38. Data Generation for CAAD with Digital Photogrammetry

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The rapid advances in sensor technology and processing hardware make the development of a Digital Photogrammetric System for Architectural Photogrammetry possible. This system is able to acquire images with sufficient resolution for Architectural Photogrammetry. Geometric and topologic information for a CAAD-System can be derived with manual and/or semi-automated methods. This paper describes the current status of such a system which is under development at the Institute of Geodesy and Photogrammetry in cooperation with the Chair of Architecture and CAAD, both at the Swiss Federal Institute of Technology in Zurich.

Introduction

The basic hardware requirements and the data flow are given. Primary processing steps are outlined. An example project is discussed from data capture over photogrammetric calibration to the three-dimensional object description of an architectural object. The functionality of the software package DEDIP (Development Environment for Digital Photogrammetry) relevant to the data generation for CAAD is explained using the example project. Issues of image acquisition systems are explained and requirements shown. An outlook on software developments to increase the level of automation is given.

Data Flow in a Digital System for Architectural Photogrammetry

Figure 1 shows data flow and hardware components involved in the data generation for CAAD with Digital Photogrammetry. Images can be acquired with film cameras as well as with cameras using solid-state sensors. Conventional film cameras still provide for an unsurpassed resolution. Images with over 6000 by 6000 pixels would be required to match the resolution of a medium format film camera. The disadvantage of film cameras is that the film must be developed and digitized before the data is available for processing. Solid-state cameras have the advantage that their data is immediately accessible.

On the lower end of solid-state sensor based imaging systems are Still Video Cameras. They use analog recording on floppy disks and the image size is in the order of 512 x 512 pixels. On the upper end are cameras which use standard sensors with displacement methods and high resolution area sensors. Former create images with 2994 by 2330 (Kontron 3000, Kontron...
to 5500 by 7050 (Rollei RSC, Luhmann 1990) pixels, but can only be used for stationary objects and under stable lighting conditions. Cameras with high resolution area sensors are available with up to 4048 x 4048 sensor elements (Janesick et al., 1990). Prices for still video cameras range from several hundred to several thousand Swiss Francs. High-resolution cameras start at about sFr. 20000 and reach beyond sFr. 100000. The advent of imaging systems for High Definition Television (MTV) will lead within the next years to a large decrease of prices for cameras with an image size of 1920 x 1035 pixels. The image quality of Still Video Cameras will be vastly improved by the incorporation of digital recording technologies.

**Figure 1.** Data flow and hardware of a Digital System for Architectural Photogrammetry.

Data Processing is performed on a Digital Photogrammetric Station. Currently the Digital Photogrammetric Station and CAAD-System are different units, but could already be based on identical hardware platforms. 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.

Figure 2 depicts the processing steps of data generation for CAAD with Digital Photogrammetry. After the image acquisition an orientation and calibration must be performed. Some basic geometric information on the object and/or the camera-stations from which the images were taken must be provided by other means. Usually the three-dimensional object coordinates of well defined features (e.g. signalized points) are used, but the distance between two points is also sufficient under certain conditions. After the orientation and calibration the geometric relation among all images and between images and object are known. This is used for the measurement of the architectural features. The three-dimensional coordinates of a feature can be computed once it has been identified and measured in at least two images. The location of features in all other images can thereafter be predicted from their three-dimensional position. This enhances the measurement speed and improves the
reliability of the measurement process. The semantic identification of features is currently performed interactively. This could be supported by information from the CAAD-System and/or an expert system.

All tasks, from image acquisition to the data transfer, are performed with the software package DEDIP (Development Environment for Digital Photogrammetry, Beyer 1987; Grün and Beyer 1991). It provides, among others, modules for image acquisition, interactive measurement of pixel coordinates, a bundle adjustment program, and measurement of architectural features. The current capabilities of the system will be shown in the following sections with a practical project.

Figure 2. Processing steps in Digital Architectural Photogrammetry.

**Project Villa Cassel: Architectural object**

The timber frame house Villa Cassel is chosen to demonstrate the capabilities of the existing system. Villa Cassel was built for the English banker Sir Earnest Cassel at the turn of the
century. It is located in a nature reserve of the Swiss Alps close to Riederalp (Wallis). Figure 3 shows the surroundings and the back facade of Villa Cassel. The front facade, which is 21 m wide and 17 m high, was used in this project.

Figure 3. Villa Cassel, Wallis, Switzerland.

Figure 4 gives a schematic representation of the house and the camera-stations. A Canon CI-10 color Still Video Camera was used to take two images at each of the four camera-stations. One image was acquired with the camera upright and the other with the camera rotated by ninety degrees around its optical axis. The sensor is 8.8 by 6.6 mm and the images have a size of 508 by 466 pixels.

Figure 4. Object and camera configuration.
Orientation and Calibration

Before any measurement of architectural features can be done, the position and orientation of all images and camera-stations must be determined. This was performed using points signalized with targets consisting of black circles on a white background. The three-dimensional object coordinates of all signalized points were determined with theodolites to an accuracy better than 3 mm. Figure 5 shows an image taken at camera-station B (see Figure 4). The three signalized points in front of the house and the 19 targets on the facade are identifiable.

The pixel coordinates of the signalized targets were measured with Least Squares Template Matching. After a transformation from the pixel to the image coordinate system, the coordinates were introduced in a bundle adjustment program together with the three-dimensional object coordinates of 5 signalized points (control points). The position and orientation of all images, the object coordinates of all points, and the additional parameters were computed by a least squares adjustment with the bundle adjustment program of DEDIP (Karara 1989; Beyer 1990). The additional parameters are used to compensate for the effects of systematic errors introduced by the non-ideal geometric characteristics of the imaging system. The reference coordinates of the other 17 signalized points were withheld from the bundle adjustment. The coordinates of these points were used to verify the accuracy by comparing the values obtained by the bundle adjustment with the reference theodolite values. Without calibration (no additional parameters are used) the accuracy of the 17 check points is in the order of 200 mm. With calibration the accuracy is in the order of 16 mm in object space, which corresponds in image space to 1/4 of the pixel spacing. This is quite good considering that the camera uses a color sensor and that the image quality was significantly degraded by the analog recording on the floppy disk of the still video recorder.
The importance of calibration can also be demonstrated with the influence of the systematic errors on the image coordinates as shown in Figure 6. The regular grid represents the position of points at a 5 mm spacing, if no systematic errors were present. The deformed grid shows the influence of the systematic errors. The vectors between the two grids indicate the correction of the image coordinates by the additional parameters. The vectors at the points are differences to the reference positions projected into the images. The effects of systematic errors are approximately 20 times larger than the attained accuracy. A good calibration is therefore a prerequisite for any precise extraction of geometric information.

**Figure 6.** Influence of systematic errors showing the large deformations in relation to the achieved accuracy. Relation (point vector:grid) = 10:1.

### Measurement of Architectural Features

After orientation and calibration the geometric relation of object and images is reconstructed. This can be relied on for the measurement of architectural features. The features must be detected and classified according to topologic classes. Geometric primitives describing each feature are measured. The features and their topologic classification depends on their use in the CAAD-System. In the following, the resolution requirements of imaging hardware with respect to architectural features are explained. Thereafter, measurement approaches for basic geometric primitives are addressed.

### Camera Resolution

It was shown above that the geometric accuracy of standard CCD-cameras, and in particular of Still Video Cameras, would be sufficient to map an entire architectural object of this size with two images. The practical problem lies in the fact that the geometric accuracy is only achieved for large signalized points with good contrast. The characteristics of architectural features are very different. The resolution of the camera must be suited to imaging of the features to be mapped. Some of the problems and requirements are demonstrated in the following.
Figure 7 shows part of a window in two images acquired with the CI-10 camera. It is very difficult to decide which pixels represent the corresponding parts of the window corner in the left and right image. The pixels of images acquired with the Canon CI-10 correspond to an area of 38 mm by 33 mm on this object. A feature must span several pixels to be identifiable and measured with sufficient precision. Therefore features must span at least 120 mm on this object. On the contrary, when using the high-resolution ProgRes 3000 camera an area of 6.9 mm by 7.1 mm on the object would correspond to one pixel, under otherwise identical conditions. This camera could be used to extract features spanning only 20 mm on this object.

![Figure 7. Window in two images demonstrating the difficulty to identify corresponding features due to insufficient camera resolution.](image)

The difference in resolution is demonstrated in Figure 8. It shows zoomed portions of a close-range testfield. The images were taken with a standard solid-state camera (Figure 8 a) and the high-resolution camera ProgRes 3000 (Figure 8 b). The great difference in resolution of these two cameras is conspicuous. This demonstrates the need for high-resolution solid-state imaging systems.

![Figure 8. Comparison of standard solid-state camera (a) and ProgRes 3000 (b) with images of a testfield.](image)
Precise Feature Location

In this project Least Squares Template Matching (Gruen 1985J) was applied to measure the precise position of signalized 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 using updated values for the affine transformation with a user defined interpolation algorithm from the data of the image. Figure 9 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.

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 signalized points as well as architectural features, provided an artificial template can be generated for the feature. It is therefore a very precise and general measurement method.

Measurement of Points

The simplest method to determine the location of straight lines is to measure the coordinates of their end points. Potentially, the pixel coordinates of those points can be measured manu-
ally, semi-automatically and full automatically. Only the manual and semi-automatic measurement modes have been used in this project. Figure 10 shows a typical configuration of the workstation screen for the manual measurement of architectural points with DEDIP. The regions of the images, in which the coordinates of features are to be determined, were displayed on the screen and the operator measures the coordinates of corresponding points with the cursor. 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 this test. The measured coordinates as indicated with marks and their respective numbers are shown in the figure.

**Measurement of Points via Line Following**

Figure 7 shows a related problem to the resolution requirements for the measurement of architectural features which have been explained above. The vertices describing the image feature 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, by first locating the linear elements of the feature to be measured, and then deriving the vertices/corners as intersections of these lines. Figure 11 shows an example of this technique. The initial position of the linear element is indicated by the operator with the cursor (see Figure 11 a).
Figure 11. Example for measurement of points via line following. Line no. 1 and line no. 2 define point no. 5.

Starting from this, the line is tracked by the algorithm using the first partial derivatives of the image, which are visualized in Figure 11 b. Finally, a straight line is fitted to the results by following that line (see Figure 11 c). The points defining the architectural feature are computed as intersections of selected straight lines (see Figure 11 d). The first results of this measuring technique have been very encouraging.

**Outlook**

Some of the basic measurement methods to determine geometric primitives were described. These methods can be extended so 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 with existing measurement approaches. The system could furthermore be supported by information from a CAADSystem and/or an expert system. This includes knowledge of architectural styles, the construction of
features, and objects built out 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 through visualization the interactive measurement and/or guide the automated recognition and measurement. Such a combined system would include algorithms of a Digital Photogrammetric Station and a CAAD-System.

Conclusions

The potential of Digital Photogrammetry as an important data source for CAAD has been demonstrated. The accuracy requirements can already be achieved with standard CCD-cameras for well defined and sufficiently large features. It has been shown that high-resolution digital imaging systems are required to image architectural features with sufficient detail to be identifiable and measurable with sufficient precision. Manual and semiautomatic measurements can already be performed with great ease. The improvement of the semiautomatic measurement procedures and the development of fully automatic measurement systems represents an interesting and challenging research and development topic. 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.

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References


