

FURTHER DEVELOPMENTS IN HIGH PERFORMANCE SCANNING

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ABSTRACT:

High performance scanning is a routine part of the digital photogrammetric production workflow. Modern scanners offer geometric precision similar to analytical plotters and high quality CCD sensors capable of faithfully capturing the information in the aerial photograph at 12 bits per channel to provide excellent dynamic range and tonal set-up. Modern practice is typically based on scanning positive or negative roll films. One of the critical requirements of the best scanners is high optical resolution at very high speed, motivated by the desire to complete roll-film scans overnight. Currently this can be done on the Leica DSW600 Digital Scanning Workstation for black and white photography owing to its industry fastest scan times of 2 minutes per 23 x 23 cm frame. No scanner can yet do this for a 500 foot colour roll. Recent improvements attempt to extend this performance on the DSW to colour, while at the same time improving image quality and control. Leica Geosystems has undertaken a number of innovations aimed at these goals, including: large format 12-bit sensor; novel LED illumination system, to increase amount and uniformity of light, enlarge the illuminated area to maximize scanning speed, reduce cost and improve reliability; coatings on stage plate and cover glass to eliminate Newton Rings; higher performance linear encoders to optimise geometric integrity; software refinements, including ease-of-use features and JPEG2000. These advances are incorporated in a new model, the DSW700, but most are available to users of existing scanners by means of a well defined upgrade program.

1 INTRODUCTION

Scanning is an accepted, proven phase of the digital photogrammetric workflow. Since the late 1980s, Leica Geosystems

and its predecessor companies have striven to respond to customers' increasing demands for scanning performance, in terms of geometry, radiometry, speed and ease-of-use. A summary of the various models introduced is given in Table 1.

Model	First shipment	CCD (mega-pixels)	Bits	Pixel size range (μm)	Scanning times (minutes) (b/w, color, 12.5 μm)	Host	Main innovations
HAI-100/ DSW 100	1989	2 * 0.25	8	12.5, 25	60, 180	Micro-VAX, Unix PC	Scanned whole image, not patches; two sensors for different resolutions
DSW200	1994	4.2	10	5-15	10, 30	Sun SPARC-station	High speed via large format sensor
DSW300	1997	1.6, 4.2	10	4-20	5, 14	Sun Ultra	Roll film
DSW500	1999	1.6, 4.2, 6.3	10	4-20	3, 7	Sun Ultra, PC	Xenon strobe illumination, PC host
DSW600	2002	8.0	12	3-22	2, 5	PC	12-bit sensor, easy pixel size change

Table 1. Main features of Leica DSW scanners

The 4.2 megapixel sensor in the DSW200 gave the DSW line the market lead in speed, to which Leica Geosystems has held ever since. The exhibition of the DSW300 model at the XVIII Congress in Vienna (Dam and Walker, 1996) enabled customers to exploit not only higher performance than the previous DSW200 model, but, importantly, was capable of accommodating roll film. The DSW500 (Dam *et al.* 2000) included an innovative stroboscopic illumination source un-

der software control, a 6.3 megapixel sensor and a PC host, all providing yet more performance. The DSW600 followed in 2002, the primary innovation being a high performance 12-bit sensor. Throughout all this hardware development, the software kept pace, moving through a range of platforms and continuously adding functionality, speed and ease-of-use. Standardization on Windows XP in 2003 simplified maintenance and support.

1.1 Upgrades

Meanwhile, in addition to introducing new models, Leica Geosystems had built up a base of several hundred customers who required support and wished to benefit from the innovations. The focus had shifted slightly from raw performance towards greater reliability, further ease-of-use, which was addressed through software, and the desire to upgrade earlier models. Leica Geosystems responded, as early as 1999, to customers' requirements with upgrades to enable earlier scanners to benefit from technical refinements. In 2001, it became possible to upgrade DSW300 models to DSW500 status. After the introduction of the DSW600, this program was extended considerably. Customers could upgrade DSW300 and DSW500 models to DSW600, including sensor, lens, integrating sphere and related electronics. A roll film upgrade was available also for DSW300 and early DSW500 models to raise their performance and reliability to DSW600 standards. Similarly, earlier models could be upgraded with the DSW600 wiring harness, including modern cable technology capable of operating for years without problems despite the millions of X and Y movements of the stage plate. Finally, a newly designed colour wheel arrangement was developed to replace the existing sub-assembly in the DSW300, in order to increase reliability.

2 RECENT REQUIREMENTS

Though the DSW600 was the fastest scanner in the marketplace and reliability had increased beyond earlier models, there was still scope for development and innovation. Early in 2004, a major release of the software included significant improvements, for example tonal enhancement of the fiducial marks without disturbing the rest of the image. Customers requested further performance improvements, however. Spurred by the increasing competence of photogrammetric service companies, with their growing attention to smooth workflows, and by the letting of large government contracts, especially in the US, projects grew extremely fast and firms or consortia undertook mapping tasks involving huge numbers of rolls of film. A good example is the project managed by Surdex of St. Louis, Missouri to produce digital orthorectified imagery of 574,119 square miles of Missouri, Oklahoma and Kansas, requiring 31,522 exposures (Molander, 2003). The project required eight aircraft and four scanners – two DSW500s and two DSW600s, working round the clock. With such enormous projects, customers wish to proceed from image acquisition to triangulation as fast as possible. The critical limitation is the time taken to scan a roll of color or false color film. At the same time, radiometric quality assumes additional importance, because time saved in radiometric manipulations to produce attractive deliverables is extremely valuable. Naturally, when capacity is fully utilized in these enormous projects, reliability is of the essence.

Once the DSW600 had successfully entered the marketplace, Leica Geosystems turned its attention to further development. One direction was the continuing search for higher performance, cost effective sensors. Another was examination of new technologies capable of brighter, more uniform illumination of larger areas, so that the whole field of the sensor could be used to maximize speed and the tonal range could be extended to make use of the 12 bit sensor. A possible source of increased robustness might be replacement of

the mechanical color wheel assembly whereby a filter wheel was rotated in front of the light source, assuming three positions to capture a patch of color or false color imagery. Finally, new approaches became available to reduce Newton rings, one of the biggest remaining image quality issues.

3 RECENT DEVELOPMENTS

Key technologies in a product guide its evolution. Three of those, the illumination system, optical and sensor components, have been responsible for many of the performance and quality improvements over the 15 years comprising the six DSW models. In the latest model, the DSW700, the illumination system is being upgraded from traditional black-body to solid state. The sensor is being changed for a higher performance version. Finally, the optical system is being treated to eliminate the old problem of Newton rings.

3.1 Treatment of Newton rings

Newton rings are one of the oldest artifacts in film printing and scanning. They are artifacts that flat bed scanners produce when the film is not held perfectly flat between the pressure plates. Typically, they become visible in a colour scanned image as a rainbow series of light and dark rings around non-descript points in homogeneous areas (Figure 1).

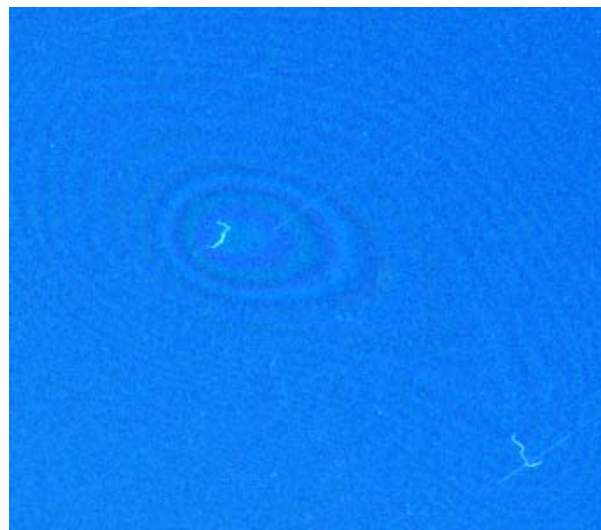


Figure 1. Typical Newton ring pattern

They are, however, not related to the image itself, but to the film surface in contact with the glass plates. Unless a special optical fluid is used to eliminate the air gaps and therefore the index change between two media, Newton rings will usually form. Physically, they are formed from the re-combination of reflected light waves bouncing between two semi-transparent surfaces that are smooth and whose distance varies slowly. When the distance variation is small compared to the wavelength of light, then the reflections can create visible interference fringes on re-combination. Spectral coherency and collimation of the light will affect their exact frequency, amplitude and attenuation as well as the surface spacing and susceptibility to reflection. These interference fringes become rings around a surface point disruption, like dust, that causes the distance gap to falloff gradually and radially. The rings will also have a rainbow coloured appear-

ance, in a colour scan, due the exact film/glass distance selecting the frequency of light at which the reflections are different by a half or full multiple of that frequency or colour. Sometimes the film is simply allowed to curl slightly owing to the pressure plate not fully holding it flat. In this case, long fringe patterns are formed along the curl direction. All this must happen within the depth of field of the scanner optical system to be seen, which is the justification for a slight out of focus adjustment that some graphics arts scanners use to reduce these rings. One dark and light fringe spacing represents a one-quarter wavelength change of distance between the two surfaces. The centre point of contact is always dark, since contact produces destructive interference, and the farther ring amplitudes normally decrease with distance from the centre.

We have been exploring ways to reduce significantly the formation of ring patterns by controlling one of the contributing physical factors. We chose the reflection coefficient of the surfaces. By suitably reducing the amount of reflection between the glass pressure plates, we found we can generally reduce the ring amplitude to below visibility. This can also be incorporated in an upgrade for an older scanner.

3.2 Illumination system

The illumination system for a scanner not only plays a role in Newton rings, but also directly influences spatial image quality, colour image separation and scan speed. Image quality influences measurement accuracy as well, so indirectly the effect of the lighting system percolates down the entire imaging chain for the production photogrammetrist. Image quality is a function of many factors, here the emphasis is on sharpness, tonal gradation and range, and colour accuracy. Sharpness, while desirable for image quality, must be considered carefully, since it usually correlates also with a higher perception of unwanted artifacts in the film, such as scratches and dust. This often forces a tradeoff between extreme sharpness on one side and too many artifacts to remove or slightly less sharpness and a lower number of visible imperfections on the other. For strong detail to be captured, then either compromising or tedious methods will be needed to remove the non-film blemishes from the image. Using an automatic fill-in method can distort the image, since trying to recreate what lies underneath a dust particle must be artificially done by extrapolation. Manual editing methods like those in Photoshop are labour-intensive for large jobs. Too much detail normally arises from a too strongly collimated light source, which creates strong shadows around everything, including dust and scratches. Another negative of this detailed light is loss of scanning tonal range. The light creates high contrast in the image by packing a smaller density range within the available scanner grey levels. Experience has shown us that a 12-bit sensor range is optimally spread out within a 3.0 optical film density range for mapping applications. High collimation reduces the useable density range, which makes the system overly sensitive in tonal work. High contrast light is useful in photo interpretation: ideally a scanner would also support this application. To be successful in photogrammetry, however, it must have light favorable to the traditional mapping applications such as orthophotos. In general, diffused light allows this larger tonal range needed for merging orthos. Our goal is to offer both options in the DSW700.

Illumination systems have in the past been high cost items in terms of both standard maintenance (for example, bulb replacements) and failures that require trained support engineers from the vendor to resolve. They have been expensive, short-lived and require constant recalibration. Solid state light sources, such as LEDs, offer improvements in all these categories and have been steadily entering lighting design. LEDs have matured to offer sufficient colours, intensities and longevities for practical use in high-end scanners. After 130 years, the incandescent can be put to rest while, after 65 years, the fluorescent lamp will also soon be eclipsed, both technologies still common in scanners today. The LED, demonstrated first almost 100 years ago, is not new but its commercialisation is only 40 years old. It has become attractive for scanners since it offers the potential as a zero-maintenance, lifetime source. Expected half-life approaches 10 years of constant 24 hours per day, 7 days per week operation. Modern devices offer huge improvements over their predecessors, which often failed prematurely, through more sophisticated current controller technology as well as package design to reduce heat and maximize efficacy. Today's device works by causing current to pass through a semiconductor junction or diode. This results in light emitting from the junction in the spectrum wavelengths consistent with the semi-conductor material used. Currently AlInGaP is used for red, InGaN for green and blue, and GaN for white. The final spectral output is often strongly monochromatic and much narrower than the halogen/xenon lamp/filter combinations which follow the more broadband "blackbody" laws or the multiple-peaked and broadband fluorescents. The narrower bandwidth has advantages in measuring the precise amounts of photographic dyes in films, and can even be tuned to match the representative Status A or Status M film density sampling curves. Colour software processing can be used to convert these primary measurements to a standard colour space, such as sRGB now commonly used in electronic displays, preserving neutrality better than with broadband filter functions.



Figure 2. Ring light LED light source

The use of LEDs in the DSW allows especially for a much more efficient implementation of sequential color capture than has been used in the past. It is faster. Previous models all employed a rotating colour wheel with red, green and blue optical filters to make the colour separation while the scanner stood stationary at a given location in the film. This capture process was slow since it was a mechanical device that re-

quired at least 1 second to move between filters. Since the switching time between colour LEDs depends on electronic constants instead of mechanical ones, there is significant room for improvement. The change times have now been brought down in the new model to less than 100 milliseconds, or 10 times as fast. We are reaching the point where three band colour captures in the new model are as fast as black and white captures in the DSW600. Of course, the other salient benefit is elimination of mechanical susceptibility to failure. The new source is illustrated in figure 2.

3.3 The sensor

The third of the key technologies improved in the new model is the sensor itself. Faster and larger sensors that are also lower in noise translate directly into speed and quality improvements. The DSW uses area sensors, created or influenced by the digital photographic camera industry. The current developments in this field have emphasized 35 mm film format equivalency, of which state of the art is about 11 megapixels, causing a $9\ \mu\text{m}$ sensor pitch. To accommodate high speed photography, the readout rates have been greatly improved over the cameras of five years ago. The standard computer PCI bus is now becoming the bottleneck and we look forward to the next generation PCI Xpress bus. The Redlake ES11000 11-megapixel camera tested for the DSW700 is illustrated in figure 3.



Figure 3. Redlake ES11000 11-megapixel sensor

This speed advance is partly due to the use of multiple readout points on the chip, or taps, which can multiplex several slower pixel streams into a single high-speed stream. Also the individual tap speed can be higher while still preserving a clean 12-bit readout owing to the advanced state of the art in CCDs. The result is that composite readout speeds of 60-320 MB/sec are available. Since higher speed still commands a higher price, we choose the best compromise for our product's price/performance at any given time and can readjust the mixture when prices decline.

As a result of all these technologies, noise in the system has declined to where average capture variations are below 1 percent, both short- and long-term. This creates a cleaner, more consistent scan and allows research efforts to be redirected away from perfecting raw capture towards higher level image processing, such as dodging or automatic light balancing in roll-film scanning.

3.4 Other improvements

Ever since the DSW200, the heavy, carefully designed and manufactured cross-slide system, with its band drives and heavy motors, has enabled scanners to be calibrated to $<2\ \mu\text{m}$ rmse on each axis. Nevertheless, improvements in encoder technology have emerged over the years and the latest generation of non-contact heads on the $0.5\ \mu\text{m}$ encoders fitted to the DSW reduce backlash. In addition, with consideration for the larger sensor requiring fewer stage movements, the stage may be run at a slightly slower speed. The benefits for the stage should be greater accuracy along with less mechanical wear, while still achieving a significantly increased scan production rate.

3.5 Software developments

The launch of the DSW700 is accompanied by a new release of the SCAN, Image Utilities and FastDODGE software suite. The main enhancements, of course, have been necessitated by the changed hardware, for example new software functions to control the LED light source and the Redlake ES11000 11-megapixel sensors chosen for the initial series of the new model. At the same time, improvements useful to all scanner customers have been added, for example the availability of the JPEG2000 format on output.

4 DSW700 PERFORMANCE

As noted earlier, the big gain from the LED light source and 11-megapixel sensor is in speed. The published specifications for the DSW700 are expected to be less than 2 minutes for a black and white scan at $12.5\ \mu\text{m}$ and about 3 minutes for colour. The latter implies that a 500-foot roll can be scanned in around 24 hours at $12.5\ \mu\text{m}$, a most significant milestone.

As a result of the encoder upgrade described in section 3.4 above, the DSW700 stage should usually calibrate to $<1\ \mu\text{m}$ rmse on each axis, a performance superior to most comparators or analytical plotters, though the published specifications is expected to state a more conservative $1.5\ \mu\text{m}$ precision.

On the radiometric side, the major improvement lies in the reduction of Newton rings, the severity of which has been dramatically reduced. But the combination of the LED light source and the high-performance sensor has reduced capture noise, speeded up capture time and improved tonal sensitivity. These all have the very practical benefits of making scan set-ups and project times much faster and easier than before.

5 DSW700 UPGRADES

The arrival of the DSW700 opens up a wide range of upgrade possibilities for existing customers. DSW300, DSW500 and DSW600 models may all be updated to DSW700 status. All earlier models can be improved by replacing the existing stage plate and cover glass plates with coated ones to combat Newton rings. And the existing upgrades noted in section 1.1 continue to be available. All these options are important to customers who wish to protect return on investment associates with their existing scanners, yet enhance them to meet the growing demands of the scanning market-place.

6 CONCLUSIONS

We have seen, therefore, that Leica Geosystems has introduced a new photogrammetric scanner in response to customer demand for higher performance and improved return on investment. The DSW700 is the sixth model in the series. Its main features are an LED illumination system, a high performance 11-megapixel sensor and glass plates with a new coating to reduce Newton rings. The software has been updated to support this hardware plus additional ease-of-use features, including JPEG2000 output. Existing scanners can be upgraded with the main features of the new model.

7 REFERENCES

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