Softcopy Photogrammetric Workstations

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ABSTRACT: A summary of softcopy photogrammetric workstations developed by the General Dynamics/Helava Associates, Incorporated (GD/HAI) team during the past ten years is given. The summary starts with the Digital Stereo Comparator/Compiler (DSCC), and also includes the DMA workstation, the Digital Imagery Workstation Suit (DIWS), the Digital Stereo Photogrammetric Workstation (DSPW), the HAI-750, and the HAI-500. Some of the latest efforts have been oriented toward the commercial market place. The key aspects discussed in this paper include the handling of large amounts of imagery, geometric handling of images, elevation extraction, and feature extraction. Approaches and solutions to generic technical problems are highlighted even though only top level descriptions are given.

INTRODUCTION

THE CONCEPT OF A SOFTCOPY (digital image) photogrammetric workstation has been around for more than ten years (Sarjakoski, 1981). An example of one such workstation was described by James Case in his paper entitled "The Digital Stereo Comparator/Compiler (DSCC)" (Case, 1982). Detailed specifications for that workstation became defined when the Defense Mapping Agency and Rome Air Development Center placed a contract for the development of the DSCC.

The DSCC project was ambitious; the resulting instrument, or "workstation," was designed to meet a comprehensive set of performance requirements. The contract was won by the GD/HAI team and a dozen of the DSCC's were delivered in 1985. To our knowledge, the DSCC was the first operational "softcopy stereoplotter." Several variants have been developed since, including a new model designed for the Defense Mapping Agency, as well as commercially oriented models.

Implementation of softcopy photogrammetric workstations requires finding solutions to several generic technical problems. Interestingly, the photogrammetry portion of it poses no significant problems. The generic problems are in the image processing area. Most problems arise due to the extremely large size of the photogrammetric images. While storage of such images is no longer a serious problem, fast accessing and processing certainly are. Access and data transfer times of commercially available systems are constrained by bus bandwidth, disk access, and internal memory. Special buses and data structures are necessary for high performance. If the functionality of the best optical- mechanical analytical plotters is to be duplicated, the images must be resampled to achieve many geometric manipulations. Resampling is involved in all geometric manipulations of images, such as rectification, rotation, zooming, and even positioning for sub-pixel measurement. Continuous real-time resampling of say 1K by 1K pixel images for a stereo display is not a trivial technical task. Again, special hardware is required for optimum performance.

Problems arising from the sizes of photogrammetric images can be greatly reduced if certain trade-offs are permitted. The fundamental trades are in resolution and on-line performance. For example, a standard black-and-white 9- by 9-inch photograph digitized to a 50 micrometre pixel size takes "only" 23.3 Megabytes to store. Obviously, potential accuracy and resolution are commensurate, but the end product may still be valuable and the problems are greatly mitigated. Similarly, system reaction time can be traded for lower equipment complexity and cost. Some functions, such as rotation of the image display, need not be instantaneous. Furthermore, some tasks, e.g., epipolar rectification (if desired), can be performed as off-line batch processes.

Trade-offs in operating concepts can also contribute toward solving many technical problems. This includes image tiling, background preprocessing, nearest pixel operations, and "piecewise" image roam. Many of the trade-offs described above are not possible when the workstation must meet a given set of specifications. Most of the workstations and associated systems developed by GD/HAI fall into this category. However, the lower-cost workstations (DCCS, HAI-500, and HAI-750) are exceptions; their requirements were self-imposed by the designers. No doubt, various sets of trade-offs will be presented to the market place for "real-life" judgment before softcopy photogrammetric workstations reach their full maturity.

This paper discusses implementation of softcopy workstations designed and built by GD/HAI. Included are: the DSCC; the Defense Mapping Agency (DMA) Workstation; Digital Imagery Workstation Suite (DIWS); Digital Stereo Photogrammetric Workstation (DSPW); HAI-750; and the HAI-500. Approaches and solutions to generic technical problems are highlighted even though only top level descriptions are presented in this paper.

CUSTOM BUILT WORKSTATIONS

This section describes the softcopy workstations custom-designed and build by the GD/HAI team with special-purpose hardware to meet high performance specifications.

DIGITAL STEREO COMPARATOR/COMPILER (DSCC)

Functionality.

The Digital Stereo Comparator/Compiler (DSCC) was designed and built to strict specifications and with much functionality. These specifications define a paradigm for a "top of the line" photogrammetric workstation. A summary of these specifications is listed below.

Orientations:

- Manual, semi-automatic, and automatic measurement of fiducials, reseaus, and control points to less than 0.3 pixels
- Interior, relative, absolute, and simultaneous orientation of multiple sensor types

Data Collection:

- Automatic elevation measurement (200 points/second)
- Manual collection of contours and features
- Automatic correlation while delineating features

Data Editing:

- Manual and semi-automatic positioning
- Graphics update while reviewing, roaming, and editing

Image manipulation:

- At least 256 operator selectable 7- by 7-pixel axially symmetric individual filters
- Tonal look-up tables with reloadable breakpoints
- Histogram equalization, brightness, and contrast control
- Rotation over 360 degree range, or 90 degree steps

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- Zoom from 5:1 to 1:40
- Image roaming over 200 pixels per second
- Stereo 512 by 512 display
- Overview 1024 by 1024 color display

Graphics Superimposition:

- Points and lines superimposed in stereo while image roams
- Graphics anti-aliased to 1/8-pixel placement
- Cursor positioning to 1/32 pixel
- Overview image and graphics support

Image Capacity:

- 1000 Mega pixels

Photogrammetric functionality of softcopy workstations, such as the DSCC, is of great interest to photogrammetrists. Due to the focus of this paper on implementation, only a cursory description is included. In short, capabilities of the DSCC workstation exceed those of most previous photogrammetric instruments, as evidenced by the specifications listed above. In addition to performing tasks of the modern analytical plotters, the DSCC has powerful automatic image correlation capabilities. These capabilities include techniques particularly suited for correlation of fiducial and reseau marks, point-by-point correlation, and generation of Digital Terrain Models by Hierarchical Relaxation Correlation (Helava, 1987). The DSCC is capable of handling a variety of geodetic projections and employs an extremely flexible method for representation of image geometries in real-time computations.

Because softcopy systems allow one to view images of unusual geometries due to their warping capabilities, the ability to triangulate a variety of image types including frame, panoramic, and SPOT imagery is realized in the DSCC. The DSCC can also triangulate and view many combinations of sensor types together.

System Configuration.

The architecture of the DSCC (Figure 1) utilizes one shared resource (VAX 11/780) to provide tasking, control, and image loading to several workstations. Each pair of workstations is controlled by a VAX 11/780. Each DSCC workstation is capable of performing as an automated digital image analytical plotter/comparator. The purpose of the shared resource subsystem is twofold. First, it accepts images in various formats and on different media and converts them to a specific internal format for the workstations. Second, it controls various output devices for the cluster of workstations. During the image reformatting the shared resource subsystem hardware produces sets of minified images. The minification is done by a custom designed minifier/reformatter. Minified images are valuable for hierarchical correlation, overview presentation, and implementation of a large zoom range.

Figure 2 illustrates a DSCC workstation and the operations which flow to the workstation. A binocular viewing system provides the workstations with an appearance of typical photogrammetric plotters. Below the viewing system, in front of the operator, are an overview image display, an alpha-numeric display, a special control panel, a standard computer keyboard, and an optional mouse. The viewer is ergonomically designed. The binocular viewing system was selected for the DSCC as the best alternative available at the time of its design. The images are presented on the 512- by 512-pixel center parts of very high quality 1024 by 1024 monitors. Servo-controlled vertical positioning of the console top and viewing optics provide optimum operator comfort. Some workstation electronics are housed in the pedestal bays of the console. The primary computer equipment required to drive the workstations occupies several six-foot high racks (not shown in Figure 2).

To implement the image processing tasks, each workstation has 56 custom made circuit boards, designed and manufactured by General Dynamics. The VAX 11/780 used as the shared resource is assisted by 23 custom made boards and an input/output microprocessor. In addition, each workstation has a Floating Point Systems 5310 array processor. The array processor is primarily devoted to image correlation. Much ingenuity and effort have been expended on the design and integration of all these parts, and the software that makes them perform as intended.

The specially designed control panel in front of the operator is fully programmable. It contains buttons and dials designated for selection and on-line adjustment of filters, tonal tables, contrast, brightness, rotations, zoom levels, etc. of left, right, and overview images. A force stick and two (left and right) trackballs are also provided. These devices can be used to control ground or image coordinates. Switches to effect screen locks are available for making orientation measurements. Twelve program function switches are also available. Two handwheels, a footwheel, and two foot switches give the DSCC the "look and feel" of a typical stereo plotter.

Image Processing.

The novelty of the DSCC is concentrated in its image processor. Figure 3 gives an impression of the DSCC system architecture. The image processor implements solutions to most of the

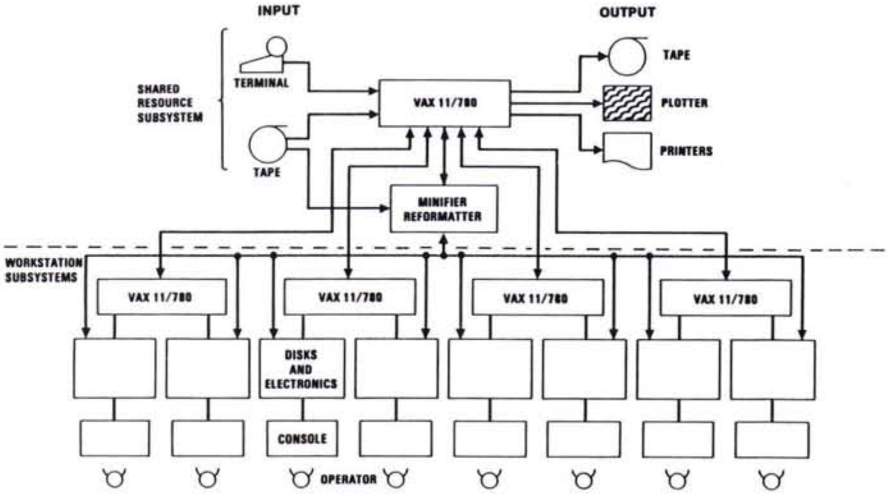

FIG. 1. DSCC system architecture.

intrinsic problems encountered in the design of softcopy photogrammetric workstations. It does so by relying heavily on special purpose hardware. At the time the DSCC was designed (late 70s early 80s), that was the only feasible way to meet the specifications of the development contract. Custom hardware would still be needed today, despite the impressive progress made in commercially available image processing products.

The image flow starts from the left of the block diagram. The blocks marked "Image Disks" and "Image Disk Control" symbolize the solution to the problem of rapid access to large image files. In the DSCC workstation the images are stored on a disk system with a capacity of 1800 MegaBytes (MB). The shared resource computer loads the disks with images in a block format, referred to as Fast Access File (FAF) format. The blocks are positioned on the disks in a manner that minimizes the access time to conjugate blocks. All five disks can be accessed simultaneously. The data from each disk is double buffered to permit a continuous output stream from the disks.

The disks feed the left and right stereo image channels. These channels are used to bring images to the stereo display, overview display, and correlator. Each channel starts with a resample memory. The purpose of the resample memories is to serve as sources of imagery to be transformed, filtered, and otherwise processed for display and correlation. The transformations include fractional pixel values. Hardware interpolators produce transformed pixel values by bilinear interpolation for all pixels in the stereo display at every 1/30-second cycle. This is a notable performance characteristic. It means that the DSCC is capable of on-line, real-time "rectification" and panning.

Both image channels include facilities for filtering and tonal

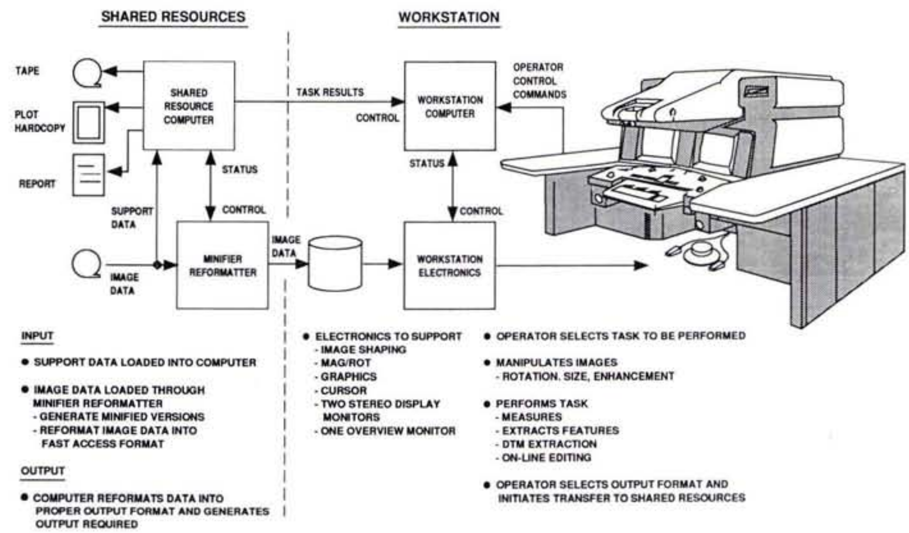

FIG. 2. The DSCC.

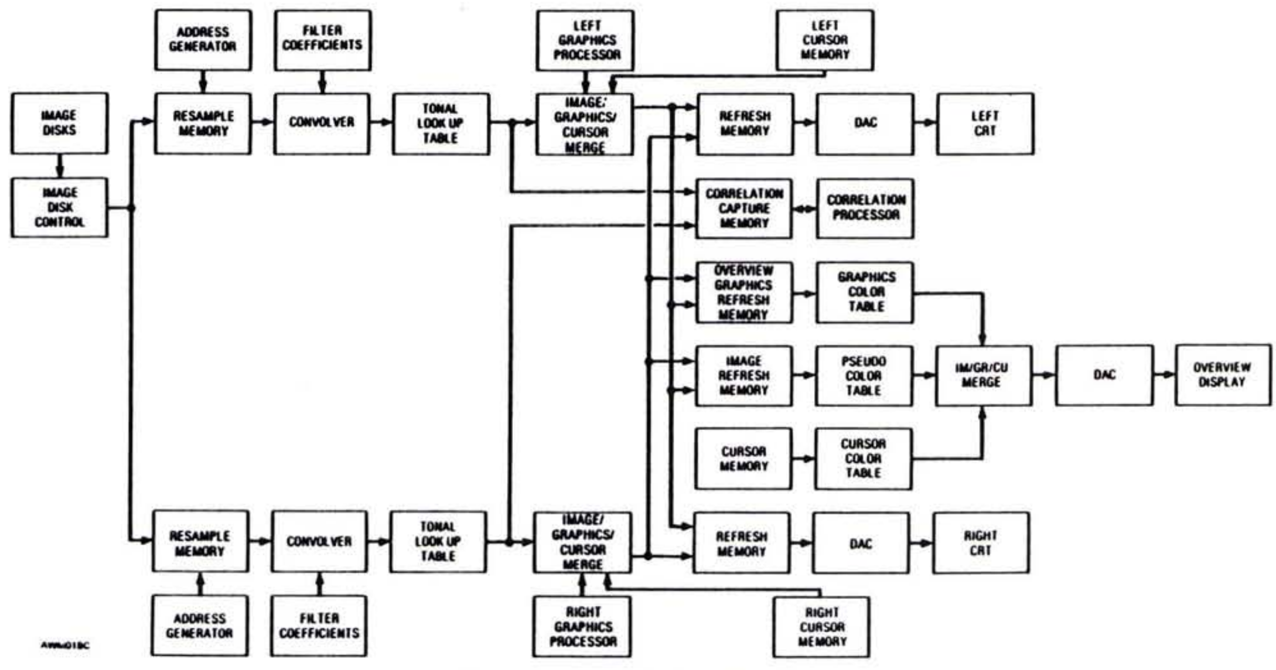

FIG. 3. Image and display processing.

adjustment. The filtering is done by 7- by 7-pixel convolvers implemented in hardware. A total of 256 filters can be accommodated. The tonal adjustments are based on tonal lookup tables. The transform curves are controlled by software to permit separate manual adjustments of contrast, brightness, and histogram.

Images, vector graphics, and the measuring marks are merged before the combined data are entered into the display refresh memories. Ground coordinate information is converted to image coordinates before it is loaded to the workstation graphics disk. There are two graphics processing channels similar to the image processing channels. The graphics processors perform vector to raster transformations and store the rasters to graphics resample memories. Geometric transformations and pixel interpolations exactly identical to the corresponding processes applied to the images are performed. The result is that the graphics coincides exactly with the corresponding image data. Furthermore, there is no jaggedness in the displayed lines. Tonal adjustments on the graphics channels permit regulation of the brightness of the displayed graphics. These graphics provide for precise operator feedback and quality control.

The measuring marks can be injected to form "fixed cursor" or "moving cursor" modes. In the fixed cursor mode, the cursor is permanently positioned in the center of the display, with the images moving "behind" the cursors. This results in operation which is visually very similar to conventional analytical plotters. In the moving cursor mode the images stay put and the cursors move "over" them. The fixed cursor mode places high demands on the image processor, particularly because fractional pixel pointing is required. The DSCC image processor does that to 1/128 pixel. The moving cursor mode reduces image processing requirements dramatically. The images need to be processed only once for potentially lengthy periods of measurements. Special cursor processing is performed for sub-pixel pointing.

The channels are fast enough to permit continuous roaming through the model on the disks at 400 pixels per second. An image transfer (jump) to anywhere within the model can be accomplished in less than two seconds. The overview display memory can be filled in 0.6 seconds. The correlator can be supplied simultaneously with stereo roaming, with image patches shaped and filtered differently from the images supplied for viewing.

Extension of DSCC to Triangulation.

The original DSCC contract did not include special provisions for triangulation. An automated capability for measuring multi-image tie points for triangulation was developed under a contract from the DMA in the mid 1980s. These capabilities are very similar to those implemented in the Digital Comparator Correlator System (DCCS) (Helava, 1987). They include algorithm based selection of tie point areas, use of an interest operator to find tie point candidates, measurement of several points at each location on multiple photographs using least-squares correlation, verification of measurements by local consistency checks, and automatic sequencing and recording of measurements. This extension of the DSCC has been well received; the workstations are used extensively for tie point measurement.

THE DMA WORKSTATION

The DMA workstation was designed as a component in a major upgrading effort started by DMA in the early 1980s. This workstation is designed to be the most comprehensive softcopy elevation and map feature extraction workstation to date.

System Configuration.

The DMA workstations are grouped into a cluster of several workstations working from a single large store of imagery. As in the DSCC, a shared resource computer system is employed to serve many workstations. A single workstation console is shown in Figure 4. Imagery is loaded to the workstation from the "Cluster Image Subsystem" (CIS). The CIS is a rack of 44 disks which operate in parallel. This allows the CIS to provide imagery on demand to all workstations in the cluster. Each workstation in the cluster provides for image decompression. This reduces the band width necessary to provide imagery to each workstation. The alpha-numeric terminals attached to the shared resources are used to manage the operations of the cluster.

A workstation functional block diagram is presented in Figure 5. Each workstation receives images from the CIS across the wide bandwidth channel at up to 270 MegaBits per second. Specially designed hardware provides the image processing and image decompression capabilities before the images are placed in resample memories. Once an image is in resample memory, it is processed in much the same way as described above for the DSCC. Differences include second-order image resampling in addition to bilinear. Any image on the CIS can be loaded into any workstation display within about 2 seconds. Images can be displayed on the stereo extraction monitor or overview monitor.

One of the major innovations in this workstation is the use of time-shared stereo viewing. In this system the stereo images are alternately displayed on the monitor at the rate of 60 image pairs per second. The stereo separation is realized by a liquid crystal screen that circularly polarizes the image in synchronism with the display. The screen is placed in front of the monitor, and the observer wears polarized glasses. The liquid crystal screen was made by Tektronix, whereas the drive and display electronics were designed and built by GD. This time-shared stereo display has been in use since mid 1986 without any problems. Similar displays are now in common use, such as with the HAI-500 and HAI-750 workstations described later. Each workstation consists of a host computer and several embedded microprocessors. The host computer is a MicroVAX 3. It serves three major functions: to store input controlling data and output collected terrain and feature data; to provide top-level control of the microprocessors; and to serve as the operator interface. The operator interface uses the popular windows-type design, but also has a command line option to expedite the process for the experienced user.

There are a total of ten 68020 microprocessors in each workstation to control the image processing, decompression, operator console hardware, superimpositioning of graphics on either the stereo or overview monitors, and to control the automated

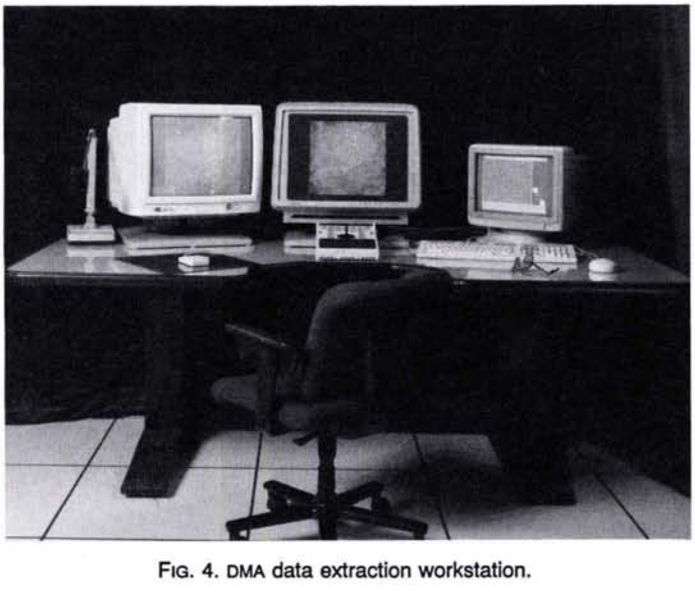

FIG. 4. DMA data extraction workstation.

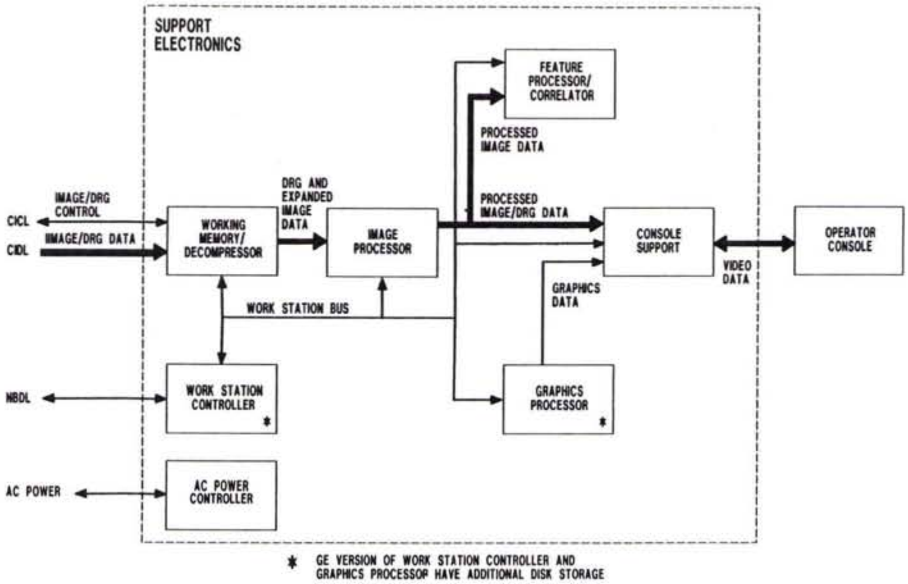

FIG. 5. Multifunction workstation.

feature and terrain extraction processes. Two array processors aid the performance of the feature and terrain extraction processes and are controlled by a 68020 microprocessor.

Functionality.
The DMA Workstation, as with the previously discussed General Dynamics' workstations, has the image processing abilities to allow for image enhancement (filter, tonal transformation, brightness, contrast, rotation, zoom, etc.) for the right and left channels of the stereo display and the overview display. The most significant improvements over the DSCC are the graphics processor and automated feature extraction tools. The graphics processor allows the continuous superimpositioning of thousands of feature vectors in stereo when the images are roamed at up to 400 pixels per second. The feature extraction tools are designed to increase production throughput in collecting digital feature data. The array processors are used to perform automatic feature delineation in three dimensions using a combination of machine vision tools. These include region growing, pattern followers, and correlation. These automatic tools can work simultaneously with the operator or independently. In addition to delineation tools, the workstation provides a knowledge-base system to aid the operator in the attribution process. Other improvements over the DSCC include increased performance and quality of the automatic DTM extraction process, and an extraction validator which automatically checks elevation and feature data for problems and blunders.

This new DMA workstations may represent the most encompassing effort known which provides automation in the extraction of elevation and feature data. This is also an important point because automation may be the key to making softcopy workstations cost effective in the commercial arena.

DIGITAL IMAGE WORKSTATION SUITE (DIWS)

The Digital Image Workstation Suite was designed and built for the U.S. Navy. This system was designed to receive a wide variety of both digital and film imagery. The workstation portion of the system is very similar to the DMA workstation. It is significantly different in the area of image loading and management. The functions of image handling represent one of the most significant problems to be solved in building softcopy photogrammetric instruments. The DIWS architecture does much to solve this problem.

System Configuration.
The System Configuration is shown in Figure 6. The input systems provide for imagery on VHS tape, 9-track tape, and film. A programmable decompressor provides for imagery which may arrive in unusual formats. Imagery is stored on the disk stack after being compressed into a standard compression format. From the disk stack, imagery is provided on demand to a number of workstations. The digitizer subsystem is used to scan film from a variety of sensor types. The digitizer can scan a 9- by 9-inch image at 12 micrometeres and store the data to a VHS tape at a rate of 2 MB per second. This provides for very rapid image input. An additional subsystem provides for image archiving. This device, known as the Honeywell Very Large Archive (VLA), holds VHS tapes in a "jukebox" type arrangement. This allows the machine to read or write any of the 600 tapes stored in the rack. The advantage of this type of device is obvious for those who desire to store large amounts of data and have it readily accessible at a workstation. The VLA can provide more than three terrabytes of image archive, and the workstation can utilize the data within minutes.

LOW COST WORKSTATIONS

So far, the systems we have described are generally more expensive than today's analytical hardcopy systems. They are also designed to be much faster in certain areas than today's hardcopy systems. This does not mean that softcopy systems cannot be cost competitive with hardcopy systems. In the following sections we describe lower cost, and lower performance, systems which have their own merits. These systems include the Digital Stereo Photogrammetric Workstation (DSPW), the Digital Comparator Correlator System (DCCS), the HAI-500, and the HAI-750 systems.

DIGITAL STEREO PHOTOGRAMMETRIC WORKSTATION (DSPW)

The GD/HAI team built the DSPW for the U.S. Army Engineering Topographic Laboratory (USAETL). The concept for this workstation came from the HAI-500 workstation and the engineers at USAETL.

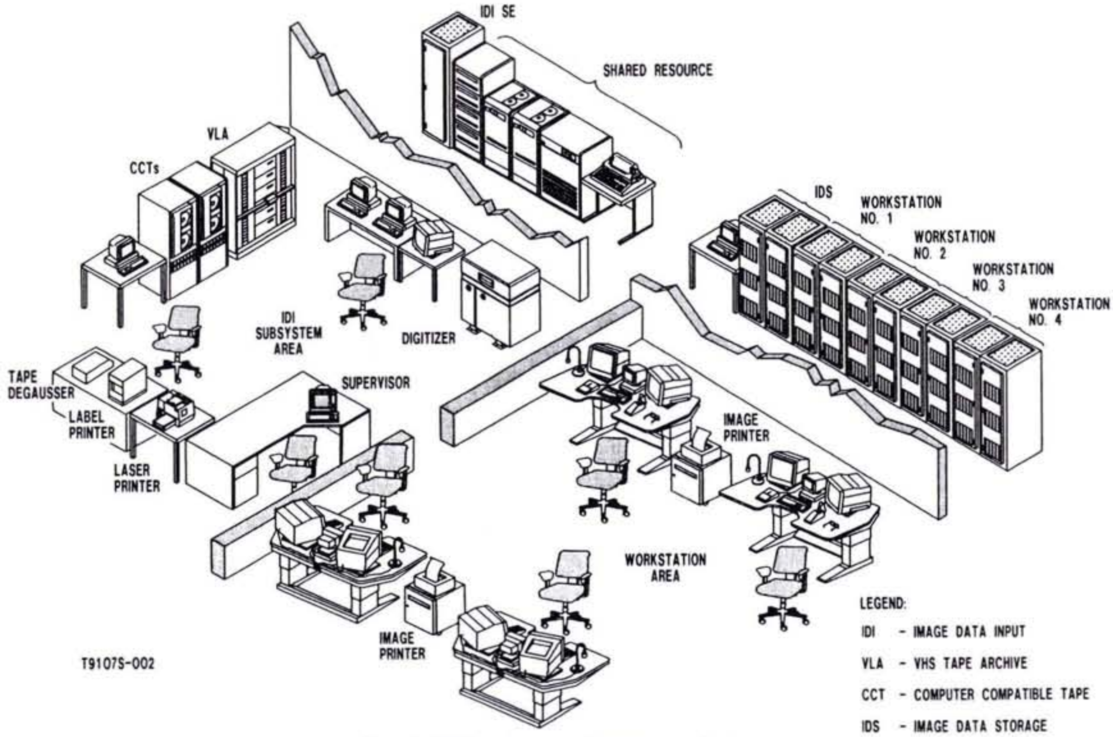

FIG. 6. Digital Imagery Workstation Suite.

System Configuration.

The DSPW is shown in Figure 7. This workstation uses completely off-the-shelf hardware combined with GD/HAI software to provide photogrammetric and mapping functions. Image input can come from scanners or 9-track tape and they are loaded to standard commercial disks. The system is SUN based and uses image processing boards to accelerate display and graphics functions. The SUN hosts an X-windows user interface, and a Tektronix's stereo monitor provides for stereo, mono, and split screen image exploitation.

Functionality.

The DSPW provides for photogrammetric functions including image warping, interior orientation, multi-image triangulation, and correlation functions. The triangulation functions are again multi-sensor as in the DSCC and provide for simultaneous exploitation of different sensor types including frame, panoramic, SPOT, and Landsat.

Exploitation functions for the DSPW include elevation and feature data import, extraction, and export. Automatic elevation extraction is provided and it is supported by interactive stereo graphics and editing functions. Feature extraction is currently being performed interactively as no automatic tools have yet been hosted on this system. The feature extraction provides for user defined classes and attributes and the user is supported by color graphics overlays and text. The DSPW system is capable of sub-pixel measurements, although not as efficiently as the previous systems. Typical manual point measurement precision for this system is 0.5 to 1 pixel as compared to 0.2 to 0.5 pixel for the systems described above. Of course, with automatic matching such as correlation, precision can be better than 0.2 pixel.

Performance in automatic elevation and feature extraction is less than the more expensive systems, but still, elevation extraction is much faster, on average, than manual methods. Because the softcopy systems provide high quality superimposed stereo graphics, quality control and operator feedback is much enhanced over most hardcopy instruments.

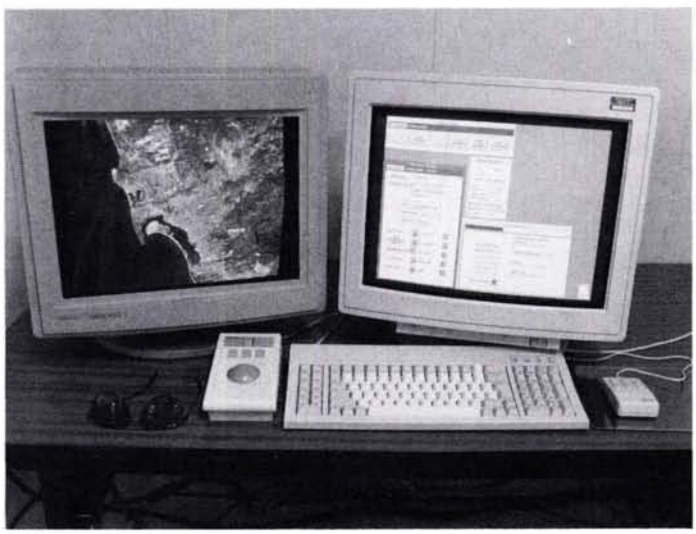

FIG. 7. Digital Stereo Photogrammetric Workstation (DSPW).

Image Processing.

Image processing performance is somewhat more limited on the DSPW than the systems described above. This system does not yet provide for image "panning" or real-time warping. Cursor and graphics positioning are provided to the nearest pixel and thus are not quite as precise as the systems described above. Image processing actions such as epipolar rectification, minification, and orthoimage generation are typically performed as background operations instead of in real-time. The system can provide filter, zoom, rotation, and radiometric manipulations on mono or stereo imagery. The imagery is tiled much like the FAF structure described above. This provides for faster access to any portion of very large images. The DSPW can provide exploitation for large images such as 9- by 9-inch images scanned at 12 micrometres. This allows the system to nearly match the precision of the best analytical plotters provided that good quality scanning is performed. Of course, this type of system is more accurate than an analytical plotter for processing digital data such as SPOT.

THE HAI-500 AND HAI-750

The HAI-500 and HAI-750 represent the lowest cost softcopy stereo systems. They were developed concurrently with the DSPW system described above and represent commercially available versions.

System Configuration.

The HAI-750 is configured the same as the DSPW system, with a Sun Microsystems, Inc., computer, image processing board, and time-shared stereo viewing using the polarized LCD monitor by Tektronix. The lower-cost HAI-500, shown in Figure 8, provides the same functionality as the Sun-based HAI-750, but uses an Intel 80386-based personal computer. Both systems use two monitors, one for the X-windows user-interface, the other for the stereo display. Input and output to the workstations is via tape (8 mm or other options) or by Ethernet from other systems.

Image Processing.

Image processing for the HAI-750 is as described above for the DSPW. Image processing for the HAI-500 is slightly altered. The HAI-500 currently uses a "piece-wise" image panning. This allows the stereo images to move on the display (more desirable than having the cursors move) within the total display memory available. The HAI-500 currently moves imagery in and out of memory slower than the HAI-750 due to the limitations of the host PC bus. Still, large images can be handled and most image resampling tasks are handled in the background. The HAI-750 uses a high-resolution, true color display processor. The HAI-500 uses an 8 bit display processor. Graphics overlay is accomplished (1) by destructive graphics, (2) by XOR graphics, or (3) the image is compressed into 5 bits and the graphics use the remaining 3 bits.

FIG. 8. HAI-500.

Functionality.

These systems provide photogrammetric functions which are similar to those described above including image rectification and minification; point measurement; interior and exterior orientation; multi-image and multi-sensor triangulation; user-defined feature specification, delineation, and attribution; automatic DTM extraction at up to 100 points per second; interactive DTM editing tools; and orthophoto product generation.

SUMMARY

We have attempted to briefly review the current softcopy photogrammetric systems designed and built by the GD/HAI team. Because this paper provides an overview of many systems, significant details of the systems have been omitted. We hope that this general introduction gives some insight into the current state of softcopy exploitation systems.

It seems clear that softcopy photogrammetric systems will begin to flourish in the commercial sector as they have in the government sector. The DSPW, HAI-500, and HAI-750 are examples of how commercially available "off the shelf" technology can be used to develop softcopy photogrammetric systems for commercial applications. Although we have not presented much numerical data about cost and performance, we still feel we can make the following generalizations. In specific areas such as elevation collection, point measurement, feature extraction, and orthophoto generation, softcopy exploitation can be more cost effective than hardcopy instrumentation. Cost/performance tradeoffs will often hinge on the types of imagery and products being generated. Scanning large stores of 9- by 9-inch imagery is still rather expensive and time consuming. For those products exploiting imagery such as SPOT, certainly, softcopy exploitation is the preferred approach. In either case, large commercial operations may benefit from softcopy photogrammetric exploitation, particularly when the products required include elevation grids, orthorectified imagery, or GIS applications. Because the costs of computer processing and storage continue to fall rapidly, it is reasonable to suggest that softcopy exploitation will become less expensive than hardcopy exploitation (even without digital sensors).

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Erratum

In the December 1991 issue of ***PE&RS***, (Vol. 57, No. 12), page 1523, the elevation difference in the cover image description is incorrect. It should be 2.6 kilometres.