collinear. If their overlap is not correctly estimated by a sensor calibration, then overlaps or gaps will occur.
3. Subsampling errors
   When scanning with a resolution less than the original one, the pixels in horizontal direction are low-pass filtered and resampled, while in vertical direction larger pixels are created by increasing the scanning speed. This leads to different treatment of horizontal and vertical features and can lead to loss of information if the scanning speed is not increased by the correct amount and is not properly synchronised to the integration time.
4. Smearing
   Due to the high scanning speed horizontal features, especially lines, will appear thicker and with lower contrast than vertical ones. This effect corresponds to an one-dimensional low-pass filtering.
5. Focusing
   The sensor plane should be parallel to the scanner glass plate and properly focused. Furthermore, due to lens astigmatism there might be different optimum focal planes for horizontal and vertical patterns.
6. Colour channels misregistration
   It can be due to positioning errors, and chromatic aberrations of the lens or other optical parts.
7. Geometric positioning accuracy, uniformity, and repeatability
   Of major importance is accuracy. If it is high over the whole scan format and stable over time, then both uniformity of scanning movement and high repeatability are guaranteed. DTP scanners have poor accuracy and uniformity. Their geometric errors are frequently varying.

8. Geometric resolution
   This actually does not refer to an error. However, it is a quality parameter that should be determined and optimised. It can refer to individual components, e.g. sensor, optics etc. However, from a user point view what really counts is the geometric resolution, usually given by the MTF, of the whole system.

9. CCD nonperpendicularity
   If the CCD rows/columns are not parallel/vertical to the scanning direction, then a shear will be introduced. The same will occur if the two scanning directions are not orthogonal to each other. This shear can be accommodated by an affine transformation in the photogrammetric interior orientation of the images.

10. Grey scale linearity
    It refers to the relation between generated electrons in the sensor and output grey values. Ideally this relation should be linear, but with current technology linearity is limited to about 0.5% due to the on-chip amplifier.

11. Dynamic range
    As with geometric resolution, dynamic range is a parameter (not an error) that should be determined and optimised. It refers to the ability of the sensor to detect fine grey level changes and to accommodate images with high contrast. If the latter is not possible, then the grey values are saturated. Since the dynamic range depends on the noise level and this depends on the density, dynamic range should be estimated for different densities. Typically the upper range of the densities is limited, i.e. the scanner can not detect grey level differences in very dark regions.

12. Colour balance
    Since CCDs typically have a nonuniform response in the visible spectrum, i.e. in blue the sensitivity is lower than in green and red, proper actions should be taken (e.g. individual illumination, scanning speed, or integration time for each channel) in order to achieve balanced colours in the scanned image.

13. Radiometric accuracy (electronic noise)
    Under this title different noise types are grouped (thermal noise, blooming, smear, tailing, gain/offset of individual sensor elements etc.). Since it is difficult to separate the different noise sources what is usually checked is the uniformity of the photo response (Photo Response NonUniformity) by scanning and analysing the grey values in homogeneous areas. Although the individual error sources are time dependent, it can be generally assumed that the overall radiometric accuracy is stable over time. Noise can be reduced by averaging multiple frames, cooling of the sensor and slower sensor signal integration and read-out speed.

14. Pixel size
    The pixel size may differ from the size implied by the scanning resolution and furthermore it can be different in horizontal and vertical direction. The actual pixel sizes can be estimated by an affine transformation in the photogrammetric interior orientation.

15. Colour purity and other colour quality properties

16. 3-chip linear CCDs
    The three CCD lines (one for each colour channel) should be parallel and the distance between the lines should be accurately known and an integer multiple of the sensor element pixel spacing.

B. Frequently varying errors

1. Temporal radiometric variations
   Usually checked by estimating the grey level temporal variation of homogeneous areas.

2. Stripes
   Both dark and light vertical stripes can occur due to dark current noise, dark current nonuniformities, different sensitivity or wrong calibration of the individual sensor elements, illumination nonuniformity, dust, and blemishes (defective sensor elements).

3. Echoes due to multiplexing
   Multiplexed read-out can occur with multiple linear CCDs or with large area CCDs which use multiple read-out to increase the read-out speed. Since adjacent information in the video signal does not refer to adjacent elements in the original image, sharp transitions (e.g. from very bright to very dark pixels) in the analogue signal may be caused. This can lead to echoes, i.e. repetition of the signal in all multiplexed output (e.g. with ML-CCD repetition of the signal of each linear CCD in all other linear CCDs).

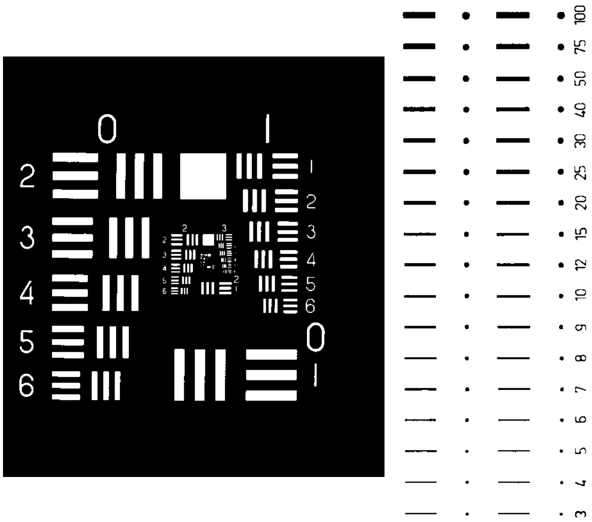
4. Different noise patterns and response between the CCDs (ML-CCD)
5. Vibrations
   Caused by instabilities of the positioning system of the scanner, particularly when the scanning speed is high.
6. Illumination nonuniformity and instability
   Nonuniformity may be due to the illumination source, border effects or the optical parts (e.g. illumination drop-off at the border of the lens). Stability depends on the illumination source and the stability of the power supply.
7. CCD saturation
   It is related to the dynamic range (see above). Even if the dynamic range of the sensor can accommodate the density range of the image, saturation can occur if the values of the minimum and maximum density of the image are not estimated properly. These values are used to map the sensor output to the grey values, and ideally should be automatically detected by the scanner for each individual image and each colour channel.
8. Dust, threads, film scratches etc.

In DTP scanners the errors in CCD direction considerably increase towards the borders of the scanner stage, and in scanning direction they increase slightly towards the end of the scan. As it can be seen from the above, the frequently varying errors mainly refer to the radiometry, whereby frequently geometric errors refer to geometric positioning. The description of a high-end DTP scanner (Agfa Horizon) and the errors it exhibits are given in [2].

5. Test patterns

Here some important test patterns will be presented:

1. Resolution charts
   Resolution patterns on glass plate (positive or negative) with sufficiently fine resolution are commercially available from different companies. The most common are the USAF test plate using 3-bar targets (Figure 1a) and the NBS test plate with 5-bar targets and resolutions of 0.25 - 228 lp/mm and 1- 500 lp/mm respectively in steps of ca. 1.12. 15-bar targets have the advantage that they provide 10 cycles that are not distorted because of being near the ends, and through averaging the MTF can be determined more accurately. Such targets are produced by Itek and Heidenhain (Dr. Johannes Heidenhain GmbH, Dr.-Johannes-Heidenhain-Str. 5, D-8225, Traunreut, Germany) with a resolution of 1 - 1000 lp/mm and 1 - 625 lp/mm respectively in steps of ca. 1.26 (both targets include only vertical lines). Resolutions of 3.6 - 100 lp/mm completely suffice to test scanners with pixel size from 300 dpi to 5 microns, while the most interesting range is 20 - 50 lp/mm. Razor blade edges can also be used to estimate the MTF by employing edge gradient analysis methods. Other patterns that can be used are: (a) parallel groups of n-bar targets ($n \geq 3$) with increasing frequency, whereby n increases with frequency, and (b) Fresnel zone plates that consist of concentric rings with radially symmetric, sinusoidal intensity distribution and exhibit a linear relation between local spatial coordinates and spatial frequencies. Important quality aspects of resolution targets are high contrast, sharp, well-defined edges, planarity of glass plate, and accurately known line width.
2. Gray scale wedges
   Such patterns are sold e.g. by Kodak and Agfa. Kodak offers the SR37 opaque grey scale wedge (21 x 2 cm) with density range 0.0D - 1.8D and 0.05D density steps, and the transparent ST34 wedge (13 x 1.5 cm) with range 0.0D - 3.4D and 0.1D density steps. A pattern containing a larger number of steps can be fabricated in a photographic laboratory and the densities can be accurately measured with a densitometer. The commercially available patterns should also be measured with a densitometer, kept free of dirt, and if they are worn out they should be replaced. Important requirements for such targets is high homogeneity of each density region and accurate knowledge of the density values.
3. Patterns for testing Photo Response Non-Uniformity
   For such tests the previously mentioned grey scale wedges can be used. An alternative is to use a neutral low density object, e.g. the scanner glass plate.
4. Fundamental features
   Since lines and dots are fundamental features in cartographic/photogrammetric applications, their reproduction (image quality) should be checked by scanning lines and dots of varying size (see Figure 1b).



a) b)

Figure 1. Test plates from Heidenhain.

Figure 2. Grid plate to be scanned together with the film in on-line tests for scanners that scan in one or two swaths.

5. Test charts for tonal and colour rendering etc.
   The UGRA/FOGRA (UGRA, c/o EMPA, Unterstr. 11, Postfach 977, 9001, St. Gallen, Switzerland, fax +41-71-227220) reproduction test chart is a 20 x 27 cm photograph which can be used for control of tonal rendering, colour rendering, grey balance, image reproduction, and image quality, e.g. defects such as dominant colour casts, improper grey balance, graininess etc. Kodak also sells opaque and transparent patterns (12 x 10 cm) with reference colour table and CMY colour model, and colour separation guides.
6. Grid plates
   Grid plates are used to check geometric aspects (especially accuracy). Typically they consist of grid lines with a spacing of 1 - 2 cm and a thickness of ca. 20 - 40 µm. For accurate measurement of the line intersections, the line width should be at least 3 pixels, e.g. for 600 dpi scanners 127 µm.
7. Grid plates to be scanned together with the image
   Such plates can be used for geometric calibration of DTP scanners. The plate should have geometric patterns at the borders which must be scanned simultaneously (on-line tests) with the film (a proposed grid plate is shown in Figure 2).
8. Aerial films
   As test patterns high quality black and white and colour aerial films should also be used. The films can be selected such that an average and a difficult case are represented, e.g. medium and high film resolution, medium and high contrast.

Scanner vendors may use additional or similar patterns, or other calibration devices inside the scanner. Other companies that sell different test patterns, even custom-tailored, are Baumert IMT (Industrielle Messtechnik AG, Im Langacher, CH-8606 Greifensee, Switzerland), Teledyne Gurley (514 Fulton St., Troy, NY 12181, USA) and Max Levy Autograph Inc. (220 West Roberts Ave., Philadelphia, PA 19144-4298, USA). Some photogrammetric companies also sell plates with grid lines and 1 - 2 cm grid spacing.

All above patterns, with the exception of the glass grid plates, can be bought at less than 1000 SFr. each. The price of the grid plates varies depending on the quality specifications, and type and density of patterns. A plate with 11 by 11 grid lines and 2 cm spacing may cost 2,000 - 3,000 SFr., while grids with dense patterns may cost more than 10,000 SFr. An alternative would be to use high resolution stable Estar thick base film, measure the patterns at an analytical plotter, and monitor possible film deformations by occasional measurements. Various patterns can be created using a CAD system, subsequently rasterised and plotted at a high resolution raster plotter. Some precision microdensitometers can also write on films fine, high contrast and geometrically accurate patterns. Details on test and calibration procedures for image scanners are given in [3].

6. Geometric accuracy

Without calibration, flatbed DTP scanners have positioning errors (RMS, over the whole format) of ca. 0.1 mm and usually even higher (the actual error of each individual scanner can be determined by scanning a grid plate with known reference coordinates). This accuracy may be sufficient for some applications. Consider for example a scanner with 100 microns geometric error, used to generate hardcopies of digital orthoimages in scales 1:24,000 and 1:12,000, using 1:40,000 scale input imagery scanned with 25 microns, and an orthoimage pixel size of 1 m (equal to the footprint of the scan pixel size). The scanner error translates to a planimetric error of 4 m in the digital orthoimage, and 0.17 mm and 0.34 mm in the 1:24,000 and 1:12,000 hardcopies. This approximates the measuring accuracy in topographic maps, and may be acceptable for many users.

Geometric calibration of DTP scanners can improve their geometric accuracy significantly, thus making these scanners suitable for other applications too. In the literature there exist reports on geometric accuracy after calibration of the order of 0.1 pixel. This can not be generalised and can be considered a bit too optimistic. Slowly varying errors (e.g. lens distortion) occur mainly in the CCD-line direction and can be calibrated by a grid plate to an accuracy of 0.1 pixel. Frequently varying errors (e.g. vibrations, positioning errors in the scan direction) occur mainly in the scan direction and require scanning of dense test patterns at the borders of the film and calibration for each individual scan. The remaining geometric errors after calibration mainly depend on the density of the patterns and the linearity and size of the occurring errors between two neighbouring patterns (sudden errors between two patterns can not be recovered). The latter depend on the design and stability of the scanner.

The Agfa Horizon scanner was tested with a grid plate. The RMS geometric error over a 23 x 23 cm format using an affine transformation and all 500 grid points was found to be ca. 50 microns. However, when only the four corner points were used for the estimation of the affine transformation, the remaining transformed 496 points had an RMS of 80 - 100 microns. The errors in the direction of the CCD line are very stable and independent of the scanning resolution, the position on the scanner stage and the time of scanning. The errors in the scanning direction are almost independent of the scanning resolution, but depend on the time of scanning and especially the position on the scanner stage. After quantifying the scanner's errors it was estimated that after calibration an accuracy of ca. 0.25 - 0.5 pixel can be achieved. For 1200 dpi this means a geometric accuracy of 6 - 11 microns (compared to its uncalibrated accuracy of 80 - 100 microns). This opens the way for more applications, but at a cost: grid plates (2,000 - 4,000 $), development of calibration software, more computations for calibration and, if necessary, image resampling.

7. Conclusions

DTP scanners are the fastest growing segment in the scanner market. Improvements in their overall quality, scan format, geometric and radiometric resolution and lower prices should be expected. Most companies that produce DTP scanners have an expertise in optoelectronics and mechanics and can certainly improve the positional stage and the optics of the scanners to achieve a geometric accuracy of less than 5 microns. It would be very nice for the users to have many scanners to choose from. This would lead to a bigger competition, lower prices and better quality. However, DTP scanner vendors either are not familiar with scanner requirements for cartographic/photogrammetric applications, or they simply ignore this market and concentrate on much bigger ones like desktop publishing etc. Thus, realistically an improvement in the geometric accuracy of the DTP scanners (this would make them more expensive and unattractive for customers in the big markets), or the production by DTP scanner manufacturers of new scanners specifically for cartographic/photogrammetric applications should not be expected. What could be done however, is the optional provision of customers with calibration patterns and software at an extra cost which could be around 4,000 to 6,000 $. Some companies could even use hardware processing that is present in their scanners to perform very fast certain operations needed in calibration (e.g. interpolation). The software development could be even be made by a third party (e.g. a university), if the scanner vendor does not want to invest into it.

In their current state, DTP scanners can be used in some photogrammetric tasks. The important point is that the user must clearly define the application requirements and examine himself whether they (particularly the geometric accuracy) can be fulfilled by a given DTP scanner. 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, however, 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.

References

[1] Baltsavias E., Bill R., 1994. Scanners - A Survey of Current Technology and Future Needs. In Int'l Archives of Photogrammetry and Remote Sensing, Vol. 30 - 1, pp. 130 - 143.

[2] Baltsavias E., 1994. The Agfa Horizon DTP Scanner - Characteristics, Testing and Evaluation. In Int'l Archives of Photogrammetry and Remote Sensing, Vol. 30 - 1, pp. 171 - 179.

[3] Baltsavias E., 1994. Test and Calibration Procedures for Image Scanners. In Int'l Archives of Photogrammetry and Remote Sensing, Vol. 30 - 1, pp. 163 - 170.