PHOTOGRAMMETRIC SCANNING INNOVATION IN THE LH SYSTEMS DSW500

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ABSTRACT

The principal innovations in the DSW500 compared to the DSW300 include a stroboscopic light source, smaller integrating sphere, lighter color wheel, and choices of computer platform (NT or Unix) and sensor (1.6 and 6.3 megapixel units as well as the 4.2). Roll film transport remains a popular option.

Extensive software improvements are being made to accommodate these innovations. New strategies for multiple operating system optimization and code maintenance have been defined. Scan throughput and user interface evolve. Work continues on the challenges of dynamic range, noise, color rendition and dodging. User friendliness has joined high radiometric accuracy and geometric precision as a leading customer requirement. Great advances have been occasioned by the replacement of the mechanically shuttered, continuous light source of previous DSW models with a fully software controlled, flash illumination sequence generator. This unit's wide dynamic range and greater repeatability facilitate improvements in automation and radiometry. With the decreasing cost of computer memory, radiometric correction algorithms that trade off memory for increased precision and advanced processing have appeared. The overall goal is automatically optimized, high signal-to-noise imagery that can be tonally adjusted to operator preferences.

Dodging of the frame artifacts due to sun angle and aerial camera lens vignetting has been enhanced. "On-line" dodging performed on imagery acquired during a scan but before being saved to disk provides near real-time performance and higher image quality.

1 INTRODUCTION

The DSW500 image scanner from LH Systems (figure 1) was introduced into the market place in summer 1999. The DSW500 builds on the success of our previous model scanners including the DSW300, the DSW200, and the DSW 100 models. The DSW300 is described elsewhere (Dam and Walker, 1996) and the success of the design in terms of geometric and radiometric performance has been confirmed by Baltsavias *et al.* (1998). As digital photogrammetry has matured, and users have become more sophisticated, we have been keeping pace by updating and improving the performance of our DSW product lines. The ever increasing demand for robust and automatic scanning operations has

Figure 1. DSW500 Digital Scanning Workstation on Windows NT® platform

driven the need and requirements for the DSW500. Table 1 shows the transition of the DSW product line and some of the major changes.

Year introduced	***1989***	***1995***	***1997***	***1999***
Model	HAI-100/DSW 100	DSW200	DSW300	DSW500
CCD (million pixels)	0.25 (x2)	4.2	1.6, 4	1.6, 4.2, 6.3
Pixel size range (µm)	12.5/25	5-15	4-20	4-20
Bits	8	10	10	10
Illumination	25W halogen	175W xenon	175W xenon	10W xenon strobe
Peak irradiance (FC)	300	3000	3000	30,000
Host computer options	MicroVAX/PC 25 MHz/16 MB	Sun SPARCstation 50 MHz/80 MB	Sun Ultra 250 MHz/128 MB	Sun Ultra/PC 500 MHz/512 MB
Scanning time (min.) 12.5 µm b&w/color	60/180	10/30	5/14	3/7
Software version	1.0	2.0	3.0/4.0	4.2
Number of configurations	2	1	4	15
Primary function(s)	Triangulation Scan cut film	Scan cut film	Scan roll film, AIO Image processing	Scan roll film, AIO, Image processing Dodging
New features	Image viewer	Tonal curves, Multi-format	Roll film, projects, color RadioCal	Multi-platform, rescaling, dodging
Scan Automation	Patch mosaic	Exposure setting	Roll film scanning	Image processing

Table 1. Progress of the DSW scanners

2 ILLUMINATION

2.1 Xenon Strobe Light Source

One of the major improvements compared to the DSW300 is the change from a continuous xenon lamp to a xenon strobe. The DSW scanners operate with area-based cameras that acquire images in a tile fashion across the photograph to be scanned. The high precision (<2 µm RMS) stage permits butt matching of the image tiles into a continuous image for the entire 10 x 10 inch stage area. By controlling the strobe pulses of light via software commands, the user has total control over the amount of light reaching the CCD sensors. The quantity of light input, rather than the sensor integration time, now determines image brightness. To appreciate the concept, it is useful to contrast it with the DSW300, which uses the constant intensity, continuous output, illumination principle employed in almost all scanners today.

In the DSW300 light control, two methods were combined: a mechanical aperture for major light changes; and software control of the shutter speed to vary sensor integration time. Varying integration time under constant illumination is typically used in scanners in order to vary image brightness. Image brightness becomes proportional to CCD sensor integration time or shutter speed. The DSW300 camera shutter usefully controls light over about an order a magnitude. The “useful” aspect means before either shutter times become too short for good mechanical accuracy or too long for good scanning speed. The mechanical aperture wheel could adjust the illumination over 6 factors of two, in order to extend the useful shutter speed range of 10 to about 60. The operator would manually “dial in” the gross light setting based on film type and density, then finely adjust the image brightness using shutter speed. High lamp illumination output was required since the maximum light had to be always available. In a "step and stare" scanning system like the DSW has employed for over 10 years, illumination is only needed during camera integration, which is now about 25 to 50 percent of the scan time. The other 50 to 75 percent consists of stage movement from one capture center to the next, frame transfer time and color wheel rotation time if color is selected. Even line scanners maintain illumination constantly while not scanning, so in effect most scanners generally require high wattage, continuous output and waste lamp life. Continuous arc type lighting requires warm up time to spectrally stabilize, so rapid cycling is not an option.

Owing to the "step and stare" approach, a major innovation leading to greater efficiency was feasible in the DSW500. A low wattage, multiple pulse strobe illumination system was designed to be active only during the camera integration time. The integration time itself does not affect the brightness of the image. Instead the amount of light energy generated by the strobe is the determinant, while the purpose of the integration time is only to bracket the strobe pulses. Since the stages are enclosed, the strobe will be the only significant illumination during frame capture, thus eliminating the need for and limitations of the mechanical shutter. Because the flexibility of the strobe pulse generation is greater than a mechanical shutter, the useful dynamic range controlled by the software is now based on it. This is much greater than the old range and is also sufficient that the aperture wheel is no longer required. Thus we have eliminated slight problems and unknowns due to mechanical control of shutter speed and aperture wheel. More importantly, we have added the ability fully to control input film illumination, thus increasing the potential automation of the scan radiometry setup. For example, during color balancing, regardless of film type or density, the software can automatically make a decision on the optimum amount of light for each color band. Enhancements to the algorithms will meet customers' expectations for ease of use. The user may of course adjust light independently for each band during color scanning as well. This flexibility permits the optimal sensitivity for each film type.

The technical design goals were based primarily on operator experience. They consisted of: factor of 60 dynamic range; resolution of one part in a thousand over that range; 0.5% repeatability of illumination; automatic compensation for lamp intensity falloff with aging; and easy lamp replacement by the operator. Since lamp life would now be based on number of scans rather than number of power-up hours, the goal here was three years for single-shift operation, roughly ten times longer than for halogen lamps, in order to give better overall cost/performance. These goals were achieved.

The lamp controller consists of a XILINX programmable gate array (PGA) driving a pulse trigger generator that fires the strobe in conjunction with a 12-bit digital to analog converter (DAC) for changing the input reference voltage, thereby changing the intensity of the pulse. These circuits were designed by Engineering Design Team (EDT) in Beaverton, Oregon. They allow the number, frequency and intensity of the light pulses to be changeable by the host software on a per-frame-capture basis, though they are typically constant for each band throughout a given scan. Although it is possible, the operator does not normally control these three parameters directly: they are algorithmically calculated from the operator's single parameter image intensity control, for ease of use. This algorithm generates parameter values based primarily on optimizing scanning speed. Currently, the strobe frequency can be set between 80 and 1000 Hz and the number, between 0 and 4000 pulses. Amplitude can span a range about a factor of 6 with one-part in a 100 precision. This flexibility allows the software to choose the number of pulses desired in fine steps, providing precise control over the amount of light.

2.2 Lighter Color Wheel

Color scanning on the DSW500 is achieved by keeping the stage plate stationary with respect to the sensor whilst capturing the tile three times as a wheel rotates so that red, green and blue filters are placed in front of the light source. This is a significant advantage, allowing independent light control per color band and there is precise registration of the color bands since the stage and camera are stationary during these image captures. The weight of the color wheel is critical, because the speed of rotation is a major factor in the total time taken for a color scan. Thus the unit in the DSW500 has been substantially reduced in mass compared to that in the DSW300, resulting in faster rotation and much improved color scan times, which are now less than 2.5x as long as for black and white.

3 WORKSTATION PLATFORM OPTIONS

With the increasing demand for NT based systems running on standard PC hardware, the DSW SCAN software has been entirely ported to the NT operating system. Now, both Solaris based Sun systems and Windows NT based computers can be used. Since the DSW is a high performance scanner, and thus places heavy demands on the PCI bus, we require that only certain computer platforms can be used. This limits the amount of testing and robustness problems that can occur. Today, we recommend Dell and Compaq workstation systems and Sun Ultra 10 or 60 workstations. These computers are reliable and have been tested for the demanding operations of scanning, large data transfer rates, and extensive on-the-fly computations such as image filtering, JPEG compression, resampling, etc. The speed of the DSW continues to increase with increases in the clock speed of these systems. Table 2 below gives a summary of the host computer platforms.

NT workstation	**Sun workstation**
NT 4.0 (service pack 4 or 5)	Solaris 2.6 or 7
Dell Precision 410, 420, or 610 workstation or Compaq Professional Workstation AP500	Ultra 10 or 60 workstation
Dual processor PII or PIII 400 MHz or greater	333 MHz or greater with 2MB cache
Built in 10/100 Mb networking	Built in 10/100 Mb networking
CD ROM	CD ROM
Minimum 512MB RAM	Minimum 256 MB RAM (512 MB recommended
SCSI disks preferred	SCSI disks preferred
19 inch monitor or greater (prefer Trinitron type)	19 inch monitor or greater (prefer Trinitron type)
24 bit graphics	PGX graphics or better
Consider 8mm or DLT tape drive systems for backup and data transfer	Consider 8mm or DLT tape for archive
Consider CD writer	Consider CD writer
Consider a large amount of disk space for autonomous roll film scanning	Consider a large amount of disk space for autonomous roll film scanning
Recommend PCI bus is empty except for DSW500 camera interface card	

Table 2. DSW host computers

4 SENSOR OPTIONS

With the introduction of the DSW500, three camera options for the customer are offered. The customer can now choose between a range of scanning speeds and costs. These cameras are: Kodak 1.6i Megaplus – 1.6 million pixels; Kodak 4.2i Megaplus – 4.2 million pixels; and Kodak 6.3i Megaplus – 6.3 million pixels.

Each of these cameras has 9 µm "full fill" CCD arrays. This means that the full 9 x 9 µm area of each pixel is light sensitive. While the quality of each of these cameras is identical, the cost increases with the number of pixels in each camera. The speed of scanning varies with each camera and with the density of the film and the number of bands to be scanned. Table 3 lists typical scan speeds for each camera type under the NT operating system on a dual Pentium 500 MHz processor Dell computer. Times will vary slightly depending on CPU speed, disk types, film type, scanning area, etc., and reductions continue to be achieved due to ongoing software improvements.

Camera Type	**1.6i**	**4.2i**	**6.3i**
Black and white at 20 µm	3	1.5	1.5
Black and white at 14 µm	5.5	2.8	2.1
Black and white at 12.5 µm	7	3.3	2.6
Color at 20 µm	8	3	3
Color at 14 µm	15	6.5	5
Color at 12.5 µm	18	8	6.5

Table 3. Typical scanning speeds for a single aerial photograph (in minutes)

The DSW500 with autonomous roll film feed generates huge volumes of data. As can be seen from the scan times above, one scanner can produce a lot of scanned images in short order. Furthermore, very little overhead accrues if options are turned on while scanning. These include JPEG compression, image sharpening, and image rescaling while scanning on-the-fly. Thus a user can choose these options with very little penalty in scanning performance.

As with the DSW300, the physical scan pixel size is adjustable and can be physically set at any value between 4 and 20 µm. Once this is done, the user may choose to output the image at a pixel size that is a binary multiple of the physical setting. In addition the image rescaling option enables absolutely any pixel size to be achieved by software resampling.

5 SOFTWARE IMPROVEMENTS

5.1 Update of Tonal Transfer Curve

The DSW500 software offers the user a complete set of radiometric adjustment tools that greatly simplifies the process of obtaining realistic color imagery with a full histogram. The tools are available for use with both the real-time image browser and the pre-scan image in a fully integrated tonal package. These tools include the ability to preset the radiometric parameters during the setup of a roll film or cut film job. This allows the user to pre-store the setting for changes occurring over the project. These settings include the amount of light and the tonal transfer curve settings. The tonal transfer "curve" is the method by which the radiometry can be adjusted in a very non-linear way. The setting of the tonal transfer curve is a key to obtaining optimum scans from a variety of films and exposure types. These tools include histogram normalization and colormap adjustments. The colormap adjustment tools have been greatly expanded. New features include "undo" operations and histogram updates that reflect colormap changes. The time required to set up a scan has been greatly reduced by internally storing ten bits of radiometric information during the pre-scan or during browsing. This 10-bit radiometric data is then re-used for all tonal adjustments to obtain the optimum tonal transfer curve. This technique allows the user to work with the full dynamic range of the sensor while making radiometric adjustments even though the final output may be compressed to eight bits. Tonal controls now include the option of superimposing the tonal characteristics of a different monitor during scan setup.

5.2 Calibration

Like the DSW300, the DSW500 is very stable and does not change significantly over time. However, regular calibrations, about once a month, are recommended to keep users familiar with the operations and provide a history over which any change can be understood. Both scanner models have stage and sensor calibrations, which together take about an hour to complete after which operations can continue as normal. The geometric calibrations are identical and automated.

Radiometric calibration on the DSW500 does the normal sensor flat-fielding for each individual color band on a pixel by pixel basis. In addition, camera dark level is set for no light response. Camera gain, pulse frequency and pulse amplitude are all set to achieve a standard average white point response when no film is being imaged. The DSW500 also offers a much more fully automated radiometric calibration since there is no manually controlled aperture setting involved. The calibration adjusts the system to produce a constant illumination over the life of the light source resulting in light settings that can be referenced to absolute film density.

6 CONCLUSIONS

The improvements in the DSW500 compared to the DSW300 are incremental rather than radical. The use of leading edge technology in the form of a stroboscopic light source is exciting, but for the user is merely a means to higher reliability, performance, and lower maintenance and parts replacement costs. The other developments draw less on innovative hardware but are all the more critical for users. The choice of sensors results in three options at different price points, giving users a choice. The characteristics of the 1.6i and 6.3i sensors are almost the same as the 4.2i except for the numbers of pixels, so the challenge of introducing them has been predominantly a software one, plus one hardware improvement – a smaller integrating sphere with a larger aperture in order to illuminate the whole field of view of the 4.2i at all resolutions and of the 6.3i up to 15 µm. One might expect that many users would opt for the 1.6i to minimize cost, but the 6.3i has proved remarkably popular, comprising around half of the units ordered so far. The option of the 6.3i was added with two groups of customers in mind: scanning bureau service companies, for which speed is of the essence; and specialist organizations from the intelligence world for which fast scanning at high resolutions (<10 µm) is critical for normal operation. But it seems that speed is still attractive to a large proportion of customers. Whether speed is simply exciting *per se* or whether users perceive the "delay" between the beginning of scanning a large project and the beginning of automated triangulation as unacceptable, is not clear.

The addition of the Windows NT platform is the most obvious response to user needs. Many customers have standardized on the NT platform. Given that the PCI-bus frame grabber card fits into both PCs and the latest Sun Ultras, and given that porting to the new platform is greatly facilitated by modern software development tools, this step has been a straightforward one, albeit very meticulously performed. Finally, however, the ongoing development of software is the real challenge that underlines the very real difficulty of meeting customers' requirements for superb radiometry and aesthetic appeal on all kinds of imagery.

The "step and stare", modular design of the DSW500 leaves open the way to adopting innovations in illumination and sensor technology as they appear. More efficient light sources in the future may well emerge that are more cost effective and will yield more light without requiring more power. New sensor technology is rapidly improving. Since 1994, the DSW has exclusively used the 10-bit Kodak Megaplus camera models, which, except for an increasing range of array sizes, have not changed fundamentally. In 1999 Kodak sold its Megaplus subsidiary to Roper Scientific. So far this has caused only a change in the logo placed on the cameras. However, basic improvements for some of these models are imminent. Specifically, the 1.6i camera model is now being tested with Kodak's new blue sensor chip. This CCD, which uses a modified front-illuminated design, gives the camera greater overall sensitivity than the standard 1.6i CCD by a factor of two. The key design change consists of semi-transparent electrodes that are open to much greater incoming illumination. This is particularly true in the shorter blue wavelengths (hence the nickname), where up to four times the previous quantum efficiency has been achieved owing to significantly less scattering than before. The prediction is that the enhanced blue response should help scanners by improving sensitivity to the cyan-magenta color film dye layers. This new 1.6i model is being evaluated by LH Systtems and should soon enter the DSW product line. Elimination of the mechanical shutter requirement in the DSW500 has made it faster and easier to try new sensor and camera products. The practical results of this innovation are expected to include not only improved radiometric quality but also greater speed. Further radiometric advantages are likely to accrue a little further into the future with enhancements to the sensors providing 12-bit rather than 10-bit data. Finally, sensors with larger CCD arrays are certain to appear in the market-place at reasonable prices and these can be incorporated if their performance is interesting.

Minor mechanical improvements, that seem inevitably to be incorporated during the process of hand-building small numbers of units every month for long periods, will lead to higher speed, as will the certain increases in computer speed, in terms not only of processor performance but also bus and disk speeds. Progress will be made with dodging, balancing and the other radiometric challenges. We must still work to make the setup of high quality scanning even easier for inexperienced operators. And work in progress includes a solution for the familiar problem of scanning color negatives in an optimal way tonally while still capturing the fiducial marks in a faithful manner.

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