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THE USAGE OF IMAGE PROCESSING METHODS FOR INTERPRETATION OF THERMOGRAPHY DATA

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Abstract. *For assessment of old buildings, thermal graphic analysis aided with infra-red camera have been employed in a wide range nowadays. Image processing and evaluation can be economically practicable only if the image evaluation can also be automated to the largest extend. For that reason methods of computer vision are presented in this paper to evaluate thermal images. To detect typical thermal image elements, such as thermal bridges and lintels in thermal images respectively gray value images, methods of digital image processing have been applied, of which numerical procedures are available to transform, modify and encode images. At the same time, image processing can be regarded as a multi-stage process. In order to be able to accomplish the process of image analysis from image formation through perfecting and segmentation to categorization, appropriate functions must be implemented. For this purpose, different measuring procedures and methods for automated detection and evaluation have been tested.*

1 INTRODUCTION

The method of infrared measurement is based on a physical phenomenon on which a body emits electromagnetic radiations at a temperature above the absolute zero point. Once the intenseness of these electromagnetic radiations is determined, we would be able to detect without contact the temperature distribution on surface areas which is not observable with our eyes. To further process the acquired thermal image, there are various methods of digital image processing. However, the possibility with the aid of existing thermal graphic software is restricted, because there are only a limited number of functions available. Consequently, today's building assessment through thermal graphic analysis is restricted to a manual evaluation of thermal graphic measuring data on the basis of a color printout of a photo, and thus a color temperature spectrum is used as a complement. Therefore, if the thermal graphic data could be expanded into a continuous computer-aided planning of renovation or reconstruction, the efficiency of a thermal graphic building analysis could be largely improved. At present, a computer-aided planning of renovation measurements is used only partially.

2 PRESENT SITUATION OF RESEARCH

Infrared thermography is an effective and robust inspection method in the field of building construction, which is also legally acknowledged for analysis of building stock and analysis of building engineering. Besides as a pure inspection method, thermography in architecture provides a valuable aid in condition inspection of a whole building for a subsequent energy calculation. For assessment of old buildings, thermal graphic analysis aided with infrared camera have been employed in a wide range nowadays [6], [24]. The thermal graphic analysis is restricted to a manual and pure qualitative evaluation of thermal graphic measuring data on the basis of a color printout of a photo, and a color temperature spectrum is thus used as a complement. The data obtained this way could be used at most in further planning process in paper form.

Commercial software is limited to visualization of measured temperature [7], [9], [13]. For example, it is possible to display the maximal and minimal temperatures in a chosen range of measurement, to exhibit horizontal and vertical temperature profiles for the overall image and to show isotherms. But a method to extract and evaluate thermal image components does not exist.

To evaluate images, especially grey value images, there is a varied experience in the field of image processing, of which numerical procedures are available to transform, modify and encode images. At the same time, image processing can be regarded as a multi-stage process, at which a set of operations are available to extract data from images [14]. Such a hierarchical schema can be divided into five phases: image gathering, restoration, enhancement, segmentation and classification [22].

The first two phases belong to real image recovery and can be developed through quantization of spot space by means of thermal graphic measurement and digitalization and interpretation of the measured radiation values. For image perfecting, different operations are introduced in [15], [16], [23]. Thermogram is accepted for inspection. [1] lists how to reduce noise ration, to promote image contrast, to correct median distortion of gray values, to eliminate inhomogeneity in an image and to adjust filter to increase the frequency of important information and restrain unimportant information as goals. An image will be decomposed into individual regions through segmentation, which are adequate for interpretation as segments. The neighboring pixels of regions that are associated together as relevant content are integrated according to one homogeneity criteria as well as are separated according to inhomogeneity criteria. For this purpose there are different pixel-oriented, edge-oriented, region-oriented and model-oriented methods [11]. After segmentation, features from the generated representation will be calculated. Based on that, the interpretation of images will be decided at the stage of classification. Many libraries exit already that provide functions of image processing [10], [12], but an application and implementation of the presented methods in thermal graphic survey are not made so far.

Once the thermal graphic information is recognized, an appropriate deformation as well as equalization is required for a later comparison with other survey technics. For the purpose of a geometrical deformation, a projective transformation must be made. Suitable commercial software for it is metigo BASIC of focus GmbH Leipzig [20], which enables the measurement of height, length and plane besides a scale deformation. In order that only one deformation is possible, equalization to another perspective is not possible.

3 APPLIED METHODS

3.1 Digital image processing

Thermal images are often known as so-called "false color image", which are dyed gray value images since an object emits more (=white) or less (=black) radiations. In order to develop a method for detection of typical thermal image elements such as window lintel and thermal bridges, methods of processing digital images are used. The tasks of image processing include generation, perfecting, segmentation and classification of image or raster data.

The first step after image generation is to take measures to perfect digital thermal images so as to eliminate noise and highlight edges and thus to make final procedure of evaluation easier and more reliable. Image processing consists of contrast intensification, contrast balancing and filtering (linear and non-linear) in spot space and frequency space. A study of parameters concerning characteristics and possible combinations is provided in a diploma thesis [17].

The subsequent strategy of segmentation analyzes the image in pixel groups, which, in a later interpretation, will show typical characteristics e.g. the size and form of a structure that is composed of pixels. Pixel-oriented methods are among several segmentation methods, which determine for every image point whether it belongs to a segment or not. There are methods working with

- fixed: $$g_{new} = \begin{cases} g_{\max} & , g \geq T \\ 0 & , g < T \end{cases} \quad \text{or} \quad g_{new} = \begin{cases} g_{\max} & , g \in [T_1, T_2] \\ 0 & , else \end{cases} \tag{1}$$

- iterative: $$T_{i+1} = \frac{O_i + U_i}{2} \tag{2}$$

  T_0 ... initial value,
  O_i, U_i ... average value over object and underground gray values

- dynamic: local value T(x,y) as average value over the neighbourhood of (x,y)

threshold values.

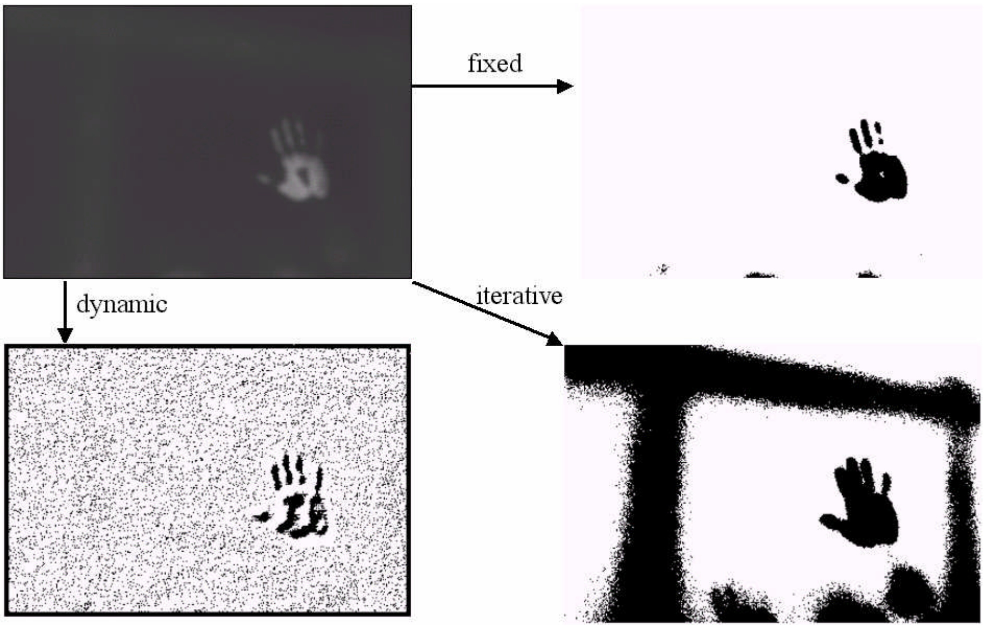

Figure 1: Operation mode of threshold methods

There are also edge-oriented segmentation methods, which separate regions according to inhomogeneity criteria. A gradients-based edge detection with first order derivation refers to a search after the maximal sum of gradient vectors. It demands the partial derivation of first order in all directions of special gray value function g(x,y). It is proper to use differences of first order to compute gradient vectors:

$$\frac{\partial}{\partial x}=\begin{pmatrix}-1 & 0 & 1\\ -1 & 0 & 1\\ -1 & 0 & 1\end{pmatrix},\quad \frac{\partial}{\partial y}=\begin{pmatrix}-1 & -1 & -1\\ 0 & 0 & 0\\ 1 & 1 & 1\end{pmatrix},\quad \|\nabla g\|_2=\sqrt{\left(\frac{\partial g}{\partial x}\right)^2+\left(\frac{\partial g}{\partial y}\right)^2} \tag{3}$$

Furthermore, edges can also be found through zero points in the second derivation like in Laplace operator or through regularized edge detection like Sobel operator. The discovered edge pieces are often very thick and not connected with each other, which need a further processing, i.e. skeleton or edge tracing methods.

A further method produces region-oriented segmentation, through which the togetherness of regions is described according to homogeneity criteria. Region-merging and split-and-merge are fundamental methods to segment an image according to these criteria.

The model-oriented segmentation introduces modeling knowledge with object characteristics into the segmentation process. Simple models with few parameters are used in template matching or Hough transformation.

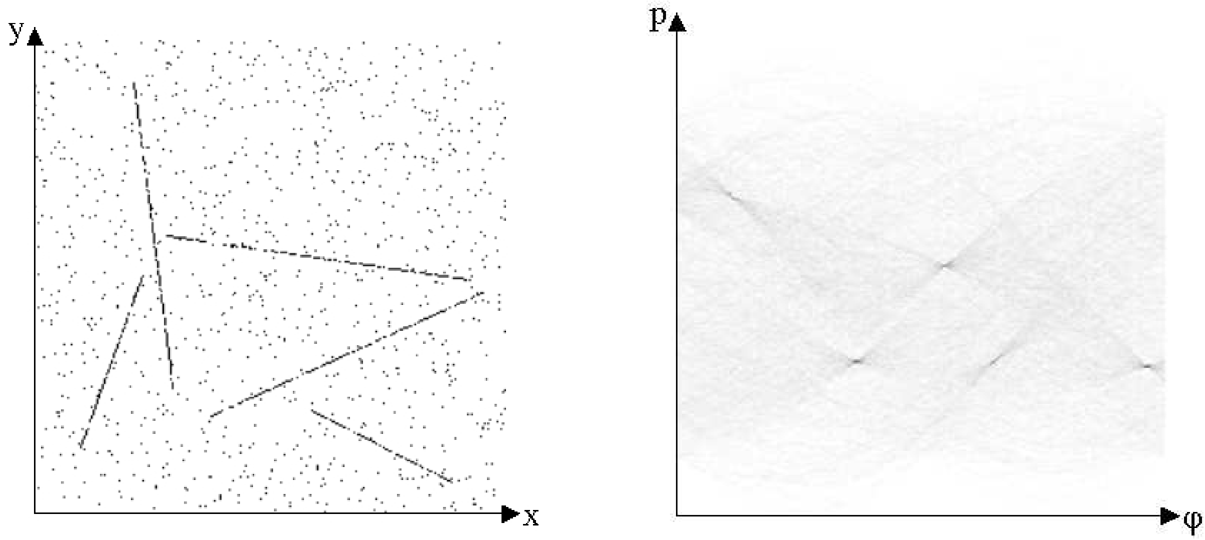

Figure 2: Line representation with noise in the image space (left) and Hough space (right)

3.2 Close range photogrammetry

The equalization and deformation of fine plane in object space is made possible by means of close range photogrammetry, whereas equalization, as a projection on the image plane, is only a special case of deformation. In this way, it is possible to compare the building facades taken from different positions through a projective transformation. Direct and indirect deformation differs from each other.

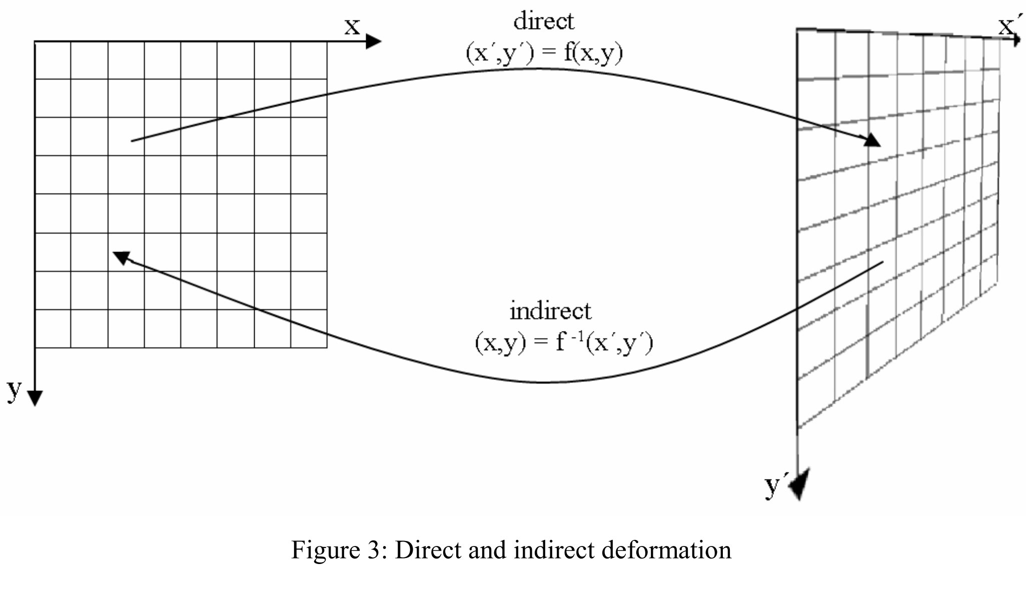

Figure 3: Direct and indirect deformation

By direct deformation, every pixel of the original image is assigned a position in the deformed image. The problem is multiple- and non-allocation in deformed image, which demands a costly post-processing. Through indirect deformation, every pixel in deformed image is assigned a source-pixel in the original image, i.e. the deformed image takes the gray value from the (indirectly) computed position. It may occur that non-integer positions are computed and a gray value allocation must be made through re-sampling method, such like nearest neighborhood or bilinear interpolation.

The projective transformation is described through the following formula and characterized through eight parameters:

$$x' = \frac{a_{10} + a_{11}x + a_{12}y}{1 + a_{32}x + a_{32}y}$$
$$y' = \frac{a_{20} + a_{21}x + a_{22}y}{1 + a_{32}x + a_{32}y} \qquad (4)$$

The eight parameters are determined by four reference point pair (x_i,y_i), (x_i',y_i') , i=1,...,4. The system of equations stated below is valid and may be easily proved. With more than four pairs of point correspondence, the parameters can be found through computation of equations.

$$\begin{pmatrix} -x_1x_1' & -y_1x_1' & x_1 & y_1 & 1 & 0 & 0 & 0 \\ -x_1y_1' & -y_1y_1' & 0 & 0 & 0 & x_1 & y_1 & 1 \\ -x_2x_2' & -y_2x_2' & x_2 & y_2 & 1 & 0 & 0 & 0 \\ -x_2y_2' & -y_2y_2' & 0 & 0 & 0 & x_2 & y_2 & 1 \\ -x_3x_3' & -y_3x_3' & x_3 & y_3 & 1 & 0 & 0 & 0 \\ -x_3y_3' & -y_3y_3' & 0 & 0 & 0 & x_3 & y_3 & 1 \\ -x_4x_4' & -y_4x_4' & x_4 & y_4 & 1 & 0 & 0 & 0 \\ -x_4y_4' & -y_4y_4' & 0 & 0 & 0 & x_4 & y_4 & 1 \end{pmatrix} \begin{pmatrix} a_{31} \\ a_{32} \\ a_{11} \\ a_{12} \\ a_{10} \\ a_{21} \\ a_{22} \\ a_{20} \end{pmatrix} = \begin{pmatrix} x_1' \\ y_1' \\ x_2' \\ y_2' \\ x_3' \\ y_3' \\ x_4' \\ y_4' \end{pmatrix} \qquad (5)$$

3.3 Software engineering

A concept of a graphical user interface was programmed with methods of software engineering and usability to apply the functionality of the image processing phases. The total programming was object orientated planned in C++ to enable an efficiently development of several data objects. For this purpose the library wxWidgets [25] was used. In cooperation with the professorship of programming and software engineering of the LMU Munich the development of the graphic program is provided in a diploma thesis [18]. In that process the criteria of usability of [5] should be followed:

- effectiveness to solve the problem
- efficiency to handle the system
- and contentment of the user of the software.

4 RESULTS

4.1 Processes of computer vision and advantage for building reconstruction

Significant knowledge for image enhancement arrangements of thermal images is delivered from [17]. But it was not possible to find a function which enables to enhance every image. For this reason combinations of several filters were analyzed and modules arranged, that were verified and judged by assessed by effect and aim. In this process two modules were found, that especially suited for. The used concept of contrast enhancement, smoothing and edge accentuation is shown in the figure below.

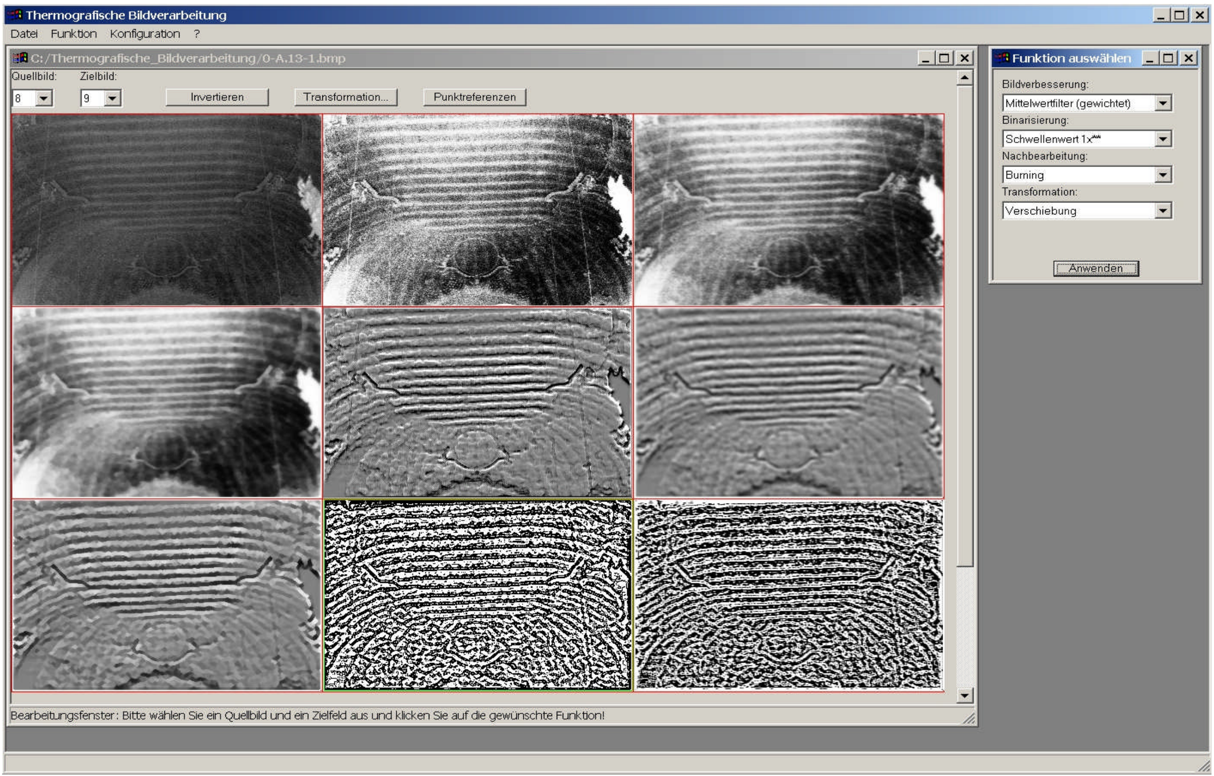

Figure 4: Graphic program with image enhancement arrangements

Gray value images can be transformed to binary images through the application of threshold methods. The following postprocessing was analyzed through thinning methods. Particular the influence of image enhancement methods were explored to the following thinning process and different methods were compared. The burning-algorithm of [19] that was also compared with barycentre methods by [21] was proved as effective. The result of the burning-algorithm is a centerline with the distance of each edge point. Furthermore the application of filters such as $\begin{bmatrix} 0 & 0 & \\ 0 & 1 & 1 \\ & 1 & 1 \end{bmatrix}$ was tested which worked quick and robustly. In general, the filter method delivers good results and the burning-algorithm delivers only useable results provided that image enhancement is realized.

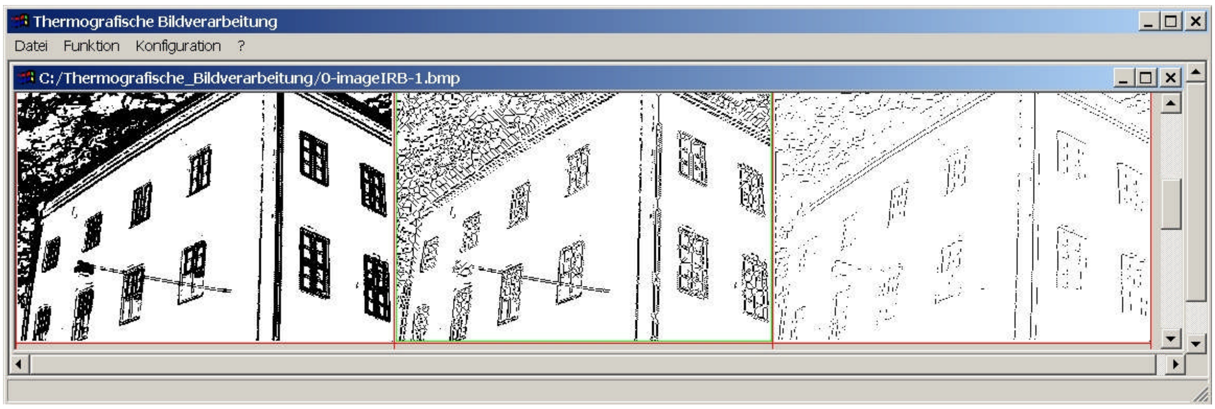

Figure 5: Binary original image (left), burning-algorithm (mittle), filter method (right)

The next image processing phases are realized with the application of methods of section 3.2 "Digital Image Processing". Especially for detection thermal bridges and lintels it is important to find windows at first to avoid segmentation of further irrelevant parts. After the segmentation of the windows the area of interest can be reduced according to the current model. For lintels it is the region above the window and for thermal bridges the region below. The following fine search can be realized in several steps and can be refining stepwise. To determinate regions different region criteria can be used. A detailed description of the algorithm is shown in the next figure.

(1) *image generation*

- take thermal photography
- read the digitized radiation
- convert to gray value image

(2) *initialization*

- read image and identify dimensions
- visualize the image in a window

(3) *search in full domain*

- image enhancement:
  smoothing filters to eliminate noise
  gradient filters to emphasize edges
- generate binary image:
  pixel oriented segmentation through threshold methods
- connect regions:
  region crowing through neighbouring relations
- select regions:
  area criteria such as form, length, size, ...
  several iterations

(4) *search in reduced domain*

- reduction:
  reduce search domain to the segmented regions
- generate binary image:
  pixel oriented segmentation through threshold methods
  region oriented segmentation through region crowing
- select regions:
  area criteria such as form, length, size, ...
  several iterations
- morphological operations:
  strukture elements such as rectangle, ellipse, ...

(5) *evaluation*

- temperature through threshold of the segmentation
- size through number of pixels

(6) *output*

- visualize the segmented parts
- valuation and comments
- save results

Figure 6: Algorithm to detect thermal image elements

The description of the program is presented as generally as possible to adjust it for every application. Solutions for tasks of thermal images were found through this algorithm. The results of the image detection are shown in the lower figure. An evaluation of the segmented thermal image elements such as thermal bridges is possible by strength respectively temperatur through the threshold of the segmentation and by size respectively comprised area.

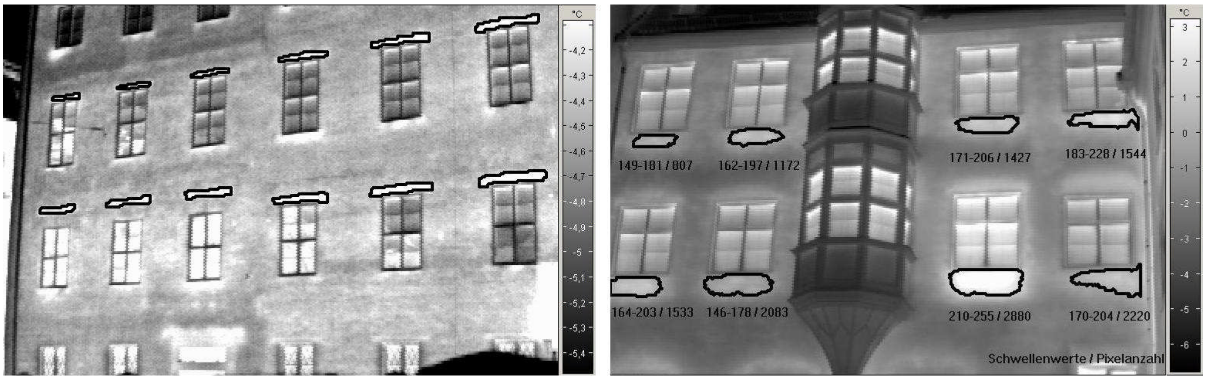

Figure 7: Segmented lintels (left) and valued thermal bridges (right)

By that the explicit prove of thermal bridges and its area can be comprised given for [8] in combination with [4]. To apply the process of image processing a graphic program as a graphical user interface was developed that enables to read and manipulate thermal images. A description and tutorial of the program is given by the diploma thesis of [18].

4.2 Reference to further images and a building model

To survey and take the building data is the most important precondition for a successful planning and realization of the actual building's survey. However, a single building survey method can provide neither comprehensive and objective documentation nor a sufficient primary model, and so it does not meet the requirements of a wide range of application. In this regard, demands have been raised through historical problems in fields of archaeology, historical construction research and preservation of ancient monuments, through renovation and reconstruction measurements as well as through the construction of building information system. Only through a combination of many survey methods can an information basis be produced, which can be analyzed for various problems.

The geometrical correctness of the measured thermal data is not very well because of the low resolution of the used infrared cameras. Is there a high accurate geometry available for instance a laser scan, it is possible to project the thermal data onto the surface of the geometrical representation and to supply to further analysis.

The equalization of photographies of the same object through different techniques (thermography, digital photography, laserscanning) is possible with reference points through a projective transformation. The deformation of thermogram to a digital photography of a stone walled soffit is shown in the figure below. Thereby the circular adjustment of the stones is visible in the thermogram.

Figure 8: Digital image with thermal image

The integraition to a digital building model is necessary to simulate the life cycle. With that the ecological and economical benefit of different revitalization alternatives can be compared and a optimal solution can be found for old buildings. The research project F248 of the master project "Stoffflussmanagement Bauwerke" [3] delivers a product model, which provides long-dated prognoses of energy and material flow rates of buildings. The additional thermal information can be included into the product model with the aid of the software Architectural Desktop 2005 [2] through the three possibilities:

- hyperlink through property-window of ADT 2005:

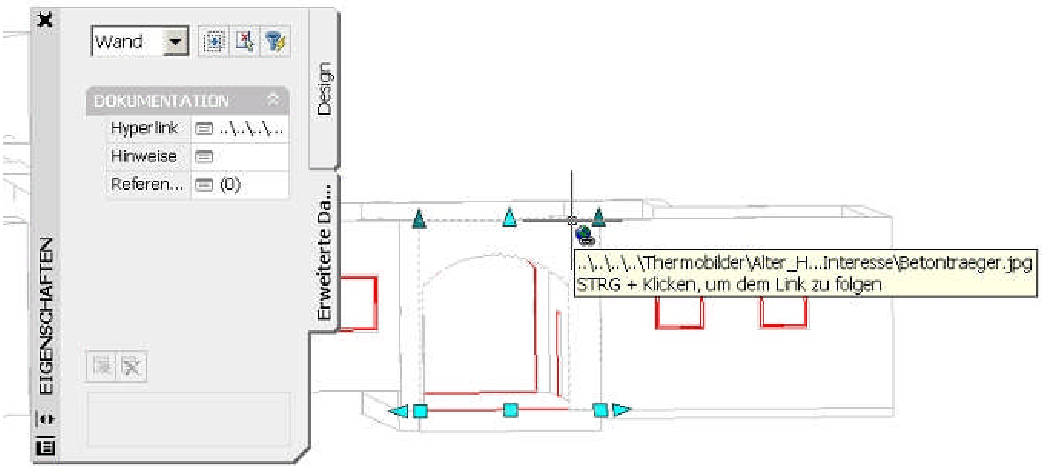

Figure 9: Hyperlink-method

- insert image through ADT 2005:

Figure 10: Projected image onto model surface

- Arx-modul of the cooperation project F248:

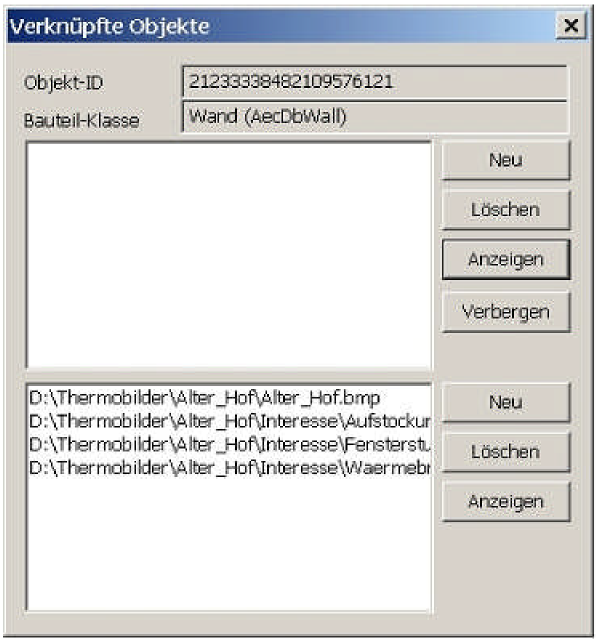

Figure 11: Connected through Arx-modul

The temperature of an object can be detected without contact, but importantly, the information value obtained from thermography is limited for the reason that thermography displays the measurement of surface infra-red radiation and therefore can not provide information about possibly existing multi-layer construction or other three-dimensional structures. It is not possible to look into the wand. Although more can be observed in a thermogram than with an ordinary camera, only indirect conclusions can be drawn about the structure behind the surface. In this respect, the thermography must be complemented with additional information such as a comparison with known types of inner structure and manual references by the user. Statement about thermal features can be made only for the whole construction part.

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