Digital Photogrammetric Processing Systems - Current Status and Prospects

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Abstract

Recent advancements in computer and sensor technology have improved the capabilities and dropped the costs of digital components so drastically that digital processing systems are becoming increasingly available. This paper reviews design concepts of fully digital processing systems, focusing on systems with primarily photogrammetric functions. It addresses potential, characteristics and operational aspects of Digital Stations. The rapid development in this area also requires an outlook in the near future. The prospects will indicate that the time has come for Digital Stations with truly photogrammetric functions, to be used in fully automatic and interactive mode with high accuracy capabilities.

1. The Digital Station as a new category of photogrammetric instruments

Attempts to process aerial image data fully automatically with analog devices were first reported by P. Rosenberg in the early 1950s (*Rosenberg , 1955*). With the advent of digital image processing technology a new level of flexibility in algorithmic design emerged. Digital processing of space images, medical and other "non-conventional" imagery were among the earliest applications. This technology however, because of its frontier character, was not available for the great majority of the photogrammetric community.

Only recently have the advancements in semiconductor technology and micro-electronics - and the related decline of costs - caused a severe change in the availability of digital sensor technology and digital processing systems. Present-day photogrammetry has fully realised and accepted the change in working tools and is reaching out for the latest technology and the opportunity to enter new applications. Some of the recent Symposia are clearly indicating the new direction (Commission III: "From Analytical to Digital", Rovaniemi, Finland, 1986; Commission V: "Real-Time Photogrammetry - A New Challenge", Ottawa, Canada, 1986).

From the discovery of photography on it took about one century to the first analog instruments, from there on it took another half a century to the introduction of analytical plotters into civilian practice, but it took only another twelve years to introduce the new class of processing instruments: The digital system.

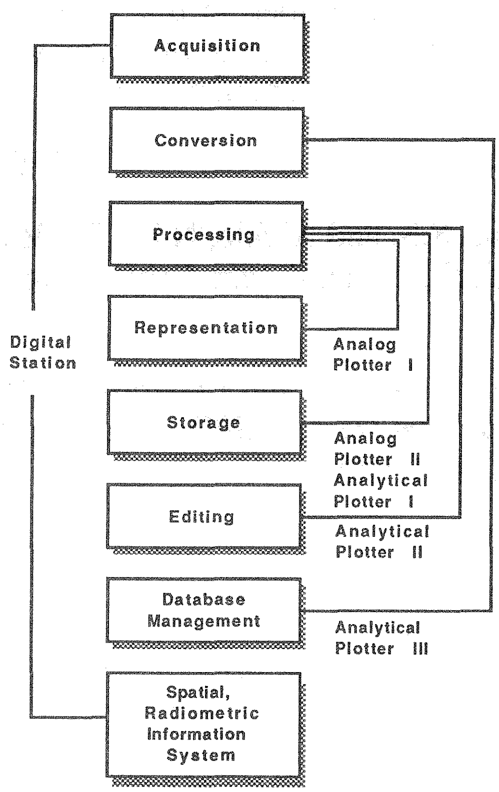

Fig. 1: Functional capabilities of photogrammetric instruments

In the context of digital photogrammetric processing systems the author prefers to call these instruments "Digital Stations", because of their unique ability to acquire, store, process, administer and output data and to perform all photogrammetric and related tasks in just one system. Thus this universal instrument represents much more than the term "Digital Plotter" would suggest. Figure 1 shows how a Digital Station ranks among other categories of photogrammetric processing instruments with respect to its functionality.
This paper is concerned only with fully digital systems, which are based on photogrammetric criteria of functionality and performance. It addresses inherent potential characteristics, and operational aspects of Digital Stations. Since we are at an early stage of system development, some design concepts are discussed and a view of hardware components is given with side-glances at latest developments.

2. Potential of a Digital Station

Analog and analytical photogrammetric data processing is characterized by a great variety of different instruments, e.g. comparators, stereoplotters, triangulators, rectifiers, orthoprojectors and special application equipment for non-conventional imagery, each of them used to perform certain specific tasks. These instruments vary greatly with respect to design, construction, universality, flexibility, accuracy, usage, control, input and output. Only the analytical plotters feature a certain degree of task integration, i.e. they allow execution of different types of tasks on the same instrument.

Products of a Digital Station could be

- Line and point mapping; image maps
- Point positioning; single model, triangulation
- Mass point generation; DTM
- Synthetic image products

Modes of operation are

- Operator controlled
- Semi-automatic
- Fully automatic

It can process

- Mono, stereo and multi-image arrangements
- Terrestrial, aerial and satellite imagery
- Different kind of imaging sensors, sensor combinations, non-imaging sensor data
- Digitized photographs, digital scenes

Other features include

- Photogrammetric and cartographic editing, incl. annotations
- Integration of computer graphics and image processing functions, e.g. superimpositioning of map and image data; generation and superimpositioning of synthetic imagery
- Interface to conventional instruments for input and output
- Products in analog and digital from (hardcopy, softcopy)
- Database functions; management of large amounts of data

3. Characteristics and Operational Aspects

A Digital Station is distinguished by a number of points from conventional photogrammetric instruments:

- No high precision optical-mechanical parts
- Robust measurement system; no wear and tear
- No instrument calibration, no manual image handling
- Stable images, no deformation over time
- Combination of automatic and operator controlled processing
- High degree of interactivity
- Data acquisition, processing, editing, storage and administration in a single system
- On-line and real-time capabilities

The basic photogrammetric functions could be used on a Digital Station in pretty much the same way as they are implemented on an analytical plotter. Beyond this the digital concept opens some interesting new aspects. Photometric operations, like enhancement, contrast alteration, enlargement/reduction, colouring, etc. can be performed quickly and inexpensively. Like an operator on a conventional instrument never needs the whole photograph/stereomodel at a certain moment for processing, the complete digital images do not have to be operated on (transferred, accessed, roamed, zoomed, resampled, etc.) at the Digital Station. Even in an operator controlled mode it would be sufficient to provide for a low resolution overview display on a separate monitor (for 1024 x 1024 resolution: a complete aerial photograph of 23 x 23 cm^2 could be displayed at 230 μm resolution at once) or in a section of the display/measurement monitor. Only small patches of the complete images could be used for display at the working monitor, like an operator sees only those parts of the photographs that are generated by the field of view of the optical trains. Those patches could consist of fiducials, control points, tie points, DTM-mass points, planimetric features to be mapped, etc.
If established once, the interior orientation of the images is included in the geometric definition of the pixels' locations. This relieves the operator from reestablishing the interior orientation in the case of remeasurement of previously used imagery.
The common a priori corrections for systematic error removal can easily be given to the images directly, as can those corrections which are determined by self-calibration via additional parameters in a triangulation routine. This resampling results in much better refined imagery for subsequent use and thus in better accuracy of the derived products. In addition, this reduction to the strict perspective model, without any corrections to be applied, also leads to a great simplification of the real-time loop formulae and of any other formulae which are used for processing.
An interesting option (after the interior and exterior orientations are established) would be to transfer the images to the normal case and to display and process those images.
Non-standard sensor data could be transformed into perspective imagery and then processed with the standard software.
Graphic overlay (superimpositioning) for completeness checking and quality control can be implemented easily and inexpensively even in the stereo mode.
Exciting new processing techniques can be applied, like image matching of more than two images (multi-image matching), which should be supported by geometrical constraints, and simultaneous matching of more than one patch with consideration of neighborhood conditions between adjacent patches (multi-patch matching).
Finally, only all-digital systems provide for real-time data acquisition and processing capabilities in a strict sense, which allows entry into new application areas.
There are more interesting new aspects to be considered when working with all-digital sytems, most of which will show up when processing procedures are practically implemented on a system.
In general, the Digital Station allows execution of otherwise expensive and time consuming procedures very fast and efficiently, with the prospect of attaining new levels of accuracy in the case of automatic processing.

4. Design Considerations

A modern Digital Station consists essentially of a workstation type of computer system with a more or less great variety of add-on devices. Figure 2 shows a possible configuration for a Digital Station.

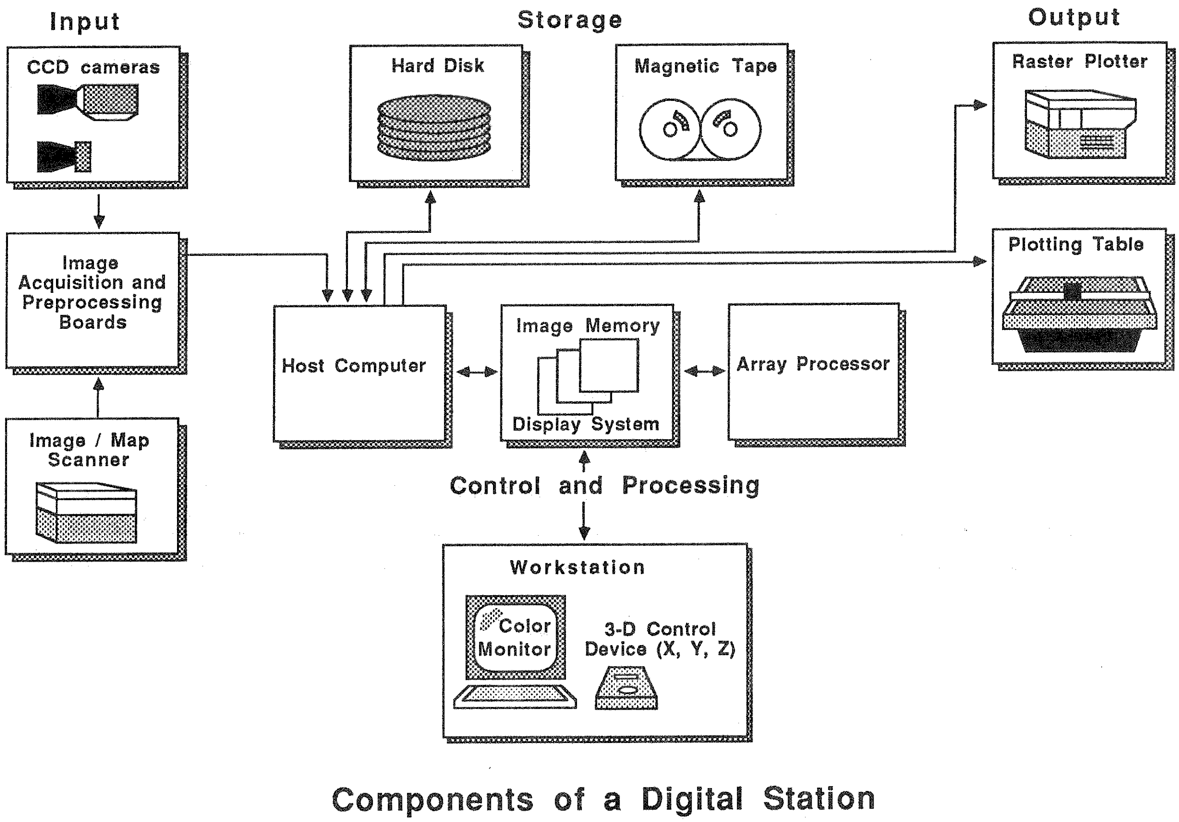

Fig. 2: Digital Station with a variety of add-on devices.

There are basically three different approaches to design and set up a Digital Station:

(a) Genetic concept
(b) Turn-key image processing system concept
(c) Modular concept

The *genetic* approach refers to custom-built systems (compare *Case, 1982*), which might be of great functionality and performance, but as far as costs are concerned, out of reach for the non-military user.
The *turn-key image processing system* concept uses an off-the shelf image processing unit to serve as the heart of the system. Grouped around this unit would be add-on devices in order to extend the functionality. Typical realizations of this concept are found in *Albertz, Koenig, 1984, El-Hakim, Havelock 1986, Gruen 1986 , Gugan, Dowman 1986,* with the image processing sytems Gould de Anza IP6432, DIPIX ARIES II, KONTRON IPS 68K, I^2S and GEMSYS35 respectively. The advantage of this approach is that some of the functions of the IP-system can be utilized for photogrammetric purposes right away and allows access to the digital domain very quickly. The disadvantage, as we have encountered, lies in the lack of

openness of such systems with respect to add-on hardware and software modifications or extensions. Performance in terms of basic IP-functions is usually acceptable, but functionality in the direction of image analysis functions is mostly poor.
It is our experience that the *modular* approach has the most intriguing long-term perspectives. Modularity means openness on the hardware and software side, it also stands for flexibility and adaptability with respect to costs and functionality. One can start with a small inexpensive system, and gradually build up as the financial means allow it.
All sorts of problems with hardware installations (interfaces, board implementations), the need to write extensive software packages from the very beginning, and the task to design and develop a suitable user interface for image and non-image data handling will cause a slow start with this concept. But once a certain operational level is reached, the independence and flexibility pays off in terms of quick modifications and extensions of software and by the ease in replacement of older components by the latest high performance hardware. Figure 3 shows a part of the (stereo) image acquisition and processing module of the second generation **Di**gital **P**hotogrammetric **S**tation (DIPS II) of our group at the Institute of Geodesy and Photogrammetry, ETH Zurich.

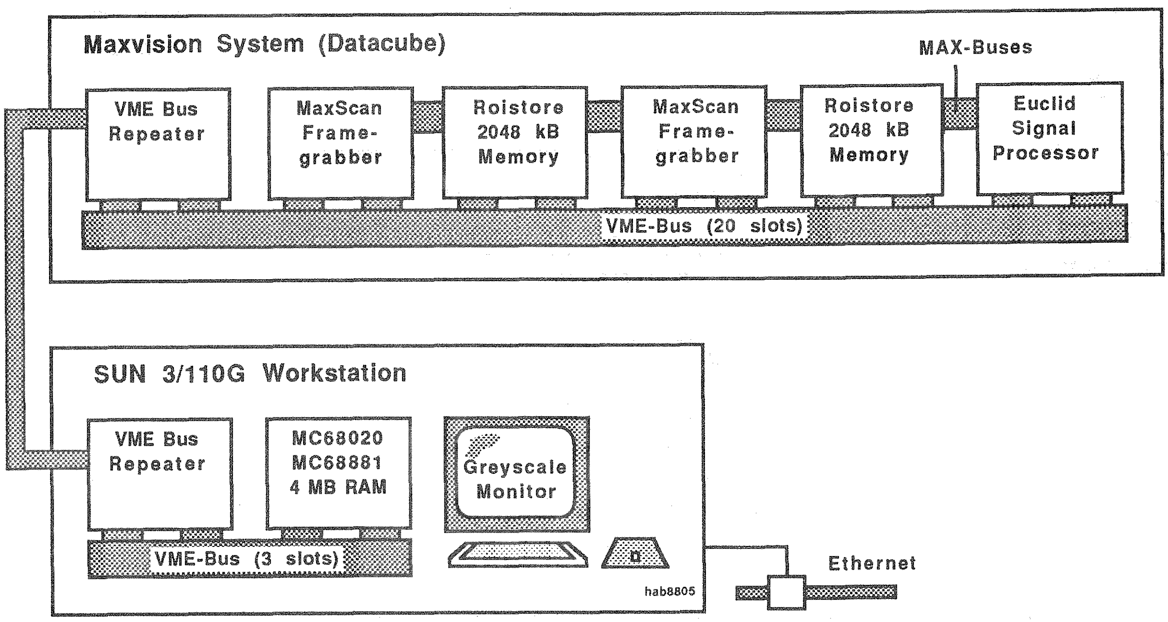

Fig. 3: The modular approach of DIPS II. Shown is a part of the image acquisition and processing module.

It seems that the UCL-group (*Dowman et al., 1987*) has recently also switched to the modular approach, using SUN Computers for image handling, computation and display.
The DCCS (Digital Comparator Correlator System) of Helava Associates Inc.*(Helava , 1987)* represents somehow a mixture between a genetic and a modular approach. It uses off-the-shelf hardware components, which however are integrated into a seemingly fixed system. Flexibility and room for expansion is mainly on the software side. The system was originally offered just as a triangulator, but growth potential is indicated in several directions, e.g. DTM generation, orthophoto and stereomate production, and feature extraction.
MacDonald Dettwiler's MERIDIAN system *(Swann et al., 1988)* does not yet represent a full Digital Station, because it is mainly oriented towards automated DTM-extraction and orthomap production from primarily MSS, TM and SPOT scenes, thus lacking flexibility.

5. A View at Components

The necessary components of a Digital Station depend on the functions required. A system like DCCS *(Helava, 1987)* uses only a few peripherals because of its restricted task requirement (triangulation and DTM generation).
Among components one may distinguish between software and hardware, and essential from less crucial units. Particularly if the host computer does not just serve as a controlling device but images are passed through it a critical check of its components is of great importance. Of particular interest should be the

- Display system and user interface
- Bus transfer rates
- Processor performance

5.1 Display System and User Interface

A good graphics monitor is crucial for operator comfort and precise measurements. The following parameters should therefore be considered in an evaluation procedure:

- Brightness
- Picture clarity, contrast
- Geometric distortion
- Defocusing, convergence
- Flicker
- Reflection, glare
- Pixel non-linearity

A bit-mapped display is standard nowadays. A 1150 x 900 pixel resolution already provides for a comfortable working environment. High resolution display systems are now available at 2048 x 2048 resolution with 0.125 mm dot size (AZURAY 2000/BW) and will in the future greatly improve the user interface.
A flicker-free non-interlaced monitor with at least 60 Hz refresh rate is mandatory.
The usual 8 bit plus 1 bit overlay depth of standard workstations is not sufficient. A depth of 24 bits plus 2 or 3 overlay bits has to be requested.
Grayscale monitors give a crisper display than colour monitors. Colour, on the other hand, if not needed for the images anyway, is preferable for overlay operations.
For fast and convenient framebuffer updating and image display a double buffered framebuffer is mandatory.
RAM for image storage and display should be as large as possible in order to be able to accommodate even large image formats. 2 MByte RAM boards are currently standard. They allow to store eight 512x512x8 bit scenes. GEMSYS 35 supports up to 16 modules, each of 16 MByte, to extend memory capacity by up to 256 MByte. This voluminous image memory can be accessed by a display generator which can handle up to 3 display planes and store up to 2 MBytes per display plane.
A digitized aerial photograph of 12.5 µm pixelsize requires about 20 000 x 20 000 pixels or about 0.4 GByte. This indicates the tremendous requirements that are put on these display systems when processing standard aerial photographs. To make it clear: panning/scrolling through an aerial photograph does not require this amount of RAM; one could set up a virtual memory procedure where, let's say, an 8 MByte RAM holds for stereo display two 2000 x 2000 pixel images. If, during panning/ scrolling, the perimeter of an image is reached a flag is automatically activated which loads the adjacent image from disk, thus replacing a part of the old RAM-stored image. In this respect it is interesting to note that real-time disks like Fujitsu PTD 474 MB come with 9.3 MByte/sec, allowing a video transfer rate of 30 frames/sec of 512 x 512 x 8bit images.
Fast roaming for overview operations could be done in a coarse resampled image (an aerial photograph could be stored in a 512 x 512 pixel image at 450 µm pixel size).
For precision measurement purposes a maximum roam rate of 2.5 mm/sec (at the scale of the aerial photograph) should be requested, which corresponds at 12.5 µm pixel size to 200 pixel rows/columns per second. This requires, when working with 512 x 512 pixel images in

stereomode, a data transfer rate of 0.2 MByte/sec, which does not cause a real problem. Furthermore, for precise pointing the size of the images and thus the data rate could be substantially reduced.
The resolution of the human eye corresponds to about 70 μm pixelsize at reading distance. Standard workstation display monitors have pixel sizes of 200-300 μm. This would require a displayed image to be optically reduced by a factor 3 to 4 for appropriate operator viewing. This problem is not so much obvious when viewing continuous graylevel images, but becomes very disturbing when binary images are displayed.
The resolution of the measurement systems of modern photogrammetric instruments is usually 1 μm. Requesting this resolution from a digital system means that the displayed images have to be either zoomed or resampled during roaming accordingly. Integer zooming is inexpensive, but the pixel structure shows up soon and disturbs the pointing. On-line resampling needs special hardware, like the MK II Warper System from DATACUBE INC., a set of two boards which evaluates a bi-cubic polynomial in 32-bit floating point format at 5 MHz and a reduced bi-quadratic polynomial at 10 MHz.
A key problem is the stereo display. There is a great variety of technologies to choose from:

- Anaglyphs
- Stereo Image Alternator (Shutter principle, time multiplexing)
- Stereoscope technique (single tube/split screen; twin tubes; miniature tubes)
- Polarization (single tube/split screen; single tube, active, passive (PLZT, LCD); twin tubes)
- Autostereoscopic with vertical parallax induced alternating pairs
- Lenticular screen
- Holography
- Others (Cycloramic display, LC sandwich screen, vari-focal mirror, etc.)

Technologically fully developed and financially affordable are anaglyph, split screen stereoscope, and polarization displays. Anaglyphs have the disadvantage of colour assignment (thus colour images cannot be displayed) and the related reduction in graylevel depth is 50 %.
Split screen stereoscope systems are easy to install and handle, and give clean 3D-visual models with full graylevel depth. The well-known disadvantage is the restriction to one-person viewing. This is overcome by polarization displays. Here two concepts are popular: the active and the passive system. With active systems the observer wears the shutter device. It consists of two linear polarizers whose axes of polarization are rotated by 90°. Between the polarizers is a lead lanthanum zirconate titanate (PLZT) ceramic wafer or a liquid cristal π cell which can rotate light by 90°, so that light which passes through the first polarizer also passes through the second. Two shutters are mounted similar to eyeglasses and are worn by the operator. The shutters are synchronized to the refresh rate of the monitor.
With passive systems the polarizer is placed right in front of the monitor. This shutter alternates the polarization of the images at the same rate as the images are put on the screen. The operator wears correspondingly polarized glasses. So far the author had only the chance to check the TEKTRONIX TEK 4126 system *(De Hoff, 1986)*, with colour wireframe models on display. The spectral transmission rate of this technique is only at best 30 %, and might cause problems when viewing graylevel images.
What should also be mentioned here are the helmet mounted stereo display systems that are anticipated for use by remote controllers of robots. These systems typically use two 3.2" (or smaller) LCD screens, one for each eye, mounted together on a helmet and fed directly by video camera images or from a database *(McMillan, 1988)*.

Also deserving some consideration is the hardware part of the user interface. Here a variety of control elements are available:

- keyboard, digitizing pad, lightpen, touchpad, touchscreen, trackball, joystick, thumbwheel, footwheel, footswitch, mouse, voice entry

Tests need to be performed in order to select the most suitable elements on the basis of ergonomic and accuracy criteria. A related test for single point measurements with untrained personnel is reported in *Beaton et al., 1987*.

5.2 Bus Considerations

If image data has to be channelled through a system bus, its transfer rate usually creates a serious bottle neck. For the VME bus of the SUN-3/200 series an I/0 access rate of 5 MByte/sec is specified. Practical tests have shown that this rate cannot be sustained when transferring image data. Our experience corresponds to five 512 x 512 x 8bit images per second. This may suffice for a great number of point positioning tasks, but certainly not for "continuous" operator-image interactions like panning and scrolling over large areas, and not for video real-time display requirements of image sequences.
Thus a fairly large RAM can compensate for some of these shortcomings; and fortunately, RAM is becoming more and more affordable.
For fast image data transfer "image buses" are used, which connect individual boards to each other and which are typically clocked at 10 MHz with data rates of 20 MByte/sec. New architectures already deliver 80 MByte/sec (SUN's TAAC-1) or even 240 MByte/sec (PIXAR's Pbus).

5.3. Processor Performance and Image Computing

Modern CPU chips like Motorola's 68020, especially if supported by a Floating Point Accelerator, already show a remarkable performance level, which allows many basic photogrammetric functions to be performed within the required time frame. A 4 MIPS machine like the SUN-3 280S manages easily the "inner loop" of the perspective equations for x^I, y^I, x^{II}, y^{II} - control given X, Y, Z with a 60 Hz frequency and other relevant operations.
Despite this fact it is advisable to offload the host processor so that it can effectively handle system controlling, windowing and other user interface tasks, and high level application programs that are difficult to install on a special purpose processor and which are either running outside an interactive session or even supporting user operations on-line (e.g. DTM interpolation, triangulation, automated matching, differential rectification, etc.).
For fast high level image processing and analysis however, it needs extra processor hardware. Here a number of architectures are offered, which have already partly shown their capability in very demanding machine vision applications *(Pratt, Leonard, 1987):*

- Hardwired pipeline
- Frame recirculating pipeline
- Network-switched pipeline
- Algorithmic-based pipeline
- Systolic pipeline
- Cellular array
- Augmented cellular array

Recent news about the Connection Machine of Thinking Machines Corporation, MA, with its 16 000 to 64 000 processors working in parallel clearly demonstrates the path that high performance processing takes. Although this machine "...transformed in two seconds a stereoscopic image transmitted by a pair of television cameras into a detailed, two-dimensional contour map" *(Elmer-de Witt, 1986),* thus obviously solving some of our problems in a fraction of the actually required time, it is much too expensive to be used in photogrammetric workstation type systems. Nevertheless, even less dazzling, but affordable new developments will soon change the way image computing is perceived.
The fastest progress in vision system components can be identified in those areas which are of more general interest, like general computer components, or components required for computer graphics and universal image processing applications. General and special purpose processors, image memory and image data buses belong to this category. Image Computing is currently developing at a very fast rate. A characteristic trend is the fusion of the closely related disciplines of computer graphics and image processing. Powerful systems and subsystems at a reasonable cost level that have recently emerged are (just to name a few) PIXAR Image Computer *(Pixar, 1987),* SUN's TAAC-1 Accelerator *(Transcept, 1987),* VITec Image Computer *(Computer Graphics World, 1987).* These systems feature up to 240/480 MByte/sec data transfer rates for processor and video memory buses respectively, 160 MIPS image and

graphic processing performance, and 48 MByte image memory. The potential of these systems exceeds the requirements of machine vision systems to an extend that they may as well be utilized as components of general digital photogrammetric stations.
Another new generation image computer is AT & T Pixel Machines' PXM 900 *(McMillan, Farah, 1988)*. It is a parallel configuration of up to 82 Floating Point Digital Signal Processors (DSP) with a combined compute power of up to 820 MFLOPS.
Compared to other architectures, like general purpose microprocessors, custom hard-wired processors, and bit-sliced processors, DSPs combine several advantages: ease of use, flexibility and high performance. High-level tools include C-compilers and debuggers. For high speed a C-like assembly language is available. DSPs can easily be combined to a multiprocessor configuration. Harvard architecture and hardware multipliers allow them to perform three-operand multiply-accumulate operations in a single instruction.
The TI TMS 320 signal processor chip has been very succesfully commercially. It comes with separate array multiplier, Harvard architecture and RISC (reduced instruction set) architecture.
The PXM 900 Image Computer uses AT & T's DSP 32 in combined pipeline/parallel array configurations of up to 18 DSPs in a pipeline and up to 64 DSPs in the subsequent parallel array. While the pipeline typically handles high-level three-dimensional image synthesis operations, like geometric transformations, clipping, shading coefficients and maps 3D-object space into 2D-screen space, the parallel array performs drawing and rendering functions and speeds up frame buffer access dramatically. A recent benchmark on the PXM 900 mentions a drawing rate of 16 million Gouraud-shaded pixels per second and 1 million ray intersections per second.

6. Conclusions and Outlook

The current situation clearly indicates that we are at an early stage of development of fully digital photogrammetric systems. First experiences show the great potential of this new category of instruments. Different design concepts are still being tried out, which is not unusual considering the fact that the computer components are currently advancing at an incredible pace in terms of high performance and low costs. A Digital Station will always be strongly correlated with the general computer development, and in particular with the emerging fields of "image computing" and "visualization".
These areas will benefit from new computer hardware developments, which will allow combination of supercomputer performance with workstation functionality. The emergence of true 3D-computer graphics systems, and the integration of image and non-image data, sound, text and algorithms in a simultaneous processing environment will not only provide Digital Photogrammetric Systems with an amazing level of functionality, but also redefine photogrammetric products and by-products. Historically this marks the transition from "analytical photogrammetry" with digital computer support and its primarily "list of coordinates" - oriented products to 3D-graphically visualized products. From wireframe DTMs and perspectives to solid modelling/shading and grayvalue pixel and map feature overlay, from a coordinate description of the object to full realism - photogrammetric processing and products will generate a 3D-visualization environment, combining true and synthetic pictorial information.
The integration of image processing and computer graphics hardware requirements and functions in a single processor engine will ultimately lead to combined image analysis/image synthesis systems. This development paves the way for truly functional and efficient photogrammetric systems. As "visualization" will unify the fields of computer graphics, image processing, computer vision, computer-aided design, signal processing and user interface studies, photogrammetry - as a typical "vision discipline" - will truly benefit, grow to higher levels and reach into new applications.

References:

Albertz, J., Koenig, G., 1984: A Digital Stereophotogrammetric System. International Archives of Photogrammetry and Remote Sensing, Vol. 25, A2, Commission II, Rio de Janeiro, pp. 1-7.

Beaton, R.J., De Hoff, J.R., Weiman, N., Hildebrandt, P.W., 1987: An evaluation of input devices for 3-D computer display workstations. SPIE Proceedings, Vol. 761, "True Three-Dimensional Imaging Techniques and Display Technologies", pp. 94-101.

Bridges, A.L., 1987: Three-dimensional stereographic pictorial visual interfaces and display systems in flight simulation. SPIE Proceedings, Vol. 761, "True Three-Dimensional Imaging Techniques and Display Technologies", pp. 102-111.

Case, J.B., 1982: The Digital Stereo Comparator/Compiler (DSCC). International Archives of Photogrammetry, Vol. 24 - II, pp. 23-29.

Computer Graphics World, 1987: VITec Computing. Computer Graphics World, July 1987, Vol. 10, No. 7, pp. 33-34

De Hoff, R., 1986: The next generation: Computer graphics in three dimensions. Tekniques, Vol. 10, No. 1, pp. 28-31.

Devarajan, V., Heslep, M.C., 1987: Digital photogrammetry on an advanced data and picture transformation system (ADAPTS). SPIE Proceedings "Methods of Handling and Processing Imagery", Vol. 757, pp. 84-87.

Dixit, S.S., 1987: Hardware and software architectural considerations in image and graphics processing. SPIE Proceedings "Methods of Handling and Processing Imagery", Vol. 757, pp. 131-138.

Dowman, I.J., Gugan, D.J., Muller, J.P., O'Neill, M., Paramananda, V., 1987: Digital Processing of SPOT data. Proceedings "Intercommission Conference on Fast Processing of Photogrammetric Data", Interlaken, June 2-4, pp. 318-330.

Elmer-De Witt, Ph., 1986: Letting 1,000 Flowers Bloom. The Connection Machine takes a novel approach to computing. Article in TIME, June 9, p. 52.

El-Hakim, S., Havelock, D., 1986: Digital image processing facilities at the N.R.C.C. photogrammetric laboratories. Int. Arch. of Photogrammetry and Remote Sensing, Vol. 26-2, pp. 155-156.

Gruen, A., 1986: The Digital Photogrammetric Station at the ETH Zurich. Int. Arch. of Photogrammetry and Remote Sensing, Vol. 26-2, pp. 76-84.

Gruen, A., 1987: Towards real-time photogrammetry. Invited Paper to the 41. Photogrammetric Week Stuttgart, September 14-19, 33 pages.

Gugan, D.J., Dowman, I.J., 1986: Design and implementation of a Digital Photogrammetric System. International Archives of Photogrammetry and Remote Sensing, Vol. 26, Part 2, pp. 100-109.

Helava, U.V., 1987: Digital Comparator Correlator System. Proceedings "Intercommission Conference on Fast Processing of Photogrammetric Data", Interlaken, June 2-4, pp. 404-418.

Hodges, L.F., McAllister, D.F., 1987: Three-dimensional display for quality control of digital cartographic data. SPIE Proceedings "True Three-Dimensional Imaging Techniques and Display Technologies", Vol. 761, pp. 146-152.

McLaurin, A.P., Jones, R.E., Cathey, LeC., 1987: Single-source three-dimensional imaging system for remote sensing. Optical Engineering, Vol. 26, No. 12, pp. 1251-1256.

McMillan, T., 1988: Creating VEDS. Computer Graphics World, January, p. 42.

McMillan, L., Farah, B., 1988: DSPs boost graphics. Computer Graphics World. April, pp. 89-94.

Pixar, 1987: Product Brochures. Pixar, P.O. Box 13719, San Rafael, CA 94913.

Pratt, W.,K., Leonard, P.F., 1987: Review of machine vision architectures. SPIE Proceedings "Image Pattern Recognition: Algorithm Implementations, Techniques, and Technology", Vol. 755, pp. 2-12.

Rosenberg, P., 1955: Information Theory and Electronic Photogrammetry. Photogrammetric Engineering, Vol. 21, No. 4, pp. 543-555.

Swann, R., Hawkins, D., Westwell-Roper, A., Johnstone, W., 1988: The potential for automated mapping from geocoded digital images data. PERS, Vol. 54, No. 2, pp. 187-193.

Transcept, 1987: Product Brochures. Transcept Systems Inc., 500 Uwharrie Court, Raleigh, NC 27606.

Weiner, L.R., Weiner, A., 1987: Applications for broadcast video equipment in image processing. SPIE Proceedings "Methods of Handling and Processing Imagery", Vol. 757, p. 111-115.