

# RECENT DEVELOPMENTS IN DIGITAL PHOTOGRAMMETRIC SYSTEMS FROM LEICA-HELAVA

Alex Dam  
System Engineer, Helava Associates, Inc., USA

A. Stewart Walker  
Product Manager Digital Photogrammetry, Leica AG, USA

Commission II, Working Group II/5

**KEY WORDS:** Digital Photogrammetric Systems, Softcopy, Status, Scanner, Triangulation, DEM/DTM, Orthoimage, Feature Extraction.

## ABSTRACT

Leica digital photogrammetric systems by Helava consist of the new DSW300 Digital Scanning Workstations and the DPW670 and DPW770 Digital Photogrammetric Workstations, which are monoscopic and stereoscopic respectively and are offered on a range of hardware platforms. Since the 1992 Congress, these systems have become established as leading contenders in today's busy market-place. The innovative roll film transport of the DSW300 complements the elements of the earlier DSW200 which have been retained owing to their highly satisfactory performance over the past two years. The scanning software has been extended to include operations for the operation of the roll film as well as improvements on the DSW200 functionality. The standard software of the DPWs, SOCET SET®, has undergone a host of improvements during the quadrennium and has migrated across a number of hardware platforms, requiring a diversity of graphics sub-systems for stereoscopic viewing. The major innovations include full 24 bit colour in all operations, automated aerial triangulation and much enhanced mosaicking. Equally exciting progress has been made on the feature extraction side: several packages are available, including excellent DPW implementations of the well known ATLAS and PRO600/MicroStation. Some of these now include automated tools which have been shown not only to give noticeable increases in productivity but also to reduce fatigue. GIS packages available on-line include GeoCity and System 9. The customer base has become exceedingly broad and includes private sector, local and state government, national mapping and military segments. Commercial pressures have fostered the growth of bureaux services, especially for photo processing and scanning, and have encouraged many companies to promote heavily their digital orthophoto capabilities. The future will feature migration to other popular platforms as well as profound productivity benefits in feature extraction and project management.

## 1. INTRODUCTION

Technological improvements and competitive pressures, coupled with evolving, heavy demands from a knowledgeable and competent customer base, have forced development in digital photogrammetry to proceed apace in a variety of directions. The Leica digital photogrammetric systems by Helava have been successful during the period 1992-96, primarily through sound initial designs for the various product, coupled with willingness to respond to change in computer hardware and customers' needs. These systems are well documented: the evolution from the military systems of the 1980s has been described by Helava (1991) and Miller, Helava and Devenecia (1992). The status at the 1992 Congress was reported by Miller, Thiede and Walker (1992), with updates by Miller and Walker (1993, 1995). There is also a wealth of accounts by users. The goal here is to outline the changes during the last four years, but the emphasis is on the features and benefits of the current systems.

## 2.0 SCANNING RETROSPECTIVE AND UPDATE

The last four years in the image scanner industry have been exciting, for both hardware and software. As one of the digital photogrammetric industry leaders, Helava and Leica have been in the forefront of these changes. Helava was an early entrant in the scanner business and is now entering into the third generation of its scanner product line, which began as a commercialisation of military

projects in the late 1980s. Naturally, the scanners reflect the state of both technology and digital photogrammetry over the years. The very first, military scanner used a linear array, but all subsequent models have been based on area array CCD technology (Table 1).

Model	Host	Production
DCCS	MicroVAX	1987-91
HAI-100	80386 PC	1990-91
DSW 100	80486 PC	1991-94
DSW200	SPARCstation 20SX, Ultra 1 Creator Model 170E	1994-96
DSW300	Ultra 1 Creator Model 170E	1996-

Table 1. Evolution of the scanners

## 2.1 HAI-100/DSW 100

The DCCS was a special system for semi-automated triangulation which incorporated a scanning stage and DEC MicroVAX host (Helava, 1987), but the first true scanner was the HAI-100, based on an Intel 80386 PC. This performed interior orientation and then resampled images rectified to photo space, to facilitate immediate stereoscopic viewing and epipolar correlation processes for automatic DTM generation. The scan times were extraordinarily long (two hours for a 25 µm image) by today's standards, but that was still fast enough to keep up with the competing products since they were slow too and the image preparation work performed by the HAI-100 was appreciated by customers. It was renamed the

DSW 100 when the strategic alliance between Leica and Helava began, improved its performance and reached its peak in the early 1990s, after being ported to an 80486 PC. At that time PCs were becoming capable of large image processing with their new virtual memory hardware and operating systems. Unix workstations were maturing as desktop power stations. The DSW 100 would ultimately produce 20 minute image scans at 25  $\mu\text{m}$ , but it no longer rectified the image, an operation the photogrammetric workstations could now handle, and image processing by the scanner was considered best kept to a minimum. Image quality also became an issue as the scanner output was increasingly being compared to the original diapositive. About 30 units were sold altogether, some of which were fitted with a housing containing a software controlled colour filter wheel, mounted in place of the familiar integrating sphere, and a lively second user market continues.

## 2.2 DSW200

Soon it became clear that another increase in scanner performance was needed to meet customer demand. The introduction of the DSW200, based on Sun SPARCstation 20 (Dam, 1994), at the end of 1994 increased scanner speed enormously over its predecessor to provide high resolution, high quality scans with resolutions in the 10-15  $\mu\text{m}$  range in under 10 minutes, using digital CCD technology. The DSW200 hardware design was based on xenon light source (combined with the colour filter wheel in a box removed from the xy stage), liquid pipe optic, integrating sphere, single high quality lens and Kodak MEGAPLUS 4.2 CCD camera (later 4.2i). The software, too, increased significantly in sophistication, with automated calibration and many functions for optimising the radiometric parameters with the help of the 24-bit Sun SX graphics. NITF JPEG image compression was introduced in software and became attractively fast when the Sun Ultra was introduced as the host in the spring of 1996. Top performance was now expected by customers. The scanners became like the aerial cameras they augmented, able to produce enough data to keep many digital mapping workstations busy: customers could buy more workstations without buying another scanner. Sales were buoyant, with over 50 units sold.

This continuing scanner evolution depends fundamentally on sensor technology. The sensor devices have improved substantially in both cost and performance in the last four years. Linear CCD arrays, used in most desktop scanners, have tripled or quadrupled in size (from 2k to 6k and 8k), quadrupled in sensitivity (from 8-bit to 10-bit) and tripled in modality (from monochromatic to trichromatic). Equally impressive, the popular CCD area arrays in the industrial measurement sector have increased in size (from 1k x 1k to 1k x 1.5k), sensitivity (from 8-bit to 10-bit), modality (from monochromatic to overlaid tricolor filter arrays) and speed (from 10 frames/sec to 30 frames/sec). Large area staring arrays, like those used in the DSW200, have also grown in size (from 2k x 2k to 2k x 3k or more), improved in accuracy (from .05 to .03 pixel) and yielded to increasing electronic integration, resulting in more robust camera packages that are half the size. Future models of the DSW are being planned with the 2k x 3k array and the newest 4k x 4k array camera from Kodak. Large area arrays will one day dominate the scanning market owing to their inherent efficiency and accuracy.

Shifts in computer technology have been critical too. Scanners have established themselves in the mass market place owing to increases in affordable disk storage, faster computers, better software and public demand for digital multimedia. Numerous models from dozens of vendors are available. In photogrammetry, this digital revolution has resulted in less expensive high resolution (10-30  $\mu\text{m}$ ) film scanning for the aerial mapping market. The result for the DSW200 was a wide range of developments by Sun, for example dramatic increases in speed and hard disk capacity. By the end of 1994, DSW200s were typically supplied with 3 GB hard disk capacity and offered black and white scanning of an aerial photograph at 12.5  $\mu\text{m}$  in around 7 minutes. A year later, the corresponding figures were 5-10 GB and 5 minutes. Configurations with 60 GB RAID arrays were also shipped, enabling many photographs to be stored simultaneously with fast random access, though the option of software compression is useful. These capabilities are also factors in the success of digital triangulation. Proliferation of models in the industry is a sign of success and acceptance. The Sun Ultra 1 Creator Model 170E selected for the DSW200 provides more processor power, high performance 24-bit graphics, fast and wide SCSI-2 hard disks and fast Ethernet (100-BaseT) communications, ideal for correct set up and fast storage and transfer of the rapidly acquired images.

## 2.3 DSW300

The real goal is not software and hardware *per se*, but greater productivity. The customer wishes to install a new scanner without adding a new employee and yet still increase output. Automation is the key rather than speed: faster scanning, which was a major productivity issue two years ago, will still be improved, settling at perhaps three minutes for a 12.5  $\mu\text{m}$  scan, but no longer dominates. Simpler operation, quick set up, unattended scanning and better quality control will share the spotlight. Thus manufacturers are adding sheet and roll film transports to automate the film loading process. Helava will begin shipping the DSW300, a roll film scanner model, in the fourth quarter of 1996. The software to utilise this advanced hardware must be increasingly powerful and support several fully automatic functions that in the past were generally interactive: frame search, measurement of fiducial marks, tonal pre-scanning and data storage management. In addition, new, sophisticated software for dodging is required. The benefits of these developments, of course, accrue to users of both roll film and single sheet film. Similarly, the automated set up for roll film can be used to achieve the simple, quick set up desired for scanning a single diapositive.

The new DSW300 preserves as much of the DSW200 engineering design as possible. The main innovation is the option of roll film scanning. The lighting, optics and camera are kept stationary, like the DSW200, while the film and transport move with the xy stage. The xenon light source, integrating sphere, simple optical system and Kodak camera are retained. Since it is imperative to keep the camera to film distance constant with stage travel, a stronger stage is needed to support the added weight of a roll film transport and film media. To sense and control the film roll position automatically, encoders and motors have been added to the spooling mechanism, requiring new electronics capable of four-axis control since the DSW200 controller is limited to two-axis

control. A further development is possible for motorised camera and lens movement to change pixel size. In two important respects, however, the DSW300 departs from the DSW200: the appearance is modernized (Figure 1) and the time to produce the units will be reduced.

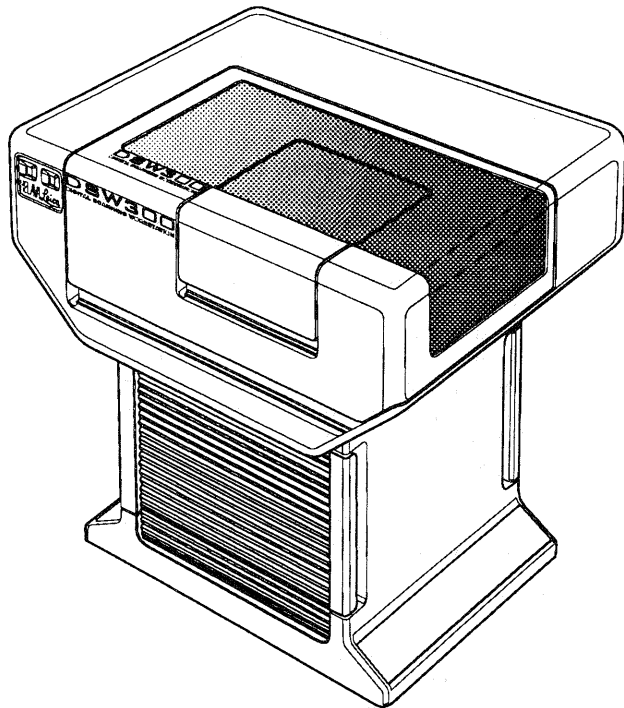


Figure 1. DSW300 Digital Scanning Workstation

Specifications for the DSW300 are similar to the DSW200. Stage size and travel are optimized for 23 cm (9 inch) film but will allow smaller formats as well. With the film transport option, the DSW300 can use rolls up to 152 m (500 feet) long by supporting a reel diameter of up to 194 mm (7 5/8 inches). The transport has a set of motorized operator controls for frame search, much as a light table would. The operator uses the controls to load, search through and rewind the film. After positioning the roll to the first frame to be scanned, the operator moves to the host computer console, a Sun Ultra 1 Creator Model 170E, to set up the scanning process. This involves identifying the aerial film camera and interior orientation choices, the tonal preferences and finally the number and type of images desired. Multiple images with no operator intervention are allowed in the case of roll film scanning. Fully automatic interior orientation makes this possible once the camera has been characterized, which takes place once and can be used for both single sheets and roll film. The benefits of automatic interior orientation are really seen with roll film: efficient data capture and significantly less operator intervention. Once a new frame is in the stage window, the program's ability to measure the fiducials allows the film area to be exactly known on the stage. By also allowing software to control the roll film advance, the scanner can automatically drive to the next frame, measure fiducials and scan the precise, predefined footprint on the film. Theoretically, successive frames can then be captured unattended for up to the entire roll.

Density range may vary from frame to frame, and that range is typically larger for original negatives as opposed

to the copied diapositives made for analytical plotters. The 10-bit CCDs perform well in capturing this larger range but unfortunately there is not a well understood method of compressing the 10-bit range into the standard 8-bit image format that works satisfactorily for all image types. Simple log or gamma processing to compress the range to 8 bits is often unacceptable since tonally flat images result. Therefore there is a need for research into more complex tonal adaptive methods that can be set up either by the operator based on visual inspection or automatically by the scanner using prescan statistical methods. Although the latter may not be as visually optimal as an expert operator on a per frame basis, they may provide greater consistency and reduce the costly scanning errors of too bright or too dark regions. The goal in an automated roll film set up is to increase the number of frames that can be automatically collected.

Finally, the last and perhaps most difficult issue in scanning raw film is to correct for vignetting and hot spots, traditionally the province of film dodging. This has an even less known set of procedures, since a desirable result may not always be precisely described. Our current approach is to normalize the image to a more or less uniform and acceptable contrast, a task which can be accomplished automatically after scanning. This more aesthetic processing is one job that may best be handled by the operator on an "as needed" basis. But perhaps the next generation scanners will be able to make aesthetic judgements too!

### 3.0 WORKSTATIONS

The evolution of the Digital Photogrammetric Workstations has been no less active and the account begins with a chronology of the development of the DPW770 and its SOCET SET software (Table 2). SOCET SET is based on software developed for custom workstations developed for the Defense Mapping Agency with expertise from Dr Uki Helava and has been offered as a commercial product for about seven years.

Host	Graphics sub-systems for stereo	Dates
80386/80486 PC	Parallax VIPER	1989-93
Sun 4/670, 4/470	VITec-30, VITec-50, Sun VX Peritek	1990-92  1993-94
Sun SPARCstation 2	VITec-30, VITec-50	1991-93
Sun SPARCstation 10	VITec-30, VITec-50, Du Pont/3Dlabs Pixel PX15	1992-94
Sun SPARCstation 20	3Dlabs Pixel PX15, Sun ZX	1994-
HP 9000 family	VITec-30, VITec-50	1994-
SGI Indigo <sup>2</sup>	SGI XL 24-bit, SGI High Impact, SGI Solid Impact	1994-
Sun SPARCstation 5	Sun ZX	1995-
Sun Ultra 1	Sun Creator 3D	1996-
SGI Indy	SGI Indy 24-bit	1996-

Table 2. Evolution of DPW770

### 3.1 Hardware developments

The digital photogrammetric workstations, too, have migrated to the Sun Ultra 1. The Fast Frame Buffer of the Creator 3D Model 170E gives a practical, off the shelf solution for stereoscopic viewing and smooth roaming. Similarly, the Silicon Graphics Indigo<sup>2</sup> with its XL, High Impact and Solid Impact graphics engines provides an excitingly powerful platform and SO CET SET has ported easily to the dual head versions of the lower level SGI Indy. Monoscopic and split screen stereo workstations are available on many models of Ultra, Indigo<sup>2</sup> or Indy and at the time of writing the SPARCstation 20 and SPARCstation 5 Model 110 were being retained owing to their economy. Like the DSW200 and DSW300, the workstations are supplied with 6 GB hard disk capacity and use 8 mm tape cartridge drives for longer term storage. The hardware environment has also been enhanced by a new hand controller based on mouse technology as opposed to the mechanical, rack and pinion approach in the earlier model, transplanted from the Leica SD2000/3000 line.

### 3.2 SO CET SET software

The SO CET SET software has been incrementally enhanced. Its current structure, including some Leica and third party packages for map compilation and DTM manipulation, is schematised in Figure 2.

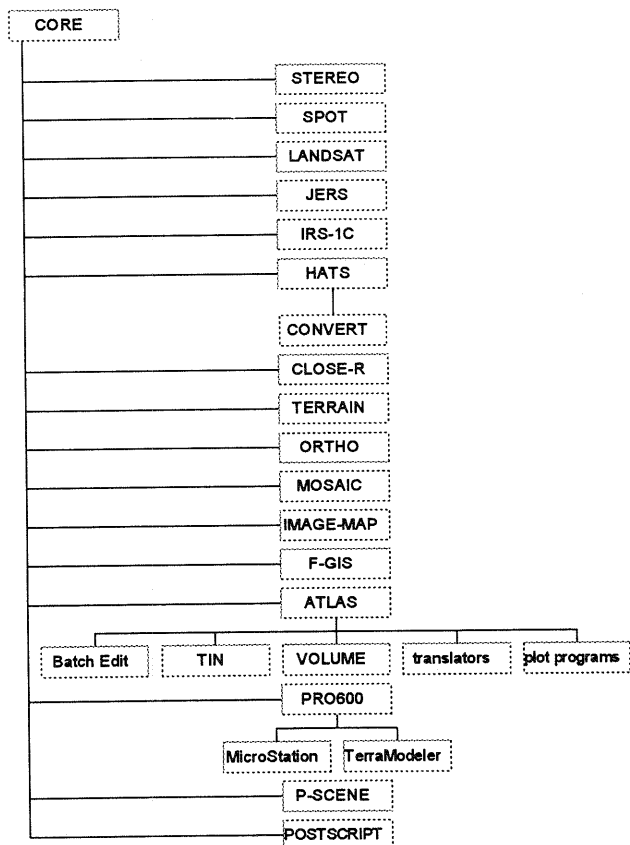


Figure 2. Structure of SO CET SET and related modules

**3.2.1 CORE SO CET.** The same automated interior orientation and JPEG compression as the scanners have been added. All operations throughout the SO CET SET suite are now available for 8-bit greyscale and 24-bit colour imagery. The range of image, vector and DTM

formats capable of being imported and exported has increased over the years. A useful feature for some customers is the model manager, whereby pairs of orientated images may be defined as stereo models, between which the user can switch by means of a single menu selection. This operation takes one to two seconds and thus outperforms analytical stereoplotters with large stage plates. Moreover, more than two models can be handled at once.

**3.2.2 Satellite imagery.** The use of data from JERS-1 was added in 1995 and a module for IRS-1C is in preparation.

**3.2.3 Automated triangulation.** A major new SO CET was introduced in 1995, called HATS (Helava Automated Triangulation System). Accounts have been given by Miller and Walker (1996) and De Venecia *et al.* (1996). The basis of the module is automated measurement of control, pass and tie points by area based image matching. The ground control points must be measured manually in at least one image and set up procedures exist to inform the system of the configuration of the block and the forward and side overlaps. The latter are much abbreviated when GPS coordinates of exposure stations are input. Cross strips, different photo scales and mixed aerial and satellite imagery are all possible. After the matching, interactive editing may be invoked to repair failure cases. Numerous blunder checks exist, from simple model, strip and block formation to data snooping after the built-in bundle adjustment. Indeed, at least one user has successfully minimised the interactive phase by going for very large numbers of tie points and making no attempt to measure failure cases manually, though of course gross errors must still be eliminated. It is also possible for users to output image coordinates from HATS to their existing block adjustment packages, for example ALBANY and PAT-B. Thus far it appears that the whole process takes around 10 minutes per image, which must be compared to the preparation, point marking and transfer, measurement, adjustment, re-measurement and final adjustment phases of analytical triangulation. Some early experiences have been reported by De Venecia *et al.* (*op. cit.*) and Kersten (1996). Current work centres on improvements to the user interface and expansion of the GPS facilities, such that a wide range of popular formats can be read and the bundle adjustment includes drift parameters.

**3.2.4 Close range photogrammetry.** Special software has been added for the orientation of close range images, including automated generation of initial values, an extended mathematical model, tracking in directions other than ground XYZ and rectification for viewing into user defined planes. The key is the transfer of image coordinates observed with standard SO CET SET functions to the PRIORI and CAP modules ported from the MAAS-CR software available for the Leica analytical plotters (Hinsken *et al.*, 1992).

**3.2.5 DTMs, orthophotos and mosaics.** There are additional strategies for automated DTM generation, together with new, interactive editing tools. Batch merging with planimetric data provides a powerful editing method too. Tests have proved the DTMs to be good enough for change detection, for example to monitor urban development or to estimate timber volumes through measuring tree growth. The latest

processors are so powerful that speeds in excess of 10,000 points per minute are achieved despite the complex, multiple pass nature of the Hierarchical Relaxation Correlation which is still the basis of the module (Helava, 1988).

While small improvements such as bicubic resampling and change detection from radiometric differences between orthophotos derived at different epochs, may affect more users, the most dramatic innovation on the orthophoto scene has been "true orthos", i.e. orthophotos with correction for building lean. The layered mosaicking with user defined seam lines and both geometric and radiometric feathering has been retained, but much faster, more highly automated mosaicking is available too. Current work includes an inference engine for determining DTM strategies for the user, refinement of the recent implementation of iterative orthophoto refinement (Norvelle, 1994) and a totally automated sequence from raw imagery through to final mosaic, which works well with satellite data. The output of image maps has been enhanced too, particularly with a PostScript option that enables lines and text to be output at higher resolution than the background image in order to take full advantage of variable inkjet, laser plotter and film writer devices.

While perspective scenes and fly throughs have been commonplace in the remote sensing world for several years, they are now acquiring the status of useful photogrammetric products and their application has emerged from the military world and found a natural home in the planning world (Simmons, 1996).

**3.2.6 Feature extraction.** Undoubtedly, the introduction of robust, practical semi-automated tools for feature extraction has been a major innovation. Three tools, for measuring roofs of buildings, for determination of linear features and for region building, are offered, all based on the principle of image processing to improve approximate measurements made by the user. Early tests with the roof tool indicate a significant improvement in productivity compared to manual measurement, accompanied by a noticeable reduction in fatigue. Further tools in development include sophisticated radiometric methods of detecting and measuring roads and gabled roofs.

### 3.3 Other software

Two small modules have been added by Leica. CONVERT is an important utility, which enables orientation data to be transferred in both directions between the DPWs and many analytical plotters. At the conclusion of HATS, therefore, it is possible to have any model available on a DPW immediately and on an analytical plotter after inserting the plates and performing interior orientation.

One of the strengths of SOCET SET has been the wide choice of software packages available for map compilation and GIS. Early dalliances with Kork, now owned by Vision International, and Aviosoft MAPce, have been superseded by strong links to a number of extremely popular products. The well known Leica PRO600 product providing an on-line link between SOCET SET and Bentley Systems MicroStation is now identical, except for the real-time portion, on the DPWs and the analogue and analytical plotters. The automated

tools mentioned above are being added to PRO600 to increase productivity. More recently, PRO600 has acquired triangulated irregular network (TIN) functionality, for sophisticated manipulation of DTMs, in the form of TerraModeler, from the Finnish company Terrasolid Oy, with which Leica has established a strategic alliance. KLT's ATLAS package is an acknowledged leader for customers who do not wish a CAD or GIS package as part of their map compilation solution. This product has been specially modified and refined to suit the DPWs. ATLAS has strong facilities for TIN manipulation and has functions to import SOCET SET DTMs for further processing. Moreover, conditions in the market-place are such that it is sensible to offer an open system and facilitate solutions including competitors' map compilation packages where customers wish to retain these and avoid retraining or reformatting costs. Thus Zeiss CADMAP and DAT/EM DGN/CAPTURE are available in addition to the products in Figure 2 and some customers also are working on integration of their map compilation software.

On-line links to GIS packages exist for Unisys System 9 and Clemessy GeoCity, the latter forming the basis of the solution designed for IGN, Paris. At the time of writing, work is in hand for a link to Leica's INFOCAM GIS, but in general terms the case for on-line LIS/GIS is not established: an off-line relationship using CAD formats and *post hoc* topology checks appears to be more popular in practice. Work is in progress such that SOCET SET's feature extraction module will be able to read and write ARC/INFO coverage files directly.

### 3.4 Dual systems

Since 1994 it has been possible to combine the scanning and workstation functions on a single SPARCstation host. Thus organisations which do not need continuous scanning can extract more value from their hardware. One popular application on these dual systems is HATS.

## 4.0 USERS

The remarkable growth of digital photogrammetry since the 1992 Congress in Washington is well known. Customers range from smaller private companies with one workstation to national mapping organisations and military survey departments with one or more scanners and multiple workstations. Every installation is different, which demonstrates how the systems business differs from the analogue instruments of 30 years ago. While it is not possible to discern completely clear trends, it is true to say that some customers exploit most phases of the digital photogrammetric process, but others concentrate on one phase or another. For example, there are numerous companies whose primary product is image rather than line maps; and there are a few scanning bureaux, who offer only scanning services and perhaps aerial photographic processing. Adoption of digital photogrammetry as the primary tool for feature collection has taken longer, but wider software choices, better user interfaces and improvements in ergonomics have encouraged greater use. Raster output has presented new challenges too. Customers have published extensively on their applications and, in some cases, their use of SOCET SET's development tools to interface to their own modules.

#### 4.1 User driven development

Users play a major role as the driving force behind the development of the product line. The size of Leica's worldwide customer base and the pedigree of Helava accruing from 15 years of military sales have given many customers the confidence to make requests and offer opportunities for these to be realised before making purchase decisions. The desire for top performance has therefore been a big incentive and the results have included the DSW200 and DSW300 themselves as well as continuing fast ports to new platforms as they appear from the computer manufacturers. On the software side, many of the customer driven developments are quite small, such as map projections, satellite imagery (IRS-1C, Swedish Space Corporation), the model manager described in 3.2.1 above, and many further enhancements in areas such as DTM strategies, image map formatting and workflow optimisation. The DPW implementation of ATLAS, the development of the close range module and the adding of TerraModeler for TIN manipulation have all been responses to customer demand. The result has been a markedly dynamic, flexible product line which is both customised to suit individual sites and characterised by fast development to keep apace with photogrammetrists' requirements.

#### 4.2 The future

While dramatic developments like the DSW300 and HATS are great steps forward, the bulk of development over the last four years has been incremental. Host computers, their peripherals and their graphics subsystems have advanced steadily and have been exploited to give ever higher photogrammetric performance. Both the scanning and SOCET SET software have had a continuing influx of new features and improvements to their user interfaces and robustness. All these trends will continue and will shape the future as much as big innovations. Nevertheless, it is possible to predict with some confidence ports to new platforms, especially Windows NT on top end PCs as well as workstations. SOCET SET will offer genuine benefits in the form of greater productivity, especially through better DTMs, automated feature extraction, map finishing and project management. It is unarguable, however, that the developments in the Leica digital photogrammetric systems by Helava over the last four years have provided a rapidly growing customer base with higher productivity combined with the capability to produce a broader range of deliverables. Leberl's "promise of digital photogrammetry" is being fulfilled.

#### ACKNOWLEDGEMENTS

The authors are grateful to the design team of the DSW300 for Figure 1 and to various colleagues for their comments on the paper and contributions to the historical information encapsulated in Tables 1 and 2.

#### REFERENCES

Dam, A., 1994. Results using the Kodak 2000 x 2000 matrix CCD camera for photogrammetric film scanning. OEEPE-ISPRS Joint Workshop on the Analysis of Photo-Scanners, Ecole Polytechnique Fédérale de Lausanne, Lausanne, 4 pp.

- De Venecia, K. J., Miller, S.B., Pacey, R.E. and Walker, A.S., 1996. Experiences with a commercial package for automated aerial triangulation." In: ASPRS Technical Papers, 1996 ASPRS-ACSM Annual Convention, Baltimore, Maryland, In press.
- Helava, U.V., 1987. Digital Comparator Correlator System. In: Proceedings, Intercommission Conference on Fast Processing of Photogrammetric Data, Interlaken, Switzerland, June 2-4, pp. 404-418.
- Helava, U.V., 1988. Object space least squares correlation. In: International Archives of Photogrammetry and Remote Sensing, Kyoto, Japan, Vol. 27, Part B2, pp. 297-302.
- Hinksen, L., Cogan, L. and Kotowski, R., 1992. A new MS-DOS based integrated software package for triangulation and data collection for close range applications. In: International Archives of Photogrammetry and Remote Sensing, Washington, D.C., Vol. 29, Part B5, pp. 11-18.
- Kersten, T., 1996. Digital triangulation with the Helava Automated Triangulation System HATS. OEEPE Workshop on the Application of Digital Photogrammetric Workstations, Lausanne, Switzerland, March 4-6.
- Miller, S.B. and De Venecia, K., 1992. Automatic elevation extraction and the digital photogrammetric workstation. In: ASPRS Technical Papers, 1992 ASPRS-ACSM Annual Convention, Albuquerque, New Mexico, Vol. 1, pp. 572-580.
- Miller, S.B., Helava, U.V. and De Venecia, K., 1992. Softcopy photogrammetric workstations. Photogrammetric Engineering & Remote Sensing, Vol. 58, No. 1, pp. 77-84.
- Miller, S.B., Thiede, J.E. and Walker, A.S., 1992. A line of high performance digital photogrammetric workstations - the synergy of General Dynamics, Helava Associates and Leica. In: International Archives of Photogrammetry and Remote Sensing, Washington, D.C., Vol. 29, Part B2, pp. 87-94.
- Miller, S.B. and Walker, A.S., 1993. Further developments of Leica Digital Photogrammetric Systems by Helava. In: 1993 ACSM/ASPRS Annual Convention & Exposition, New Orleans, Louisiana, Technical Papers, Vol. 3, pp. 256-263.
- Miller, S.B. and Walker, A.S., 1995. Die Entwicklung der digitalen photogrammetrischen Systeme von Leica und Helava. Zeitschrift für Photogrammetrie und Fernerkundung, No. 1/95, pp. 4-16.
- Miller, S.B. and Walker, A.S., 1996. Aerial triangulation - automation ups productivity! Surveying World, Vol. 4, No. 2, pp. 23-25.
- Norvelle, F.R., 1994. Using iterative orthophoto refinements to generate and correct digital elevation models (DEM's). In: Proceedings: Mapping and Remote Sensing Tools for the 21st Century, August 26-29, 1994, Washington, D.C., pp. 134-142.
- Simmons, G., 1996. Missile guidance for the photogrammetrist! Surveying World, Vol. 4, No. 2, pp. 30-32.