DEVELOPMENT OF A DIGITAL SYSTEM FOR ARCHITECTURAL PHOTOGRAMMETRY

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ABSTRACT

The availability of powerful workstations and the advent of high resolution digital imaging systems makes the development of a fully digital systems for Architectural Photogrammetry possible. In a joint project between the Institute of Geodesy and Photogrammetry and the Chair of Architecture and CAAD, both at the Swiss Federal Institute of Technology in Zurich, a digital photogrammetric system is under development.

Appropriate digital imaging systems are evaluated and tested. In contrast to existing systems where an operator is measuring all features of interest, a higher level of automation is desirable. Emphasis is placed on novel techniques for semi-automatic measurement of architectural features. Several measurement procedures have been developed, some of which are presented here.

A practical project is used to demonstrate the methods and the efficiency of this system. The steps from image acquisition to the data representation in a CAAD-system are outlined. Issues of sensor resolution and accuracy are addressed. An outlook to developments leading towards semiautomatic and fully automatic recognition and measurement of general architectural features is given.

KEY WORDS: architectural, CAD, CCD camera, digital system, non-metric.

1. INTRODUCTION

Improvements of the processing and storage capabilities of workstations are occurring at a breath taking speed. They provide the platform for processing the large amounts of digital imagery available from a wide range of sensors. With respect to Digital Architectural Photogrammetry the development of high resolution digital imaging systems is of major importance. The technology for systems with a sensor resolution comparable to medium format film cameras is available. A Digital Photogrammetric System for Architectural Photogrammetry must be capable to acquire imagery with sufficient resolution, process the data with a high level of automation, and pass it on to a CAAD-system. The status of such a system being developed in a joint project of the Institute of Geodesy and Photogrammetry in cooperation with the Chair of Architecture and CAAD at the Swiss Federal Institute of Technology in Zurich is outlined.

2. DATA FLOW IN A DIGITAL SYSTEM FOR ARCHITECTURAL PHOTOGRAMMETRY

Images can be acquired with film based cameras as well as with systems and/or cameras using solid-state sensors. Former still provide for a higher resolution, but the film must be developed and digitized before the data can be used in a digital system.

A Digital Photogrammetric Station (DIPS) is used for processing. It must provide for ample storage space for the large amount of digital imagery, a tremendous

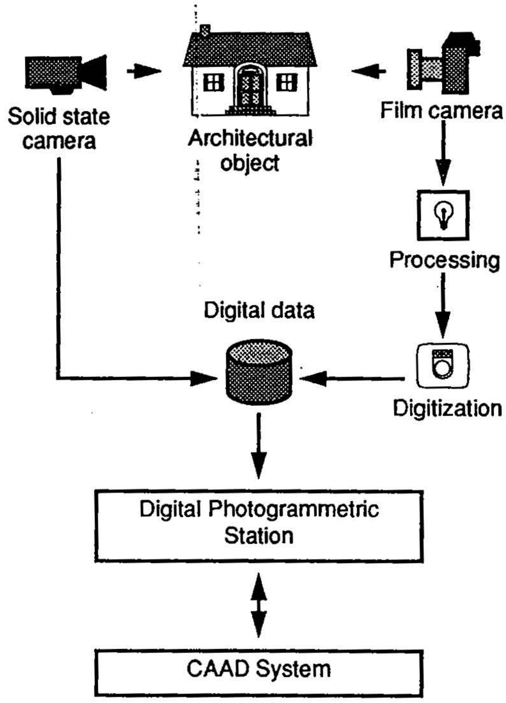


Figure 1 Data flow and hardware of a digital system for Architectural Photogrammetry.

processing performance for semi-automatic and automatic measurement algorithms, and a high resolution display for the visualisation of imagery, processing steps and results.

The hardware platform of the DIPS and the CAAD-system can be identical, but the integration of the software of both systems into one package has not been attempted. An interaction between and/or integration of the CAAD-System and the photogrammetric processing system will be necessary in the future. The CAAD-System can support interactive measurements by an operator and will be required to provide a priori information for automatic measurement procedures.

All tasks, from image acquisition to the transfer of CAD-data, are performed with the software package DEDIP (Development Environment for Digital Photogrammetry, *Beyer, 1987*). It provides, among others, modules for image acquisition, interactive measurement of pixel coordinates, a bundle adjustment program, and measurement of architectural features. Figure 1 shows data flow and hardware components involved in a digital system for Architectural Photogrammetry.

3. IMAGING SYSTEMS FOR ARCHITECTURAL PHOTOGRAMMETRY

Imagery for Architectural Photogrammetry can be acquired with film cameras and subsequent digitization or by digital imaging systems. Only the latter are addressed here as the characteristics of the former are well known. Devices of this type can be standard solid-state cameras with a video recorder or a computer with framegrabber, still video cameras, video cameras, and several types of high resolution cameras.

All cameras using one of the widely used video standards provide imagery with approximately 512 x 512 pixels. Until the availability of High Definition Television systems, which will have 1920 x 1035 pixel, the cheap off the shelf systems will be limited to this image size.

There are a number of cameras available which provide for imagery with a much larger number of pixels. The largest area array charge-coupled device available today has 4048 x 4048 sensor elements, but the price for a complete system with such a sensor is still in the order of US$100.000.-.

There are several other ways to obtain imagery with more information. The ProgRes 3000 (*Kontron, 1990*) uses a sensor with very small apertures combined with a piezo controlled displacement in the sensor plane. The partial images are assembled thereafter. Another approach uses a standard sensor and the reseau scanning principle (*Wester-Ebbinghaus, 1986*) to attain imagery with 5500 by 7050 pixel (Rollei RSC). There are also several systems with linear arrays and mechanical displacement devices. All these have the disadvantage that the image acquisition requires at least several seconds. This needs a stationary object and constant lighting conditions.

The current technology of still video cameras uses an analog recording technique for intermediate storage of the imagery. This leads to a significant degradation of the radiometric and geometric characteristics of the imagery. Still video cameras with digital recording techniques are currently appearing on the market. Even currently available still video cameras provide sufficient geometric accuracy to map an architectural object. Well defined points spanning several pixel can be determined with an accuracy of $1/5^{th}$ to $1/10^{th}$ of a pixel. But their resolution is not adequate for architectural objects. For example imaging an object of 20 m onto a 512 x 512 pixel image requires that the features of interest span at least 20 cm on the object. This is far too large for most applications and renders the current still video cameras almost useless for such tasks. This problem is demonstrated in Figure 2, which shows on the left an image taken of a church and on the right an enlargement of the indicated area. The corner of the building can still be identified, but measuring finer details of the corner is impossible.

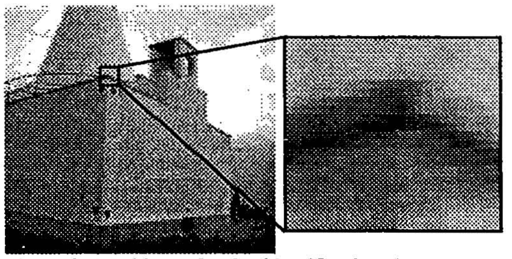


Figure 2 Problem of point identification due to insufficient sensor resolution.

The possible improvement of high resolution imaging systems is demonstrated in Figure 3. It shows zoomed portions of a close-range testfield. The images were taken with a standard solid-state camera (Figure 3 a) and the high-resolution camera ProgRes 3000 (Figure 3 b). The great difference in resolution of these two cameras is conspicuous. This demonstrates that high resolution cameras are required for the demanding requirements of Architectural Photogrammetry.

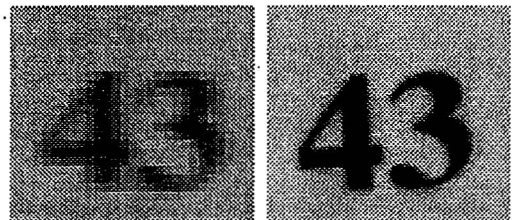


Figure 3 Comparison of standard solid-state camera (a) and ProgRes 3000 (b) with images of a testfield.

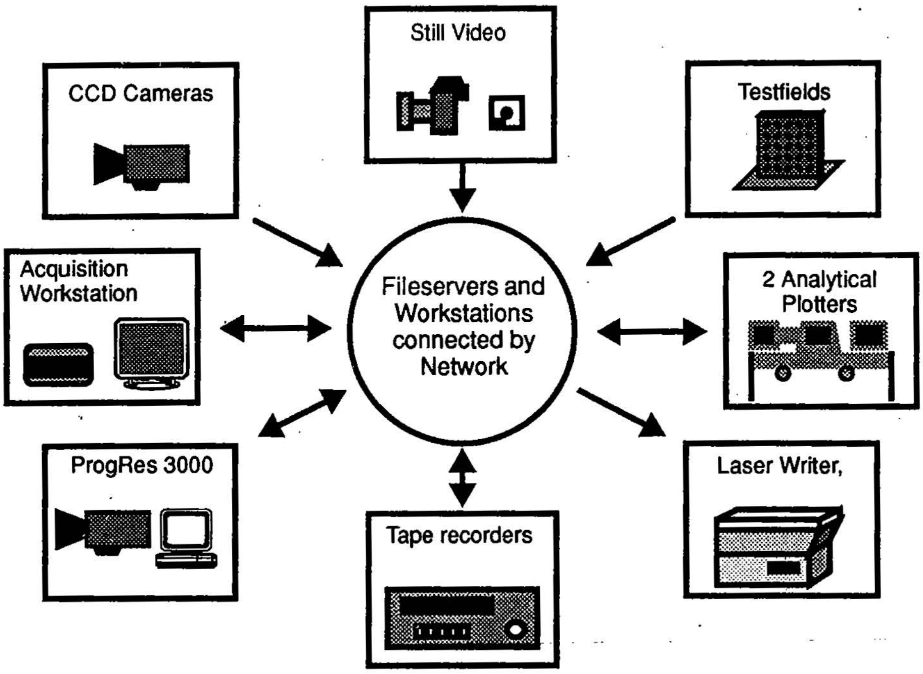


Figure 4 The Digital Photogrammetric Station and its peripheral devices.

4. THE DIGITAL PHOTOGRAMMETRIC STATION

The data analysis is performed within the Digital Photogrammetric Station (DIPS II, *Grün, Beyer, 1991*), as shown in Figure 4. The DIPS consists primarily of a network of workstations from SUN-Microsystems, to which special purpose systems like the image acquisition workstation, the analytical plotters, personal computers with interfaces for special cameras, and other input and output devices are connected. The image data of this test was digitized from the still video recorder described above with the acquisition workstation of the DIPS. Latter consists of a SUN-3E and image acquisition boards from Datacube. The ProgRes 3000 uses an interface board on a PC-AT type computer which is also connected to the network.

5. MEASUREMENT TECHNIQUES

Before the three-dimensional information of architectural relevant features can be extracted by photogrammetric methods (e.g. bundle adjustment), their position in the images must be determined. The advantage of a fully digital system for Architectural Photogrammetry is the us of digital images. These images make semi-automatic and automatic measurement methods possible. In the following the measurement approaches for basic geometric primitives and the major software aspects are addressed.

5.1. Development Environment for Digital Photogrammetry

The main software component of all measurement techniques of the digital system for Architectural Photogrammetry is DEDIP. As a part of the Digital Photogrammetric Station (DIPS), it allows to perform all tasks from image acquisition to the extraction of the three-dimensional data within one program. The program uses the SunView window system. Major functional modules of DEDIP are:

- Image handling and display,
- Input and output of images,
- Acquisition of images with a framegrabber,
- Interactive and semiautomatic measurement in images,
- Extensive routines for the radiometric and geometric analysis of images,
- Bundle adjustment program with self-calibration,
- Input of topologic information,
- Data transfer to CAAD-system.

All modules are used in this project, but only the measurement aspect is of major concern at this point and will be discussed in more detail in the following.

5.2. Point location

The simplest method to determine the location of architectural relevant features in the images is to use the cursor as a manual measuring device. This is basically identical to the measurement technique used in many systems employing a digitizer, such as Rolleimetric, Elcovision, etc.

In DEDIP the regions of the images, in which the coordinates are to be determined, are displayed on the screen and the operator measures the coordinates of corresponding points with the cursor. Figure 5 shows a typical configuration of the workstation screen for the manual measurement of points. The images were zoomed to improve the precision of the manual measurements. Here only two images are displayed, but several regions of interest can be viewed simultaneously. A screen layout with four images was efficiently used in several projects. The measured coordinates are indicated with crosses and their respective numbers, as shown in Figure 5.

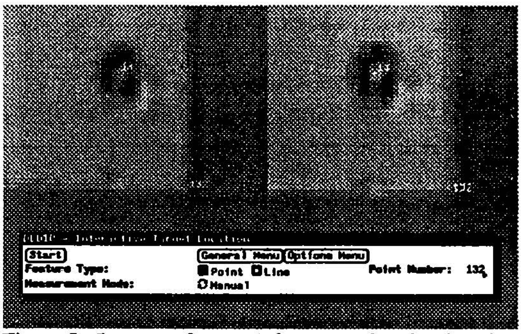


Figure 5 Layout of screen for manual point location. Here two images are displayed simultaneously.

This measurement technique does not exploit the additional capabilities offered by semi-automatic and automatic measurement methods which can be applied on the digital images.

5.3. Feature location

In this project Least Squares Template Matching (*Gruen, 1985*) was applied to measure the precise position of signalised points. It uses a template (artificial image of the feature) as reference and determines the position via an iterative procedure through the least squares fit of an affine transformation between template and patch (image region). Initially, the patch is taken at the approximate position from the image. This can for example be indicated by the operator in an interactive measurement mode. In subsequent iterations the patch is resampled from the data of the image using updated values for the affine transformation with a user definable interpolation algorithm. Figure 6 shows an enlargement of a part of the original image, the patch at the initial position, the patch after convergence of the algorithm, and the template.

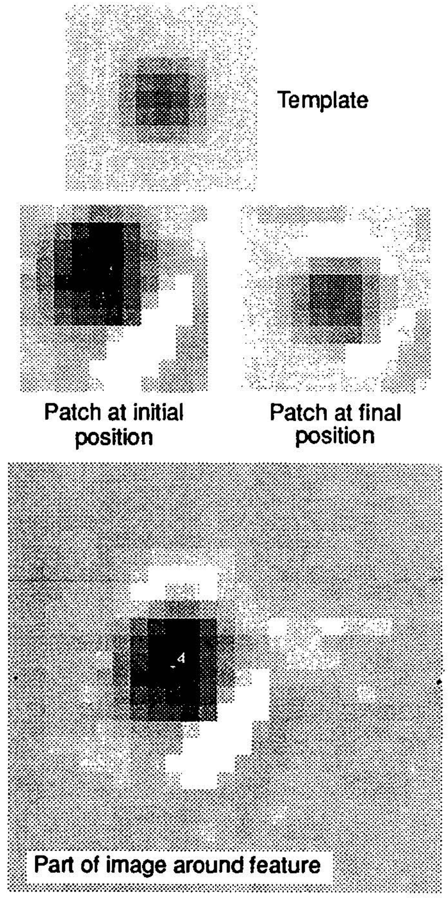
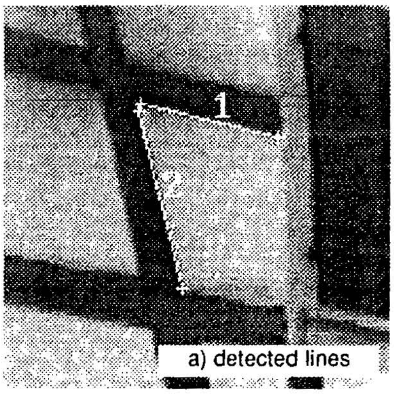


Figure 6 Image with point and number at final position, patches at initial and final position, and template of a target measured with least squares template matching.

Least Squares Template Matching provides a very high precision. In practical applications an accuracy corresponding to a tenth of the pixel spacing can be achieved for well defined features. Under laboratory conditions accuracies of a few hundreds of a pixel have been achieved. Least Squares Template Matching can be used to measure signalised points as well as architectural features, provided an artificial template can be generated. It is therefore a very precise and general measurement method.

5.4. Point location via line following

A major problem in measurement of architectural relevant features is the identification of the points in the images. The vertices describing these architectural features are often not well defined for photogrammetric tasks. In these cases the linear boundaries of the object contain more information than the vertices. The measurement technique shown here takes advantage of this. It first locates the linear elements of the feature to be measured and then derives the vertices/corners as intersections of these lines. Figure 7 shows an example of this technique. The initial position of the linear element is indicated by the operator with the cursor. Starting from this, the line is tracked by the algorithm using the first partial derivatives of the image. The result of the line following is a polygon with a step width of one pixel. If the result of this process is satisfactory, a straight line is fitted onto the polygon (see Figure 7a) This is done for all lines in the image. In a second stage the points defining the architectural features are computed as intersections of selected straight lines (see Figure 7b).



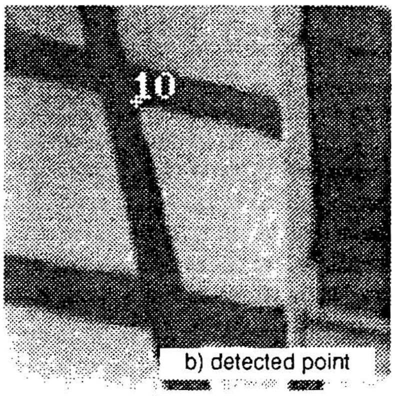


Figure 7 Example for point location via line following. Line no. 1 and line no. 2 define point no. 10.

6. PROJECT GIOVA

6.1. Architectural object

The church "Chiesa di Nostra Signora di Fatima" in Giova (Switzerland) was chosen to demonstrate the functionality of the current digital system for Architectural Photogrammetry. Giova is located in the southern alps near Bellinzona, the capital of the canton Ticino. The architects M. Campi and F. Pessina designed this church which was built in 1984-88. It stands in a privileged and dominating position, nearly 800 metres above the valley Mesolcina at the edge of a plain. The church is 14 m in length and 10 m in width and height.

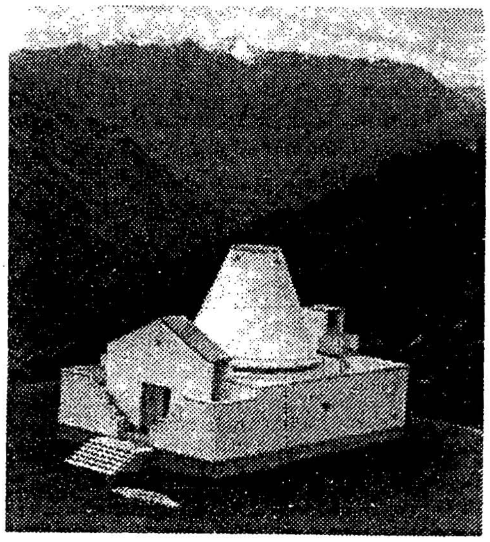


Figure 8 "Chiesa di Nostra Signora di Fatima" in Giova (viewed from north-east).

6.2. Data acquisition

A Canon CI-10 colour still video camera with a 9 mm lens was used to take the images. It employs a CCD image sensor of 8.8 by 6.6 mm^2 with nearly 380'000 sensor elements and records the images on still video floppy disks. The digitized images have a size of 508 by 466 pixels. This results in a pixel spacing of 15.3 µm in horizontal and 12.9 µm in vertical direction.

The camera arrangement was restricted by the dimensions of the church (14x10x10 m^3) and the terrain on which the church is located (see Figure 9). A steep slope to the south and the west of the church make an ideal camera arrangement for photogrammetric tasks impossible. Thus a stereo pair was taken of the north and east facade each, and three images had to be used to cover the west and south facades due to the smaller object distances.

The reference data for the photogrammetric network was determined by theodolite. Therefore 20 targets were fixed on the facades of the church and used as control points. Each facade with the ideal camera arrangement shows four targets and each facade with the non-ideal arrangement shows six targets.

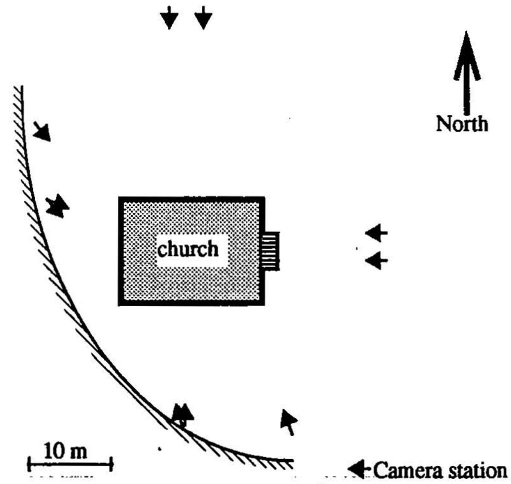


Figure 9 Object and camera configuration.

6.3. Photogrammetric analysis and results

To obtain precise calibration parameters for the camera a testfield calibration was performed beforehand. The following 10 additional parameters were determined: three parameters of the interior orientation, a scale in x-direction, a shear, and parameters for the radial and decentering distortion.

First the image coordinates of control points and architectural features have to be measured. This was done with the measurement techniques described in section 5.

The three-dimensional object coordinates were computed with a bundle adjustment using the geodetically determined control points and the calibration parameters from the testfield calibration.

Figure 10 shows a plot of the results in AutoCAD, which is used as a CAAD-system. Up to now the data transfer from DEDIP to AutoCAD has only been solved rudimentary. The results which the photogrammetric processing system delivers are 3D-coordinates of single object points. Topologic information must be added interactively by an operator on the screen. The three-dimensional object coordinates and the topologic information are automatically written into an ASCII-file, which can be read by an AutoLISP-program. The automatic generation of topological information is part of the future work.

The precision of the photogrammetric analysis is analysed with two methods. First the theoretical precision of object coordinates was determined with a bundle adjustment. The results indicate that a precision corresponding to 1/3rd of the pixel spacing in image space was achieved. The theoretical precision of the object point coordinates is 2.2 cm within the plane of each facade, and 4.0 cm in depth. The second method compares distances of the CAD-model to the corresponding distances of the construction plan. Thirtyseven architectural relevant distances, ranging from 0.5 m to 13.8 m, were chosen. The average relative

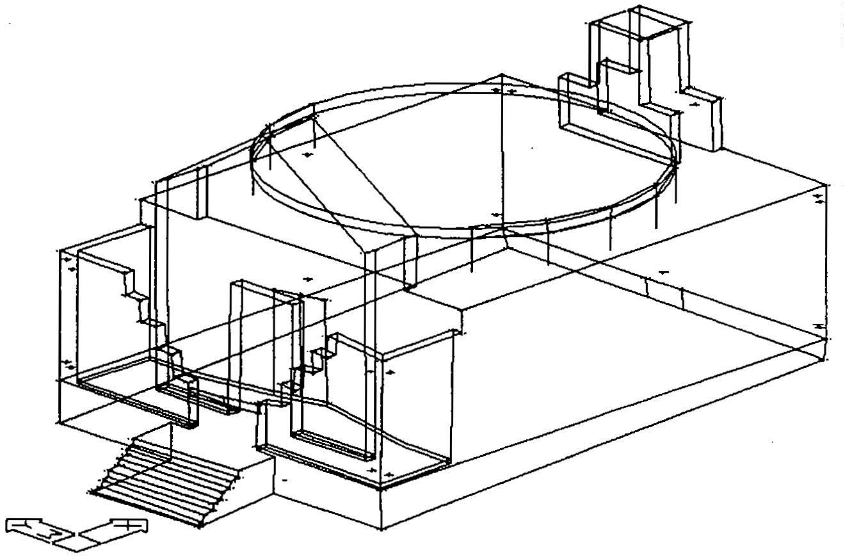


Figure 10 Results of photogrammetric analysis, represented in AutoCAD.

distance error between CAD-model and construction plan is 0.5% or 1:200. This analysis includes all deviations of the actual building from the plan. But it agrees very well with the theoretical precision of object coordinates. There a distance of 10 m can be determined with a standard deviation of 5 cm.

These results are indeed very encouraging considering the low resolution of the still video camera used. The results are also only of an initial nature as a detailed analysis with other measurement techniques is being performed.

7. CONCLUSIONS AND OUTLOOK

An overview of the digital system for Architectural Photogrammetry being developed at the ETH Zurich was given. Some of the basic measurement methods to determine geometric primitives were described. These methods can be extended in such a way that the operator can select feature classes to be measured. A priori information on each feature class can be used to support the operator. Such a system would provide a high level of automation as compared to existing measurement approaches. A major problem to be solved is the connection of semantic information to the three-dimensional data. To solve this problem an interaction between a Digital Photogrammetric System and a CAAD-system is conceivable and desirable. The system could furthermore be supported by information from a CAAD-system and/or an expert system. This includes knowledge on architectural styles, the construction of features, and objects build of several lower level features. Measurement routines adapted to special characteristics of features could be selected automatically. The data representation would therefore ideally be performed in a format easily convertible to that of a CAAD-system. The features already measured could be used to reconstruct the object through CAAD and to support the interactive measurement and/or guide the automated recognition and measurement through visualisation.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

Beyer, H.A., 1987. Einige grundlegende Designfragen zu einer Entwicklungsumgebung für Digitale Photogrammetrie auf den SUN Workstations. (DEDIP Development Environment for Digital Photogrammetry). Internal Report.

Gruen, A., 1985. Adaptive Least Squares Correlation: A Powerful Image Matching Technique. South African Journal of Photogrammetry, Remote Sensing and Cartography. Vol. 14, No. 3, pp. 175-187.

Grün, A., Beyer, H., 1991. DIPS II - Turning a Standard Computer Workstation into a Digital Photogrammetric Station. ZPF - Zeitschrift für Photogrammetrie und Fernerkundung, No. 1, pp. 2-10.

Kontron, 1990. ProgRes 3000. Product Information, Munich (FRG).

Wester-Ebbinghaus, W., 1986. CCD-Reseau-Abtastung - Ein neues Prinzip für die digitale Bildverarbeitung. IAPRS Vol. 26/5, pp. 445-453.