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DESIGN AND DEVELOPMENT OF A DIGITAL PHOTOGRAMMETRIC SYSTEM

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1. INTRODUCTION

The development of instruments in the field of photogrammetry during the last century can be seen in three phases. During the first phase analog instruments have been developed being able to measure stereoscopically in analog photographs and to produce line maps. Due to developments in computer technology, this era of avoiding computation by optomechanical istruments was followed by the so called analytical instruments, where still the images remain of analog type, but the measurement procedure and computations based on photo-coordinates are computer assisted. Recently the developments in computer (32 bit computer) and sensor technology (digital images) made the applications of image processing techniques in the evaluation process feasible. During the past 20 years users have gained knowledge in the field of digital image processing of satellite imagery for thematic and topographic mapping.

With the introduction of high resolution digital stereoscopic images originating either from satellites or from airborne sensors, the demand of processing this type of imagery in its original form (i.e. digital) for several reasons becomes of incresing importance. As an example some prototypes of digital photogrammetric workstations have been developed during the last few years (Gruen, 1988). Because digital information is being processed with digital methods and instruments, the advantages of such systems in comparison to analog or analytical instruments are:

- No need for high precision opto-mechanical parts
- Robust measurement system
- Stable image geometry (once an image is in digital format, its geometry remains constant)
- High degree of automation
- Instrument versatility (Monoplotter, Stereoplotter, Rectifier).

Recognizing decreasing hardware costs, the possible advantages of such systems in addition may be the increase in accuracy, which together with automation yields in a possible faster availability of results (Helava, 1988).

In 1987 the Institute of photogrammetry of the university of Hannover together with the company CONTEXT Vision, a Swedish manufacturer of image processing systems, decided in a joint cooperation to develop a digital mapping system, called the CONTEXT MAPPER.

2. DESIGN CONSIDERATIONS

Analyzing existing systems, there are three major approaches for the development of digital photogrammetric systems. Table 1 summarizes these approaches together with their advantages and disadvantages.

Tab. 1: Classification of existing systems

Systems	Advantage	Disadvantage
Custom built systems	great functionality high performance task related	generally very expensive
Image processing systems	direct use of image processing functions and data structures	lack of openess with respect to hard- & software extension
Modular systems	open with respect to hard- & software design and implementation; high flexibility	high effort to start up requires basic developments in the field of user interfaces and data management

The main requirements for a digital photogrammetric system are the ability of scanning within the total model area, sub-pixel measurement accuracy, 3-dimensional control of the floating mark and stereo viewing. These requirements and the possible application of digital correlation techniques were the primary design ideas at the beginning of the system development.

2.1 Hardware and components used in the project

The design and development of the system was based on an existing image processing system (see Figure 1), the GOP 302 (Konecny, 1988).
The host processor consists of a SUN-3™ supervisor processor (SVP) with 20 MHz MC 68020 CPU and MC 68881 floating point co-processor running under UNIX 4.2 operating system. Special processors like the general operator processor (GOP) for fast complex filtering and correlation and a geometric transform processor (GTP) for quick geometric transformations and resampling can be accessed via the VME bus.The digital images are stored on Winchester disks or optional optical discs. The size of the imges to be handled is limited only to the size of these discs. The basic image processing system is equipped with one display control unit (DCU) per workstation. This DCU is based on a MC 68000 display control processor (DCP) having a real-time operating system written in MODULA2, which in the booting process is

downloaded to the DCP from the SVP. The DCP controls the image display system and its related display functions. It communicates with the SVP VME-bus via a dual ported random access memory (RAM) of 16 KBytes. In addition 4 serial communication lines (TAP's) are available. Images, graphics, on-screen menus and also the cursor in its current position are stored in the display memory. The memory, a standard 2 Mbyte RAM board, is organized in an image area of 1 Megapixel (16 bit) and a menu area, where each of the cursors, menu and two graphic planes occupy a full one bit plane. Using a full bitplane for the cursor allows freedom to move over the entire display without restrictions, as well as chosing an arbitrary cursor shape. The display window is 512 x 512 pixels, which may be roamed realtime over the total of 1 Megapixel area without having to reload the image memory from disc.

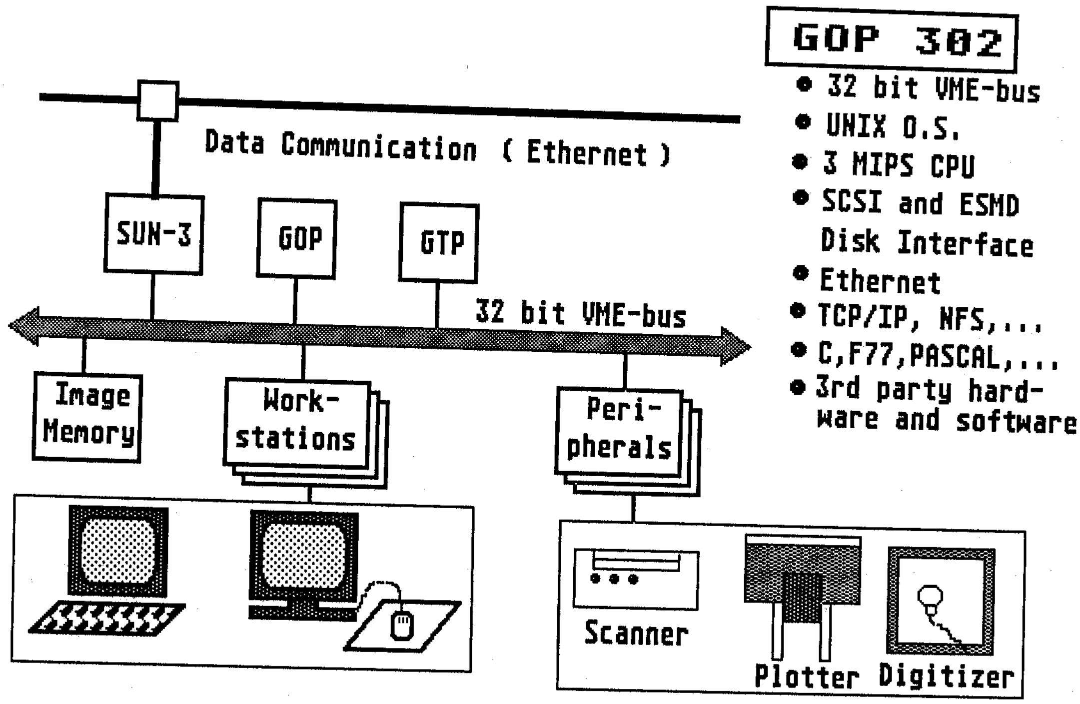

Figure 1: The GOP 302 Configuration

2.2 Software design aspects

In designing digital photogrammetric systems (Lohmann, 1989) one has to consider three major tasks, which a system should be able to work on (see Figure 2).

- **Monoplotting**

  Monoplotting (Stokes, 1987) means a map revision system, where digitized aerial photography or satellite imagery is transformed to the relevant map projection system and scale, taking elevation differences into account. For compatibility and standardization the measurement program should basically be the same as in the case of stereoplotting and image rectification, which means that in the case of monoplotting the measurement program is a subset of the measurement program for stereoplotting.

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- **Stereoplotting**

  Digital stereoplotting enables the 3-dimensional evaluation of digital stereoscopic image pairs, automatically or operator assisted with the possibility of stereo viewing of the model. It should comprise the following main features:
  - stereo viewing and control
  - handling of arbitrary image sizes
  - real-time zoom and roam
  - sub-pixel pointing accuracy
  - orientation, adjustment and compilation software
  - on-line image enhancement and feature extraction
  - automatic (correlation) and manual measurement of digital evaluation models (DEM)
  - 3-dimensional superimposition of graphics
  - on-line graphic editing functions
- **Image Rectification**

  Any image or map in the system may be transformed into any projection system. If a DEM is introduced, orthogonal projections in any coordinate system can be resampled. Mosaicking software should enable the user to produce orthophoto maps from a series of adjacing or overlapping photographs or satellite scenes.

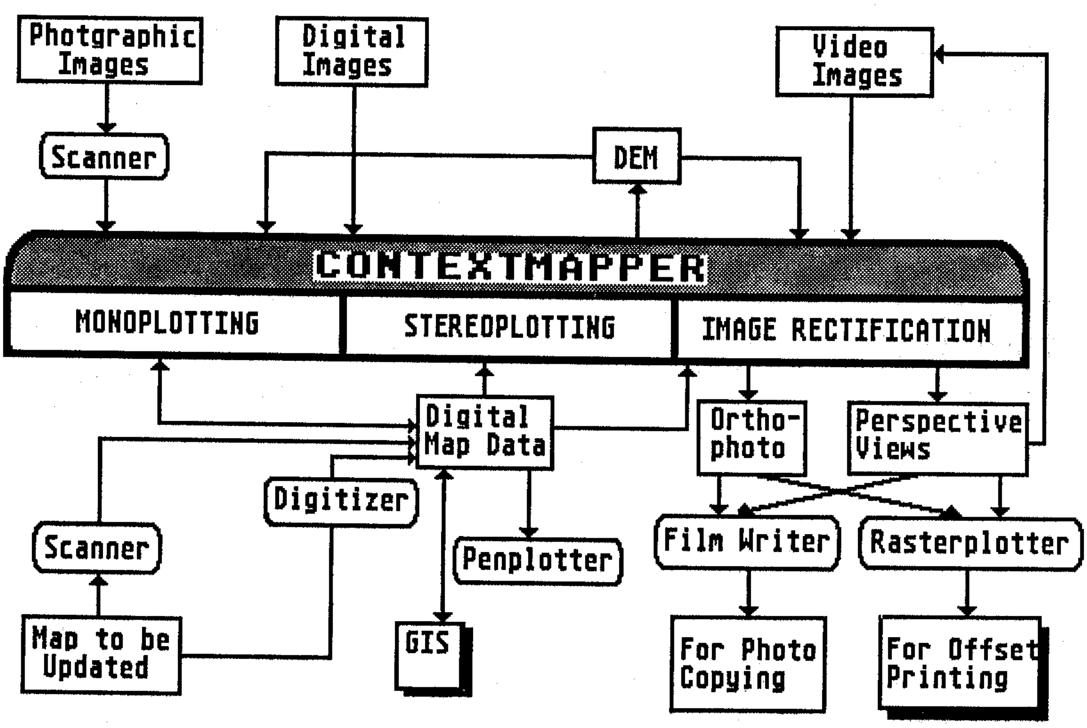

Figure 2: The CONTEXT-MAPPER System

Besides these three main tasks a variety of utilities for input and output of images, DEM, maps and other data had to be developed. For reasons of compatibility and standardization, it was decided to use 'C' as programming language.

2.3 Hard- and Software Constraints

As the development was based on an existing image processing system, several hard- and software constraints had to be considered.

2.3.1 Stereo Viewing

For stereo display different approaches are known (Grün 1988), but only three methods are currently considered to be operational, namely the anaglyphic method (Albertz, 1984), the use of stereoscopes (Cogan, 1978) and the active or passive polarization technique (Euget, 1988), the latter one demanding changes to the existing hardware. Anaglyphic methods have the disadvantage of being unable to display images in color. Therefore only the use of stereoscopes has been considered. Due to the limited size of the display windows (512 x 512 pixel) split screen techniques did not seem to give a sufficient field of view. Therefore two standard DCU's have been selected each controlling one color monitor. These two monitors have been placed behind a mirror stereoscope built into a viewing box. The selection of two DCU's in addition provided full use of color image processing power within each display. However, because using a mirror stereoscope without DOVE prisms, the images have to be resampled to epipolar geometry or at least to a common yaw in order to make full use of the on-screen menu technqiue. This resampling can be done with the geometric transform processor (GTP), which has a performance of 6 Mbyte/sec including cubic interpolation (IEEE, 1981).

2.3.2 Subpixel Measurement

In general there are only two ways to establish subpixel pointing accuracy in digital images. The one is zooming the images, while the cursor plane remains in the original resolution. This, however, requires independent zoom between graphic and image planes. The other possibility is to move the image by fractional pixels. While a resampling of the entire displayed image needs a high computing power of the display processor, it was decided to do the resampling only in the vicinity of the floating mark. Thus a 16 x 16 window around the floating mark is resampled using bilinear interpolation. The resampling is being weighted with a distance function to the floating mark, in a way, that boarder effects at the transition zone to the original image do not disturb the visual impression. This resampling, however, requires an additional workload of approximately 7.600 floating point operations (FLOPS) per cycle, which in comparison to the photogrammetric computations of ~ 200 FLOPS puts a heavy workload to the DCP.

2.3.3 Drive System

As it was decided at the beginning of the project to use only the existing hardware components all 3-dimensional control and the registration of coordinates had to be handled by a 3-button mouse, which was part of the system and which is used to control the movement of the images and the on screen menu handling. Figure 3 shows the mouse together with the associated functions of the three buttons.

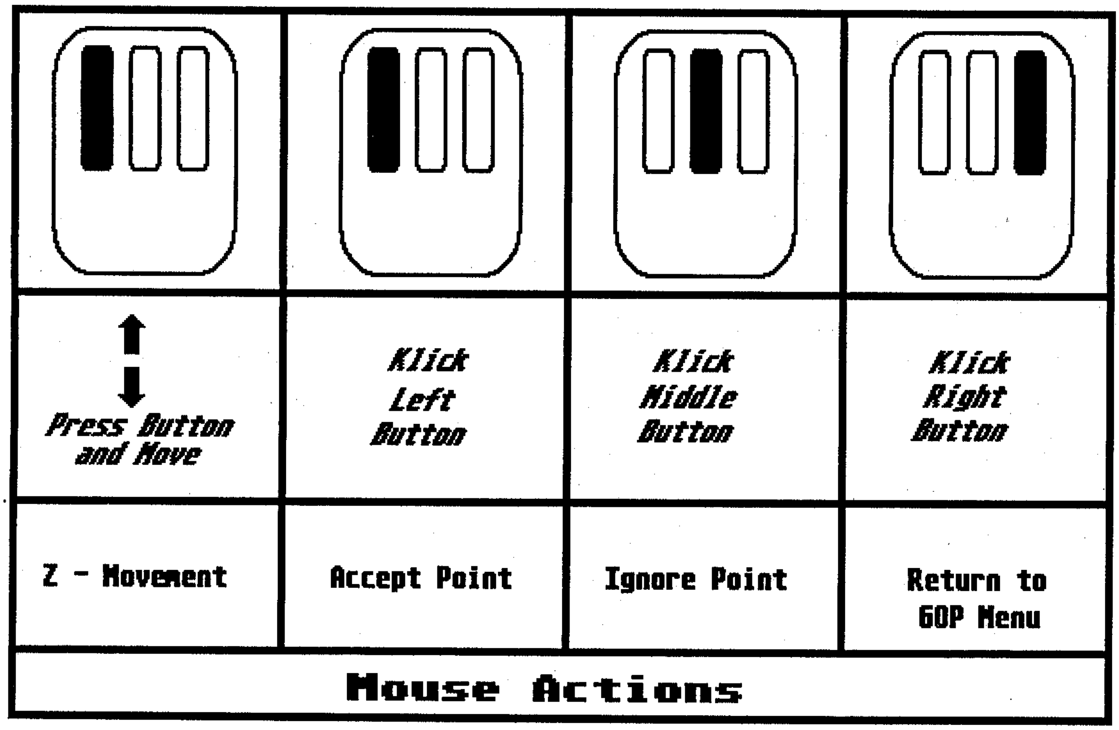

Figure 3: The mouse functions

2.3.4 Memory and Data Transfer

Due to the limited size of the display memories a stereo workstation control program had to be developed, which communicates with both DCU's via a dual ported memory and message queues. This software handles all image and coordinate transfers as well as necessary data type conversions (Figure 4).
This software also assures all interprocess communications, control and synchronisation via two listener processes (LIS), interfacing the workstation control program and the DCU's. These listener processes act on DCU requests. Whenever the display window reaches the boarder of the display memory requests for downloading image data from disc to display memory according to the last direction of movement can be handled.
The interface between the application program and the workstation controller is handled by Remote Procedure Calls (RPC's), which are implemented as kind of a library both on top of the application program as well as in the workstation controller. A so called loop library serves for the transformation of the received pixel coordinates coming via coordinate taps to the

required photo, model or object coordinate system.

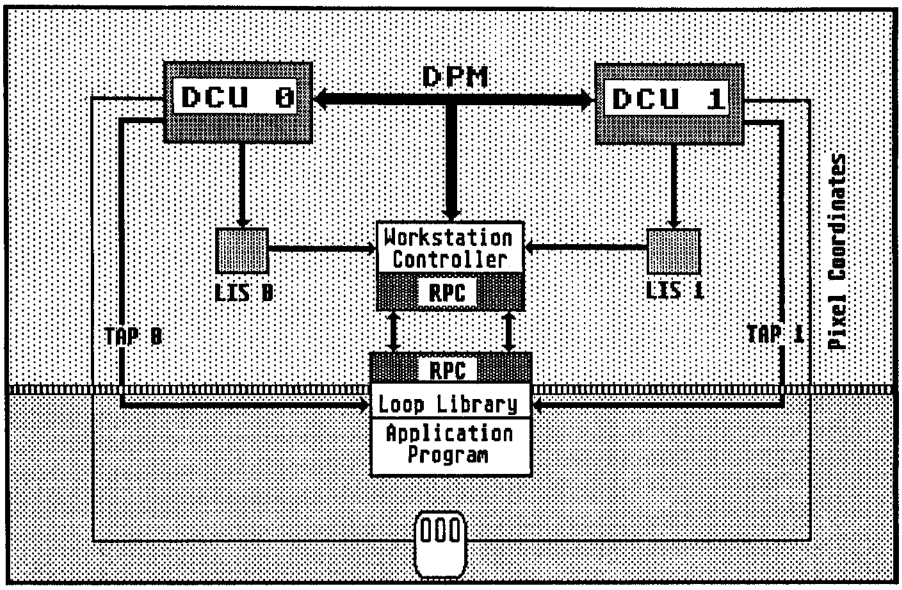

Figure 4: Control and Data Flow

3. THE OPERATOR INTERFACE

Operator control at the stereoworkstation and all interaction with the on screen menue is performed by a 3 button mouse. In addition to all existing interactive image processing functions such as zoom, pan, lookup table manipulations, graphic functions etc., beeing realized as softbuttons in the menu area (Figure 5) the photogrammetric functions have been added to the menu (Figure 6).

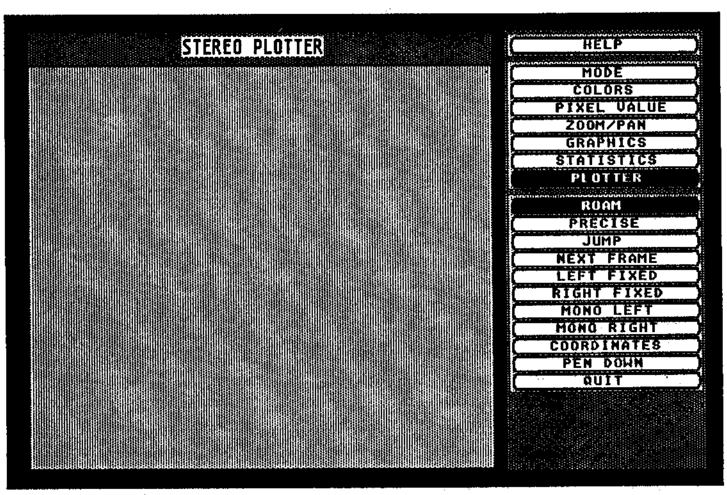

Figure 5 : The Display and Menu Area

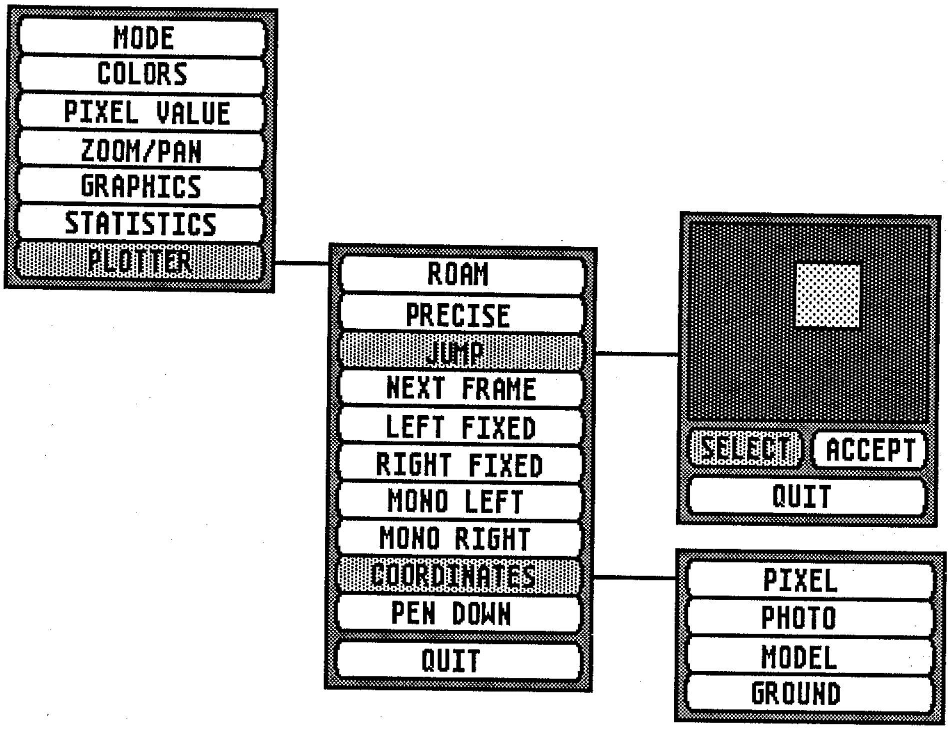

Figure 6: The photogrammetric menu

The stereo plotter utility functions inside the DCU comprise the following tools:

— Center floating mark to display window (the position of the floating mark is fixed).

— Roam both images with or without subpixel interpolation simultaneously in both DCU's, which means real time movement of the display window relative to memory.

— Fix left/right image relative to left/ right image (roam only in left/ right image).

— Next frame. This function reloads the total display memory centered at current floating mark position.

— Jump (Fast Move). When this function is activated a graphic window appears in in the menu area representing the total area of the left image. Within this window a box representing the display window can be moved arbitrarily to any position by mouse movement. By doing so the user can select any portion of the image or model to be displayed. The display memory is reloaded at the actual position of the box.

— Monoscopic viewing left or right image.

— Display coordinates in any desired coordinate system.

— Trace in the graphic planes and send coordinates of both images to the application program.

4. APPLICATION AND ORIENTATION PROGRAMS

4.1 Interior Orientation

This program is necessary only for digitized photographs. The user has the option of selecting a manual or automatic mode. In either mode the image is down sampled to the display window size and the user is asked to roughly digitize position and order of the fiducial marks, in order to define the photo coordinate system.

In automatic mode templates of the fiducials, which may be created by the user, are matched by digital correlation with the fiducials of the image file in the background with subpixel accuracy (Sasse, 1988). In case of correlation failure the image is displayed at that position and the user is prompted for manual measurement, where he can make use of all display control software options like zooming (1 to 32 times) or contrast enhancement.

Similarity or affine transformations are used to compute the interior orientation according to the number of fiducials. Each measurement of a fiducial serves for updating the pointing position for the next fiducial .

4.2 Bundle Orientation

The traditional method of exterior orientation is separated in relative and absolute orientation. This is necessary for analog photogrammetric devices. For analytical and digital photogrammetric workstations it is not necessary and will not lead to the most accurate results and also limits the configuration possibilities. For example a relative orientation with very small angle photographs has high correlated unknowns and often not usable results are achieved.

The bundle orientation program BUNOR computes approximate orientations in a very flexible manner and locates blunders in the bundle adjustment by data snooping. The orientations can also be computed with control points, located not in both photos up to independent resection of both photos. Systematical image errors can be computed by self calibration with additional parameters. Standard deviations of unknowns are listed in (Jacobsen, 1984).

4.3 Measurement Program AMOC (Advanced Measurement of Coordinates)

The program serves as an acquisition tool for image coordinates on the stereo plotter, where the user has the option either to measure in monoscopic or stereoscopic images. As input a project definition file (interior orientation) and a camera calibration file are required in addition to the endlap for the approximation of the image coordinates of a measured point in the right image.

The measured pixel coordinates are transformed to photo coordinates by the use of the parameters of the interior orientation. The measured image coordinates may be stored in a file for later use by bundle orientation or block adjustment. In addition to manual pointing the user may select the correlation option. This method requires the exact positioning in the left image while the correlator finds the homologeous point in the right image automatically. The search window for correlation may be any rectangular window up to a size of 127 x 127 pixels, while the pattern matrix is restricted to 27 x 27 pixels. Interpolation to subpixel position is carried out by calculating the point of maximum correlation with a twodimensional polynomial.

Further options are implemented such as the automatic positioning by means of known point coordinates which are known to the system by earlier models or by predigitized positions in paper hard copies.

4.4 DTM - generation

Measurement of DTM's can be made either manually or by automatic correlation. The latter requires that the user defines the window of the DTM in object coordinate system as well as the gridspacing in x and y. The correlation may be performed by an off-line process resulting in a file of x, y, z and the correlation coefficient, which may be used for editing bad points, or the user may select an interactive mode, where he can override the correlation as the images are displayed and he is able to follow the floating mark pointing to the terrain. The correlation may in addition be context controlled, which means that an existing classified image may be used to avoid correlation in unfeasable areas (i.e. forest areas). Other options allow to delete spot heights which do not fit to their neighbours.

4.5 DTM Editing

This program allows for three dimensional overlay of graphics to the model where good points, whose correlation coefficient is above a user definable threshold are marked in green and bad points are marked in red. The user has the option to remeasure those points or delete them totally.

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4.6. Contour Line Generation

Beside manual measurement of contour lines, they may be computed out of DTM files. In addition to the graphic representation of the contours they may be displayed in color, where the color represents the orientation of a contour line element in its neighbourhood or the consistency of orientation (standard GOP operation), which might be used as information for generalizing the contour lines. Figure 7 shows a correlated DTM, where the height of each point (pixel) corresponds to its intensity together with contour lines which may be derived by simple image processing techniques.

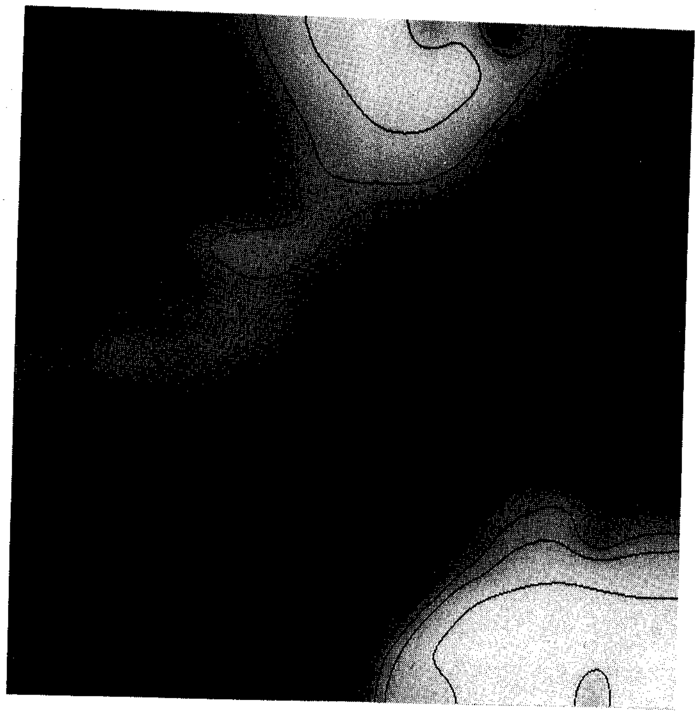

Figure 7: Correlated DTM and contour line overlay

4.7 Orthophotos and Rectification

A complete orthophoto package has been developed and implemented on the system (Mueller, 1988). Orthophotos can be created by the use of existing D T M's and orientation data which either have been measured with the system or which are originating from other sources. According to the system configuration the computation is being carried out either on the host (SUN 3/60), the GOP (General Operator Processor) or the GTP (Geometric Transform Processor). As an example Figure 8 shows an orthophoto superimposed by contour lines which has been generated by the system. As the height of each pixel is known, different perspective views of the terrain (Figure 9) may be generated. In addition by simply taking the first derivate of the DEM analysis of slope characteristics of the terrain may be performed.

Figure 8: Orthophoto with contour line overlay

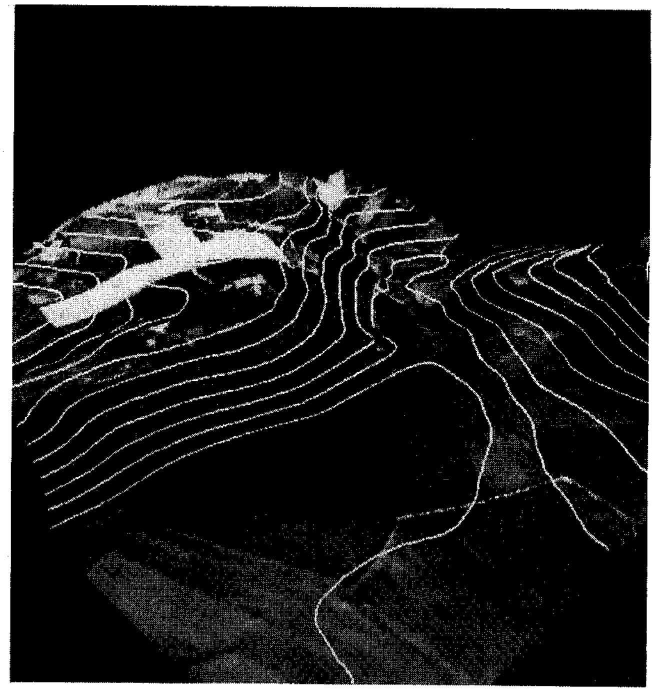

Figure 9: Perspective View of Figure 8

4.8 GIS Capabilities

An important part of the software is the communication with geographic information systems (Weidenhammer, 1989). Communication routines have been developed to link to the ARC/INFO system via Ethernet. ARC/Info's three dimensional data, the height beeing an attribute, may be stored in a local database on the image processing system and may be used as graphic overlay (Figure 10) at any time in stereo- or monplotting. This local data base serves as a tool for combining image and graphic information. Presently some work is being done to implement more GIS functions to the system.

Figure 10: Superimpositioning of ARC/Info Data (black) and measured Data (white)

5. CONCLUSIONS

The increasing performance of computer hardware and development of digital sensor systems has encouraged recently a number of companies and researchers to develop digital photogrammetric workstations. This is a development, which can be seen in the light of the increasing importance of digital image processing of the new generation of high resolution digital stereoscopic images for the purpose of map production and revision. Many of these developments, like the one presented in this paper, have been based on available standard general purpose image processing systems. Due to the recent development of very powerful new processors (Lohmann, 1989) and computer architectures with a computing power close to super-computers, as well as the existance of adequate display , data storage and retrieval technology it is expected that digital photogrammetric systems will soon have an operational level at a reasonable price, competing with analytic instruments Taking into account the developments in the field of computer vision, algorithmic developments and their knowledge based implementations it is felt that the step from analytical to digital photogrammetry will be taken in the near future.

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ABSTRACT

The design and development of digital photogrammetric stereo workstation based on a commercially available image processing system, the GOP 302, is presented. Aspects of theoretical background and practical implementation are discussed and first results obtained during the test phase are presented. The system includes a stereo display, measurement and orientation programs as well as a package for digital correlation and orthophoto production for digital aerial photography and other digital images.

DAS KONZEPT UND DIE ENTWICKLUNG EINES DIGITALEN PHOTOGRAMMETRISCHEN SYSTEMS

ZUSAMMENFASSUNG

Das Konzept und die Realisierung eines digitalen photogrammetrischen Systems auf der Basis einer kommerziellen digitalen Bildverarbeitungsanlage werden vorgestellt. Theoretische Abwägungen, die aufgrund der bestehenden Hardware bei der Planung zu beachten waren, wie auch ihre praktische Implementierung werden erläutert. Das fertiggestellte System beinhaltet Stereobetrachtung, Meß- und Orientierungsprogramme, wie auch ein Programmpaket zur digitalen Korrelation und Orthophotoherstellung. Es können mit dem System beliebige digitale Bilder verarbeitet werden.

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