

DIGITAL ORTHOPHOTO-SYSTEM FOR ARCHITECTURE REPRESENTATION

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ABSTRACT:

For the documentation of façade structures a special solution has been developed for the production of orthophotos by different nonparametric rectification terms (projective transformation, bivariable polynomials n. order, multi-quadratic interpolation). A façade is divided in different planes and sub-planes, which can be projected independently and with freely selected transformation functions. Depending on the image quality of the surfaces different resampling functions can be chosen. The treatment can be done interactively within an image pyramid on higher levels by visual control. Control points and plane limits are predetermined by an analytical plotter.

KEY WORDS: Architectural, Digital Systems, Orthophoto, System Design, Workstation.

1. INTRODUCTION

1.1. Documentation of Buildings

Terrestrial photogrammetric techniques have an important rank for the documentation of buildings. The aim is an inventory of important objects of building history and to produce plans for planning and restoration works. The demand is the object restitution at a sufficient degree of details under cost-effectiveness. The document representation utilizes line drawings or controlled photo mosaics. The line drawing emphasizes the object geometry interpreting the architecture historical and constructive features up to a desirable degree of abstraction. The actual inventory of a façade can be shown in more detail and without interpretation by photo mosaics, as well as the documentation of decay. In certain cases a combination of both, line drawing and photo mosaics, is preferable as it gives a better perception of a building.

1.2. Techniques of Documentation

In the past controlled photo mosaics have been produced by rectification. The transformation was applied to images or to parts of images of almost plane façades. This method was followed by the differential rectification, the orthophoto technique. But even this procedure has got its limitations, as surface structures with continual shape are presupposed (Seeger, 1979). Strong discontinuous shapes on façades are difficult to manage. Suitable transformations are required, which fit to the object and the task. Façades should be subdivided into delimited planes and other surfaces. The respective parts can be handled according to their attributes by suitable transformations.

1.3. Rule of Digital Rectification

This demand for various transformations can be realized on scanned images by digital processing. The production of digital orthophotos in the field of architecture photogrammetry has been shown by Bähr 1980 and Schweinfurth 1985. Today low-cost workstations and scanners allow economic solutions of digital transformation (Bähr and Wiesel, 1991). Digital methods make it possible to combine any given transformation, to integrate different image sources and to use the extraction of edges (Bähr, 1980). The following procedure shows a digital system for practical tasks of building documentation using partial image transformation up to digital rectification. A universal and pragmatic approach should be in a position to handle any control information. The future directs to the field of stereo-image matching.

2. CONCEPTION OF RECTIFICATION

2.1. Choice of Transformation Functions

The choice of suitable transformation functions shall be variable for partial planes and depend on the plane form and structure, direction of camera axis, distribution and position of control points, accuracy demands.

The digital image processing consists of a plane transformation and a resampling of the pixel structure. It is favourable to choose the inverse transformation (indirect method) and to compute the resampling from the original image matrix. Different pixel interpolations are at disposal (nearest neighbour, bilinear and bicubic spline interpolation). The choice has to result individually from the image contents of the respective partial plane, because

different interpolation errors (aliasing, lowpass error) can occur and the computer operation time is varying.

2.2. Non-parametric Techniques

Different plane transformations can be realized by non-parametric techniques with sufficient accuracy (Mikhail et al., 1975). In contrast with the parametric approach, which gives a rigorous solution by the collinearity equations, the plane interpolations (non-parametric methods) are directly determined between the projective plane $S'[s'(x',y)']$ and the image plane $S[s(x,y)]$ using a lot of control points $P_i: (u_i, v_i) \leftrightarrow (x_i, y_i)$ from the reference model $R = [s(x,y)]$.

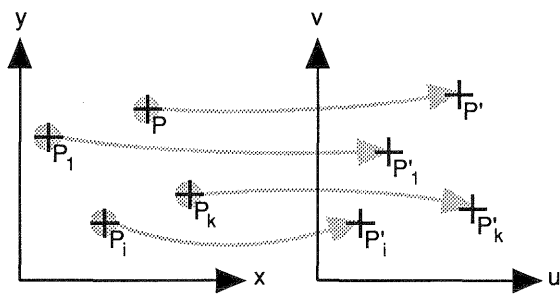


Fig. 2.2.1 Position interpolation with non-parametric techniques

The elevation co-ordinate is influencing the position of control points on the projection plane, if these are computed from 3D- object co-ordinates $P(u,v) = f(X,Y,Z)$. Different projection parameters can be used in each application. Distortions caused during the recording can indeed only be corrected by a sufficient number of control points.

The transformation of pixel coordinates following the indirect method is given by $S' \rightarrow S$ with $(x',y') \rightarrow (x,y)$, where $x'=u=u(x,y)$ and $y'=v=v(x,y)$ represent the transformations.

2.3. Interpolation and Prediction Methods

Several interpolation and prediction methods are suitable for non-parametric transformations depending on the plane shape, the distortion and the distribution of control points (Hein, 1979; Göpfert, 1987).

Projective transformation

$$\begin{pmatrix} u \\ v \end{pmatrix} = \frac{\begin{pmatrix} a_{00} \\ b_{00} \end{pmatrix} + \begin{pmatrix} a_{10} \\ b_{10} \end{pmatrix} x + \begin{pmatrix} a_{01} \\ b_{01} \end{pmatrix} y}{c_{00} + c_{10}x + c_{01}y}, \quad c_{00} = 1 \quad (1)$$

(for planes with projective distortion, oblique images)

Bivariable polynoms Qth order

$$\begin{pmatrix} u \\ v \end{pmatrix} = \sum_{q=0}^Q \sum_{p=0}^P \begin{pmatrix} a_{qp} \\ b_{qp} \end{pmatrix} x^q y^p \quad (2)$$

for irregular and delimited partial planes)

	Q	P	Surface	Deviation
Linear	1	1-q	plane	affine
Bilinear	1	1	plane	hyperbolic
Quadratic	2	2-q	curved	global
Biquadratic	2	2	curved	irregular

Table 2.3.1 Types of bivariable Polynoms Q-th Order

For the modelling of differential geometric distortions, which result from irregular surfaces, the meshwise linear interpolation as a local technique and the multiquadratic equations as a global approach appear suitable (Hein, 1979; Göpfert, 1987).

Meshwise Linear Transformation

The triangulation presupposes a steady distribution of control points. Places of unsteadiness along the triangle sides can come up. Great planes can be transformed.

$$\begin{pmatrix} u \\ v \end{pmatrix} = \sum_{i=1}^3 a_i \begin{pmatrix} x \\ y \end{pmatrix} \quad (3.1)$$

$$a_i = \frac{(x_{i+1} - x)(y_{i+2} - y_{i+1}) - (y_{i+1} - y)(x_{i+1} - x_{i+1})}{(x_{i+1} - x_i)(y_{i+2} - y_{i+1}) - (y_{i+1} - y_i)(x_{i+2} - x_{i+1})} \quad (3.2)$$

Multiquadratic Equations

The method shows a superposition of n planes of 2nd order. A plausible interpolation between the control points is achieved independently on their density and distribution but regarding their quality for a rectification. The shape of the plane is not of importance.

$$\begin{pmatrix} u \\ v \end{pmatrix} = \begin{pmatrix} \bar{u} \\ \bar{v} \end{pmatrix} + \sum_{i=1}^n r_i \begin{pmatrix} x \\ y \end{pmatrix} \quad (4.1)$$

$$\begin{pmatrix} \bar{u} \\ \bar{v} \end{pmatrix} = \frac{1}{n} \sum_{i=1}^n \begin{pmatrix} u_i \\ v_i \end{pmatrix}, \quad r_i = \sqrt{(x_i - x)^2 + (y_i - y)^2} \quad (4.2)$$

2.4. Topological Relations of Plans

For the flexibility of handling transformation functions for object partial planes f_i it is provided, that a subdivision along the places or lines of unsteadiness is possible. From the view-point of topological relation \bar{R} it is often necessary to subdivide façades in detailed parts f_j . This results in a hierarchical structure $G(f)$, in which a priori a classification of transformation functions can be handed down. Between the planes f_1 , f_2 and f_3 exists the relation \bar{R} (strict partial order), if

$$\begin{aligned} f_1 \subset f_2 \wedge f_2 \subset f_3 \quad \text{for all } f_1, f_2, f_3 \in F \\ (f_1 \bar{R} f_2 \wedge f_2 \bar{R} f_3) \Rightarrow f_1 \bar{R} f_3 \\ f_1 \bar{R} f_2 \Rightarrow f_2 \bar{R} f_1 \quad \text{for all } f_1, f_2 \in F \end{aligned} \quad (5)$$

is given.

3. REALIZATION

3.1 Principle of the Procedure

In the foreground of the system design stands a high user interaction for experimental working by the creation of orthoplans. The development of the orthophotosystem has the following principles:

- Interactive displaying of multi images in an industrial window environment.
- Using interactive manipulation for the orthophoto production.
- Interactive testing of transformation and resampling.
- Fast mode for creation of orthophotos in low-resolution.
- Batch-mode for generation of orthophotos in high-resolution.
- Input of external 3D-models (i.e. DXF from AutoCad) into the system.
- Combination: orthophoto with geometric-data.
- Using of all built-in image processing tools after generating orthophotos.
- Standard image file formats for outputs (i.e. TIFF, VFF, EPSF).

3.2. Geometry and Control Point Handling

The object geometry (control) for a digital rectification is done by analytical stereo-measurements on a Planicomp P3 combined by a CAD-system (AutoCAD), where a plane structure is defined by layers. Default attributes such as types of transformation can be assigned to the planes. The subarea hierarchy with the topological relation \bar{R} is found out of the CAD-layer structure and transferred to the orthophoto system.

Conceptively all methods can serve for the geometric data (measurements at the object, triangulated points etc.), which are necessary for single image rectification. Geometrical informations, such as the subdivision of the façade structure in limited subareas and the control points, are derived from a 3D-object model.

The position of control points and the area limits of any plane can be transformed back from the 3D-model to the image plane, if the interior and exterior orientation are known (Fig. 3.2.1). For control points of images, which are not contributing to the model, corrections may be necessary.

The free choice of projection planes guarantees the handling of image mosaics and allows the computation of control point positions and of the limits of planes, $P(u,v) = f(X,Y,Z)$.

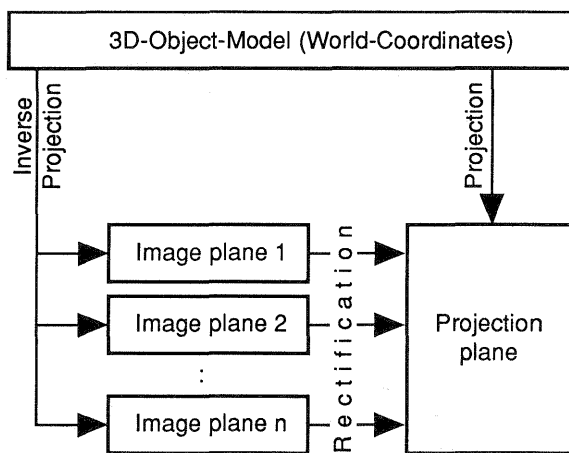


Fig. 3.2.1 3D-Object-Model

3.3. Imagehandling and Multiwindowing

For the working with digital images in an interactively window based user system a pyramid was constructed (Fig. 3.3.1). It represents a multiresolution structure of the original image (Ackermann, 1991; Rosenfeld, 1984). This concept allows to display the whole image of a lower resolution in an overview-window. In this window it is possible to select any region by zooming parts in a

subview-window with a higher resolution. Any geometric operations, especially the measuring of control points for the picture orientation, can be done (Fig. 3.3.2). Parts of the image can be digitized also and displayed in the overview-window for partial operations.

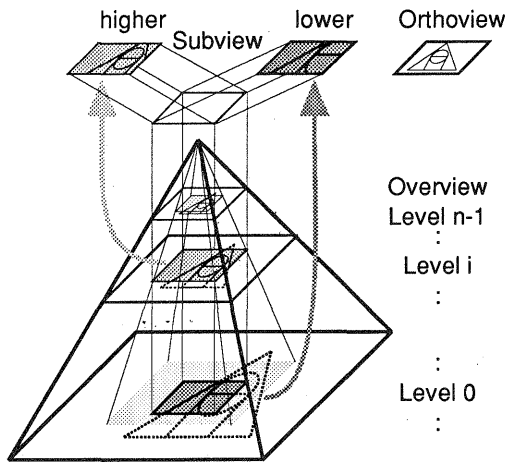


Fig. 3.3.1 Zooming in pyramid by different levels

3.4. Orthophoto Generation

The creation of orthophotos is possible in a test-mode. Parts of the image can be done with different transformations and resampling functions to control the result. The hierarchical plan structure is displayed with all control points in the image of the overview-window. For the test-mode groups or single regions of the façade can be selected. With choice of different functions a testing is possible. The result is displayed in a third window as an orthoview. For fast testing a low resolution of the projection plane must be selected to reduce the counts of the pixel transformations. But for the resampling functions by the indirect transformation, it is necessary to have access on the original image with the full resolution (low level) in the pyramid structure. Only in this way it is possible to get images with clear edge structure.

It has been shown, that the execution for transforming different plane façade areas in interactive mode can be done in adequate short time. A definitive fixation of the transformation attributes for all partial planes is acquired during a test-mode. The object orientated transmission of plane attributes takes place in the plane hierarchy. The transformation attributes of the upgraded planes are inherited to the downgraded ones, if no attributes are defined for them. All fixations are registered in a control file for the separate generation of orthophoto plans.

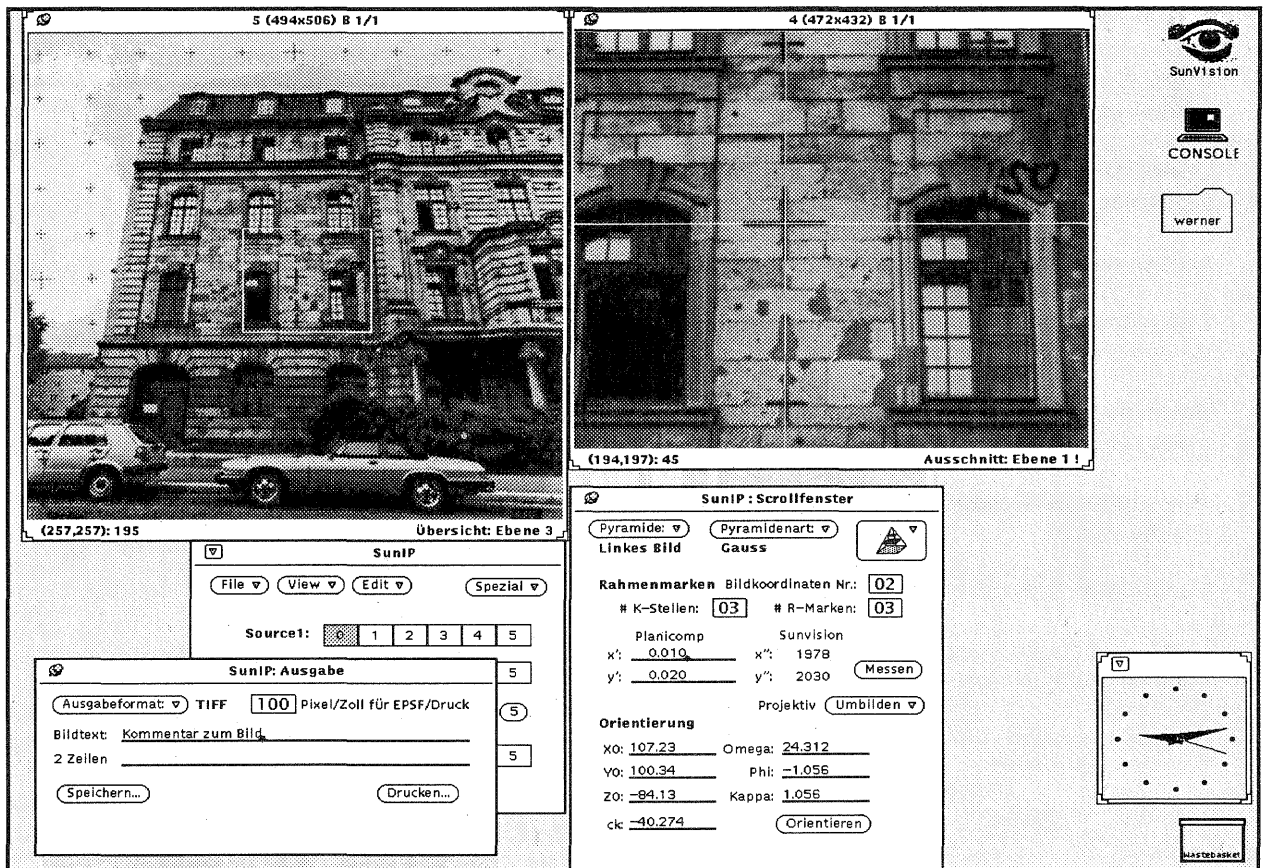


Fig. 3.3.2 Zooming from Overview to Subview

After the test phase the computing of orthophoto plans with high resolution is done in a stand-alone process. The definition of the scale and the pixel resolution (dots per inch) is possible for different output media. The orthophoto can be combined with line drawings or undergo other image processing operations, e.g. edge detection.

3.5. Software design and implementation

The implementation is based on an open industrial image processing system (SunIP/SunVision) for SUN Sparc workstations under Unix OS 4.1.2 with OPENWINDOWS3.0. For the user interface ergonomics the graphical user interface and the design principle of OPEN LOOK are applied. In SunIP it is possible to include own reconfigurable graphical user interfaces (GUI), several built-in tools for image handling and own image processing algorithms. Also tools for controlling and analysing images, subimages and regions of the digital orthophoto process are at disposal. In the image display the 2D/3D- Graphics-library XGL allows displaying, manipulation and integration of geometry objects.

4. FIRST RESULTS

The used camera was a middle format Rollei 6006 Réseau (121). For a first test a façade with prevailing even planes was chosen. Fig. 4.5 shows the final result combined with a superimposed line drawing for geometric control of the projections. The three levels of the plane hierarchy are represented in Fig. 4.2 to Fig. 4.4. A combination of the levels 1 to 3 is demonstrated in Fig. 4.1. All small planes have been rectified by linear or quadratic transformations. Level 1 (Fig. 4.2) shows a great main plane, which has been rectified projectively. The plane coefficients (17 control points) are determined by least squares adjustment. Fig. 4.6 gives the error vectors (control points), which symbolize the deviations from the adjusted projection plane. The deviations vary: mean 1.2 cm, max. 2.9 cm. Using a wide angle lens ($c = 50$ mm) this causes a relief transposition Δr of mean 0.9 mm and max. 2.1 mm in the orthophoto (scale 1 : 25).



Fig. 4.1 Combination of Rectifications

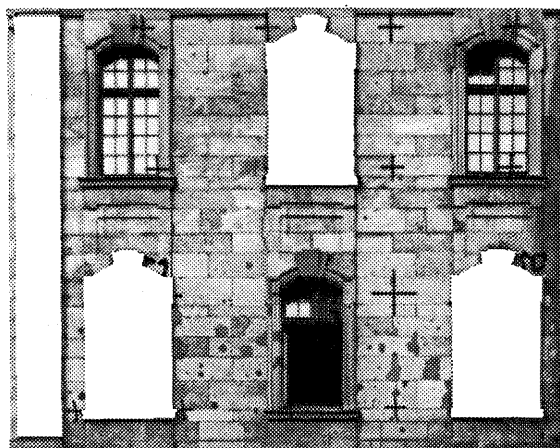


Fig. 4.2 Rectification of middle façade (Level 1)

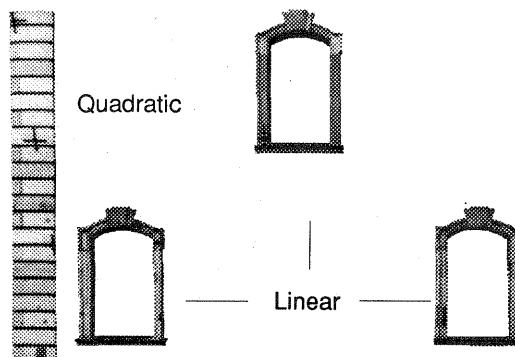


Fig. 4.3 Rectification of middle façade (Level 2)

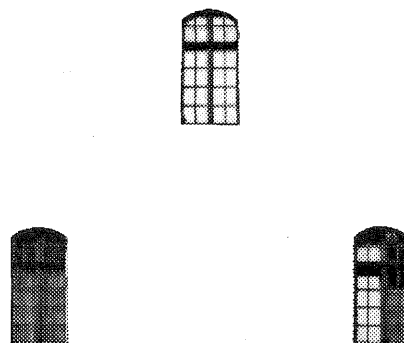
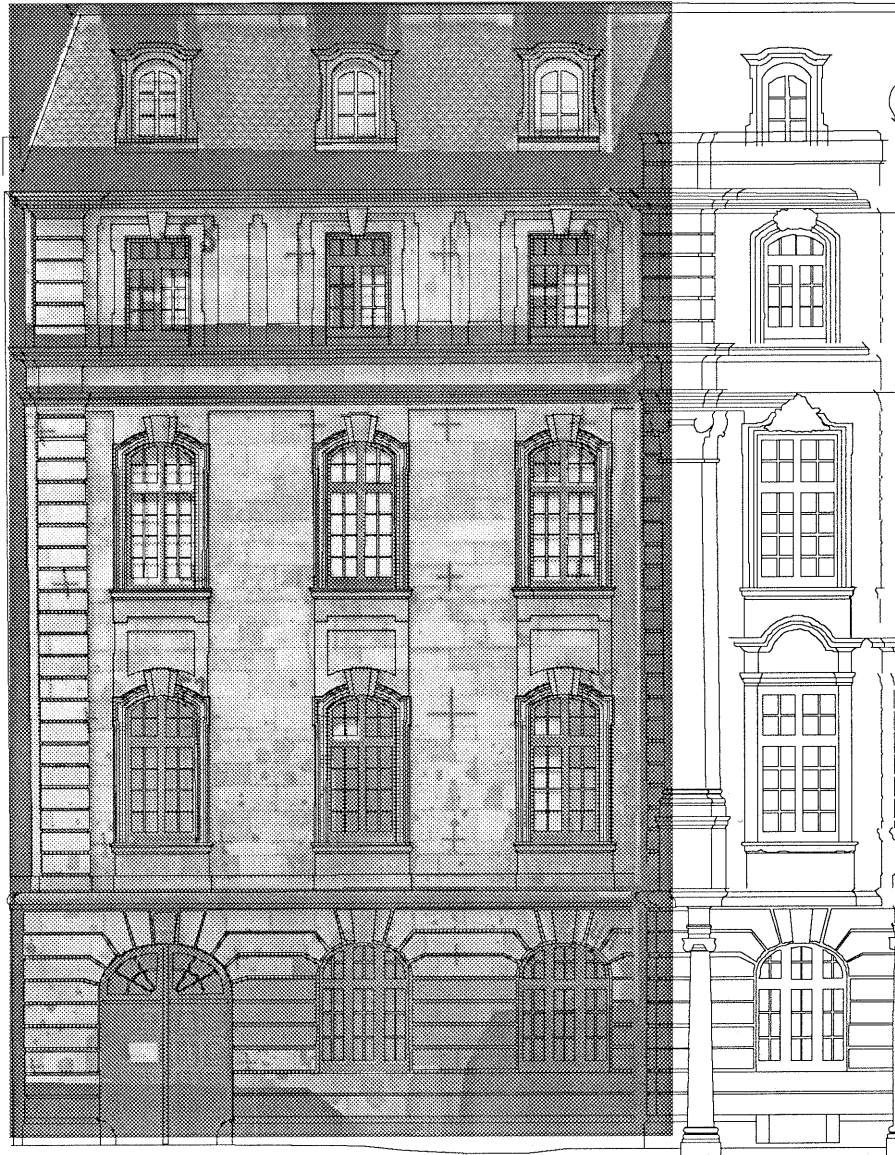


Fig. 4.4 Rectification of middle façade (Level 3)



0 1 2 3 4 5 m Scale 1:100

Fig. 4.5 Combination of line drawing and photo mosaics

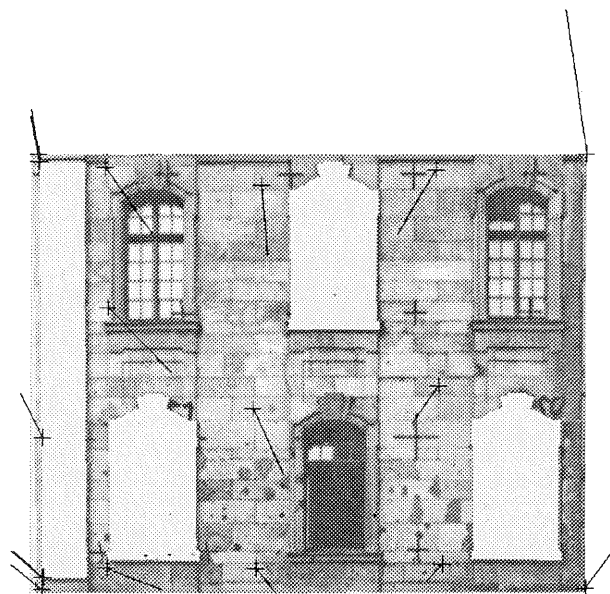


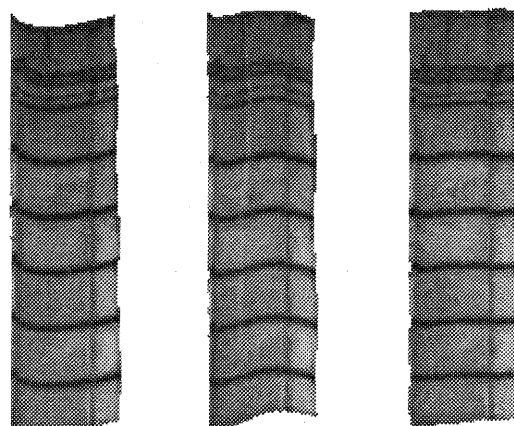
Fig. 4.6 Error vectors of control points
1 cm —

In the following test a strongly curved surface is rectified under the use of polynomial interpolation and multiquadratic transformation (differential procedure). Fig. 4.7 shows where the chosen test area is situated on the façade. 74 control points determine the surface.



Fig. 4.7 Orientation of the test region

A comparison of the results, for which was applied bilinear, quadratic and multiquadratic interpolation, is shown in Fig. 4.8. Regarding the course of the horizontal stone joints it can be recognized, that only a differential procedure, as the multiquadratic interpolation, is able to represent the position of the joints. The two polynomial functions do not approximate the surface sufficiently, what is followed by distortions.



Bilinear Quadratic Multiquadratic

Figure 4.8. Different Interpolations

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