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AUTOMATIC INDICATION OF HEAT LOSS IN THERMOGRAMS OF BUILDINGS

URSZULA MARKOWSKA-KACZMAR
Department of Computational Intelligence, Wroclaw University of Technology,
Wyb. Wyspianskiego 27
50-370 Wroclaw, Poland
urszula.markowska-kaczmar@pwr.edu.pl
http://www.ii.pwr.edu.pl/ kaczmar

AGNIESZKA SZYMANSKA
Department of Technical Informatics, Wroclaw University of Technology, Wyb. Wyspianskiego 27
50-370 Wroclaw, Poland
a.szymanska@pwr.edu.pl

LUKASZ CULER
Department of Technical Informatics, Wroclaw University of Technology, Wyb. Wyspianskiego 27
50-370 Wroclaw, Poland
lukasz.culer@pwr.edu.pl

This paper presents a method of automatic detection of heat loss level in buildings on the basis of thermal images. The designed algorithms use OCR and image recognition techniques. Several steps such as heatmap area detection and key search lead to the result which is a percentage value of areas with temperature higher than a threshold value given by the user. This approach was tested on diverse thermal images which were previously manually tagged and it has shown promising results.

Keywords: heatmap; thermogram; information extraction; image processing.

1. Introduction

Thermal imaging is a part of infrared imaging science. It bases on radiation detection and produces images called thermograms. They can show variations in temperature, because the amount of radiation emitted by an object increases with temperature. Thermal cameras produce usually images containing heatmaps with a key showing which color is assigned to which temperature value. Thermography is used in many disciplines. In medicine, some diagnostic can be made using human body thermograms [Klosowicz (2001)]. In civil engineering infrared thermography is a non-destructive technology for building diagnostics, which helps to minimize the energy consumption [Balaras (2002)].

There are some approaches which enable automatic or semi-automatic thermogram analysis. A knowledge-based system processing IR images and high-resolution visual RGB images was created in work [Ribaric (2009)]. It consists of the database, the knowledge base, the inference engine and the user interface. In operations such as image acquisition, image pre-processing and feature extraction, image registration, object segmentation, fusion and data analysis it enabled the facade diagnostics. Other approaches focus on automated texturing of 3d building models with images recorded with infrared cameras [Hoegner (2009)]. Textures are extracted for every image and tagged with camera position from all visible surfaces. Then, the textures are used for feature extraction and object recognition for analyzing buildings and assigned 3d coordinates to find features and objects.

The system processing thermal images based on L-shaped features detection with a set of steerable filters to find windows and doors on the image is described in [Sirmacek (2011)]. After eliminating detected doors and windows from the building facade, it is possible to indicate building damages and thermal leakages in buildings.

Other windows detection algorithm uses a local dynamic threshold to extract candidates for windows in the textures [Iwaszczuk (2011)]. A regular grid of windows masking correlation is used to find the position of windows. In the end, gaps in the window grid are replaced by hypothetical windows.

A few works, for example [Barazzetti (2013)] are devoted to search formal description of objects or 3D bodies.

The research described in this paper is focused on developing a method for automatic detection of a heat loss level in buildings on the basis of thermal images. It is based mainly on image recognition techniques. The method allows to indicate a percentage value of areas with temperature higher than a threshold value given by the user.

The paper consists of six sections. In the next section, we formulate our research problem in detail. In section 3 the whole thermal image processing procedure is described. The next section shows the experiments and the results. Conclusions summarize the paper.

2. Problem formulation

In the paper [Markowska-Kaczmar (2014)] we presented a method of automatic information extraction from heatmaps called HInEx (from Heatmap INformation EXtraction). This method was originally created for environmental heatmaps including information about environmental feature values, for instance, NO_2 concentration or atmospheric pressure in a given geographical region presented on the geographical map. These environmental feature values are expressed by a color on the map. Thermograms, in fact, are also heatmaps, so their processing has a lot in common with processing environmental heatmaps. Therefore, some algorithms from HInEx method after necessary adaptation will be used in processing thermal building images.

Fig. 1 shows an example of two thermograms thermograms of buildings. The main part of the considered thermogram image is proper thermogram area, containing information about temperatures of a presented object, visualized by a set of colors. It is described using a key - area containing all used on thermogram colors, put in specified order and tagged with real temperature values. The key is located usually outside of proper thermogram area. Thermograms usually contain other elements like title or other annotations, which were skipped during our procedure.

Our task was to invent a method for automatic extraction of heat loss expressed in percentage value from thermograms of buildings. In this paper, we focus on key and heatmap area recognition which gives the possibility to find the hottest areas without user's effort. It can replace basic manual analysis and give quickly the answer whether the building can have abnormalities causing heat loss or not.

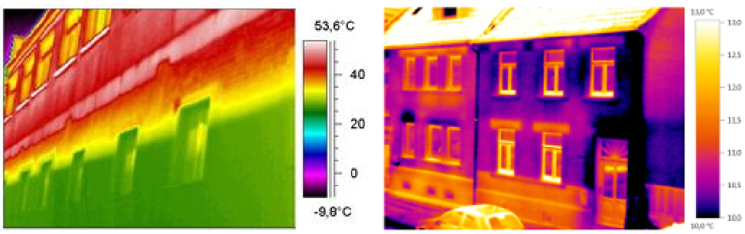

Fig. 1. Exemplary thermograms, with different color palettes.

3. The procedure

This section contains information about each step of created procedure, with algorithm description and examples of image output after significant transformations. The whole procedure is visualized by a diagram in Fig. 2.

Each step in detail is described in the following subsections. We start with a description of thermogram proper area isolation. It is the fundamental step, on which relies any others. It uses thresholding and finding uniform areas. The next step is responsible for thermogram clustering. It is essential for the reduction of colors represented on the thermogram. Then, the algorithm is looking for a key, which is used to label colors from thermogram by its real values afterward. It uses the linear approximation to predict temperature values based on colors, that are not placed on the key labels explicitly. The last step of the procedure uses threshold temperature to determine heat percentage loss.

3.1. *Thermogram area isolation*

This step aims at separating proper thermogram area from a background. In our approach color is considered in RGB color space (Red, Green, Blue), where pixel's

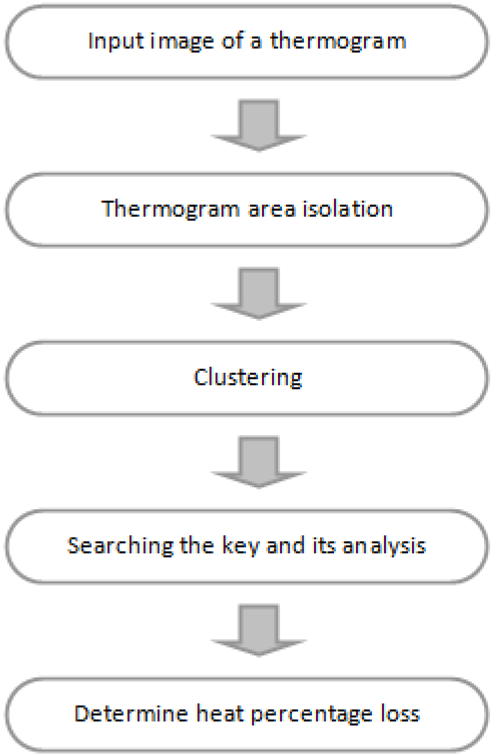

Fig. 2. Steps of thermal image processing

color is a point in 3-dimensional space (RGB color space). In RGB color system coordinates are equivalent to the intensity of each primary color, represented by a single integer from 0 to 255.

As a background, we understand the area of the image that completes area between functional elements like a proper map area and a key. Usually, it has solid color - and only that case our algorithm supports. To determine background color, an average of corner pixels colors of the image is calculated.

The next step is a threshold-like operation. This procedure replaces colors similar to the background color with white color and others with black ones. Colors are considered as similar if their distance measured on the basis of Manhattan norm is less than BACKGROUND MAX DISTANCE constant value, which was experimentally set to 5. More details about this step can be found in [Markowska-Kaczmar (2014)].

At that point, the processed image is set of black and white areas. The next step is a separation of the area, that contains a proper thermogram area. The developed procedure is based on some insights given below:

- The most area of functional thermogram elements has different color than backgrounds, so their area on thermogram is represented by black color,
- Functional element (eg. proper thermogram area) do not stick together, so they are separated by background color - on a thresholded image by white color,
- Based on two previous - functional elements are black uniform areas on thresholded image separated by white color,
- Proper thermogram area is the biggest (as number of pixels) element on a thermogram,
- One black pixel cannot belong to two areas because they are separated.

To use those insights, definition of the single uniform area is needed. As a separated area A_i we understood a set of black pixels, that satisfies condition (1)

$$\begin{gathered}\forall(x,y): C(x,y) = Black \wedge (x,y) \in A_i \Rightarrow \forall N : C(N) = Black \wedge N \in A_i \\ N \in \{(x-1,y),(x+1,y),(x,y-1),(x,y+1)\} \\ \forall k,j : k \neq j \Rightarrow A_k \cap A_j = \emptyset\end{gathered} \tag{1}$$

where $C(x,y)$ is function of coordinates x and y, that return color of pixel with that coordinates, Black is for black color, and N is neigbourhood of one pixel (x,y). That condition means, that all black pixels neighbors are in the same set - area.

Now, as we have set of A_i areas, as a proper thermogram area we consider the smallest rectangular area that contains the largest A_i area. The exemplary result of this step is presented in Fig. 3.

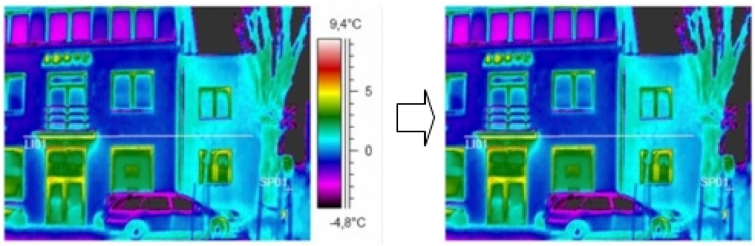

Fig. 3. Thermogram area before isolation (on the left) and after (on the right)

The algorithm is presented in pseudocode in Alg.1. The detailed description can be found in [Markowska-Kaczmar (2014)].

3.2. *Clustering*

The obtained image of the proper thermogram has one serious issue. It contains a big amount of information expressed by a wide range of colors. Therefore, it is difficult to describe it. To solve this problem we have proposed in [Markowska-Kaczmar (2014)] the approach based on agglomerative hierarchical clustering.

Algorithm 1 The extraction of the thermogram area

Require: input thermogram building image
Ensure: thermogram area
Determine background color;
roceed thresholding-like operation using the background color;
Split pixels into uniform black-colored areas;
Find GUBA - the Greatest Uniform Black colored Area;
Find the smallest rectangle containing GUBA (its upper-left and bottom -right corners define the extracted area).

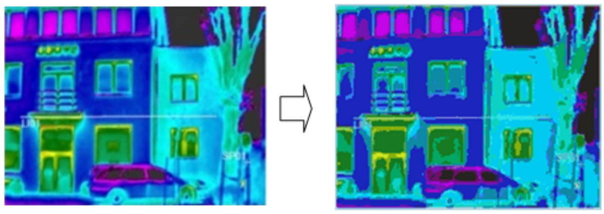

Fig. 4. Thermogram proper area before clustering (on the left) and after (on the right)

This step takes on its input an isolated thermogram image and, after clustering, returns on its output the same image with reduced amount of colors.

At the beginning, a set of unique image colors from isolated thermogram area image is created, and clusters connected with each of them are created. Then, the algorithm repeats the procedure connecting regions of pixels. Each cluster contains one or more colors, represented in the RGB color system. During this procedure, a cluster is considered by its center. Each cluster has also defined a radius, which is the largest distance between the center of a cluster and one of the contained colors. It is measured on the Euclidean norm basis. To evaluate the quality of clustering the distance between two clusters is defined as the distance between their centers reduced by the bigger radius of these two clusters.

The algorithm sorts in ascending order all distances between two clusters. Then, the first pair (with the smallest distance) of clusters is pulled. If the connection condition is satisfied, then those clusters are joined and next iteration starts. Otherwise, the next pair is pulled and it is checked, whether it can be connected. This step is continued until it is possible to find a pair to be connected or all pairs were checked. If so, the joining algorithm stops. The algorithm in pseudocode is presented in Alg. 4.

It is worth adding that the last part of clustering procedure replaces all colors within a cluster with color represented by the cluster center. The exemplary results of this step are presented in Fig. 4.

Algorithm 2 The clustering method

Require: extracted proper area of thermogram image
Ensure: clustered thermogram image

```
Store the clusters in the cluster base;
Set stop condition unsatisfied;
repeat
   Determine the distance between each cluster pair;
   Find the pair of clusters with the smallest distance that could be merged;
   if the pair was found then
      Remove it from the cluster base;
      Create the merged cluster and put it into the cluster base
   else
      set stop condition
   end if
until the stop condition is met
Replace all colors contained in each cluster with its color;
```

3.3. *Searching the key and its analysis*

This step aims at isolating thermogram key from the image. It is essential for the proper assignment of temperature values for colors.

Firstly, the set of unique colors from non-clustered proper thermogram area is created. Then, those colors are searched outside the proper thermogram area. The next step relies on observation, that those colors occur only in thermogram key. For these points, maximum and minimum value for both x and y-coordinate is determined, as well as the median value. If an average difference between the mean value and other points are less for x-coordinate, the key is considered as horizontal, in the other case - as vertical.

The next steps are described for a vertical key. The procedure for horizontal key is analogical. It starts from text labels. The labels positions are recognized by the software implementing the method described in [Sas (2013)]. It enables to find all text areas and their positions in the image. For all text labels, distances between the vertical borders of labels (left and right) and key left and right border are determined. Then, distances between the horizontal borders of labels (top and bottom) and the key top and bottom borders are also determined. If the smallest from determined distances is vertical and it is smaller than the parameter value MAX_TEXT_DISTANCE which was set to 20 pixels, then the label was considered as a key description. The algorithm is presented in Alg. 3 and described in detail in [Markowska-Kaczmar (2014)]. Key location and its labels at this moment are not giving sufficiently accurate information about certain colors real value. To make it more accurate, we used the linear approximation. For this step, each label was considered as a data point. The domain value of point was defined as labels center y-coordinate (as before, we consider this part of the procedure for vertical key) and points value as parsed label content.

Algorithm 3 *The key search* method

```
for all colors from the proper thermogram area do
  Find all pixels of this color outside the heat map area
  Find pixels in this set with maximal and minimal coordinates on at least one
  axis
end for
for all colors do
  Find the median of minimal coordinates and the median of maximal coordinates
  for each axis
end for
Count how many pixel positions from the minimal and maximal position list are
similar to the median for each axis
if there are more pixels similar to the median of horizontal axis coordinates then
  the key is vertical
else
  the key is horizontal
end if
if the key is vertical then
  Set the boundaries of the key on the X axis as the median of the minimal and
  the median of the maximal positions
  Set the boundaries of the key on the Y as the smallest minimum and the highest
  maximum from the list of all colors positions
else
  Perform similar operations for the horizontal key
end if
Find the label description for each color as the label nearest to the left pixel of
an upper limit for the occurrence of this color inside the key
Use found labels to determine linear parameters for position / value label depen-
dence
```

For each pair of those points theirs domains and values are used to determine linear parameters a and b of a line intersecting them. Those parameters are used to predict values of other points using their domain values. If the predicted value and value of point obtained from parsing differs less than MAX_RELATIVE_ERROR = 10% of parsed value it is considered as point supporting those linear parameters. Linear parameters with the greatest number of supporting points are considered as keys linear parameters.

Now, to determine an accurate value of the color from proper thermogram area based on a key, we look for this color in the key. The point, in which it was found, is used with key linear parameters to determine final color values.

3.4. *Determining heat loss*

This is the last step of the method. It starts with obtaining threshold temperature value (eg. from a configuration file).

In order to determine this temperature, the areas, where the heat transfer is significantly higher, have to be found. This areas are regarded as thermal bridges and understood as a heat loss.

The thermal bridge is a part of the building envelope, wherein the thermal resistance of the barrier (eg. the walls of the building) is significantly reduced as a result of local disorders of the wall layers (eg. material shortages, application of inferior quality material, faulty connection of structural elements). Thermal bridges are the cause of lowering the temperature of the inner surface of the wall, which leads to increased heat transfer, the interior moisture and mold formation.

The threshold temperature is assumed as the temperature of the surface of the wall where the existence of thermal bridges is not predicted. In practice, it is not possible to eliminate thermal bridges. However, the most common site of thermal bridges are: connections of walls and roof, windows and doors circuits, concave and convex outer corners of the building, connections of walls and floor ceilings as well as balconies. The wall temperature of any other area (eg. the temperature of the central surface of the wall without any door and window openings) may be considered as the threshold temperature. The surfaces with higher temperature should be considered as areas of increased heat transfer.

To determine it, the algorithm iterates through all images pixels and assigns its real temperature value on the basis of its colors and key, as it is described in the previous step. If the determined value is higher than the threshold temperature, this pixel is assigned as representing heat loss, otherwise not.

In the end, the percentage content of heat loss pixels in overall thermogram proper area pixels is considered as final result. It is given in equation 2, where L_A means heat loss obtained from the algorithm, t is for checked thermogram, P_L is the number of pixels, that was classified as representing heat loss and P_N expresses the number of pixels, that were classified as not representing heat loss.

$$L_A(t) = \frac{P_L}{P_L + P_N} 100\% \tag{2}$$

3.5. *Tagger description*

To determine algorithm performance, a manual annotator was build. The screenshot of the application is shown in Fig. 5. After loading the thermogram, user manually sets threshold temperature, selects the area containing thermogram and the fragment of the key above the threshold temperature. More precisely, in order to calculate heat loss level using tagger the following steps are performed:

- setting threshold value,
- extraction of the thermogram area,
- assignment of a threshold color value defining loss level,
- selection from the key area all colors that are above the temperature threshold,
- selection from the key area all colors that are below the temperature threshold,
- extraction of pixels on the thermogram having color included in the key area selected by the user.

  On this basis, the level of heat loss of thermogram t is given as $L_T(t)$ and calculated as in formula 3. where as P_L we understand number of pixels having color from the key area above the temperature threshold (heat loss area) and as P_N number of pixels having color from the key area below the temperature threshold.

$$L_T(t) = \frac{P_L}{P_L + P_N} 100\% \tag{3}$$

All the information is saved as a text file.

Threshold temperature was set separately for each thermogram, because they usually contains different types of thermograms (eg. winter-time thermograms of detached houses or inhome thermograms of heating systems) for which surface temperature, considered as causing heat loss, may differ.

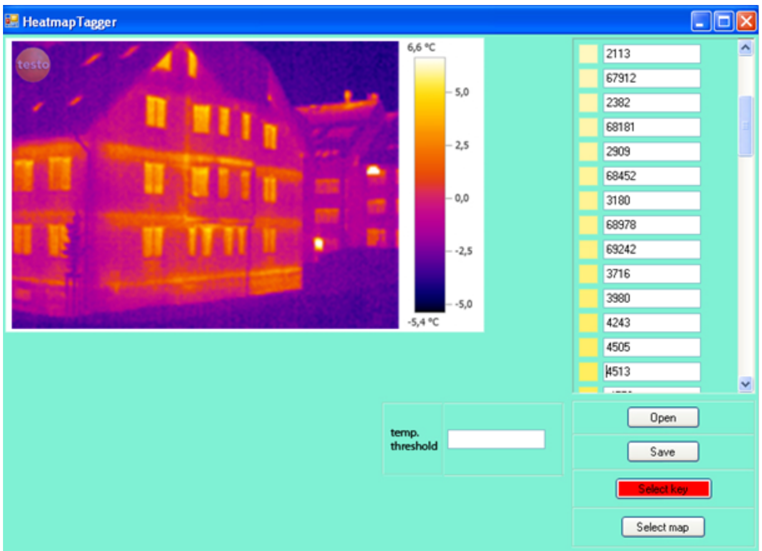

Fig. 5. Screenshot of tagger during usage.

4. Experimental Study

The aim of the experiments was to determine the method accuracy. It was performed using 57 building thermogram images taken from the Internet. Additional performance test was proceeded also for thermogram proper area isolation, key area detection and key label parsing correctness.

All images from the set were tagged with manual tagger described in previous section by the expert from the Faculty of Civil Engineering from Wroclaw University of Technology, who pointed the thermal bridges on those images.

The first step is to define the method accuracy in reference to processing a a single thermogram t. For the thermogram, we obtain the heat loss $L_A(t)$ determined by the developed algorithm. That value will be compared to the tagged value of the heat loss $L_T(t)$. It is important that both values are defined by the percentage of pixels in the whole thermogram having a color above the threshold. Their absolute difference is considered as an algorithm error $L_{err}(t)$ (eq. 4).

$$L_{err}(t) = |L_T(t) - L_A(t)| \tag{4}$$

The overall method performance was defined by an average error value of all processed thermograms, as given in eq. 5, where L_{AV} stands for an average heat loss error, t_i refers to i-th thermogram and N defines the thermogram number.

$$L_{AV} = \frac{\sum_{i=1}^{N} L_{err}(t_i)}{N} \tag{5}$$

The results are shown in Table 1. As it can be noticed, thermogram proper area isolation turned out to be very effective. It was successful for almost 93% thermograms. The identical result was obtained for the key detection. The key was detected for every thermogram, for which the thermogram proper area was isolated properly. Every thermogram proper area isolation issue was caused by invalid linking the proper thermogram area to the key which, in result, cannot be found outside that area.

Much worse result was obtained by parsing the key labels. Only 37.50% key labels were recognized properly. The main reason for such result were issues connected with text recognition. One of the most common text recognition problem

Table 1. Final performance test results

Thermogram proper area isolation	92.86%
Key detection	92.86%
Key labels parsed	37.50%
Average heat loss error	14.63%
Standard deviation of heat loss error	21.05%

was skipping decimal marks. For instance, string 14.3 was incorrectly parsed as 143. Another problem was connected with skipping minuses meaning negative numbers. For example, string −10 was incorrectly parsed as 10. Some labels were not even detected due to the low image quality of some thermograms. The average heat loss error was obtained only for thermograms with properly parsed key labels and equals 14.63%. This result is mainly an effect of clustering. For smaller clustering threshold, it would be smaller, but at the cost of information reduction for description.

5. Conclusion

As results have shown, the developed HInEx method was proved to be easily adapted to extract information from other types of heatmaps. The developed method enables semi-automatic thermograms analysis, as it requires setting a heat loss threshold by a user. If it is identical for every thermogram (eg. for a single class of thermograms, like winter-time thermograms of detached houses) the method after initial setting of threshold allows fully automatic analysis. Methods accuracy is not very high, but seems to be sufficient for a fast automatic search for edge-valued heat loss in thermograms.

However, thermogram images turned out to be harder to process then weather images. As the results presents, the number of images from which we were able to isolate thermogram area were slightly lower (93% according to 100% for weather areas). Similar results were obtained for key detection (93% to 98%) and number of parsed key labels (38% to 65%). It may be caused by lower number of elements on image - the lack of coordinate axes and their descriptions made all remaining elements closer to each other, which disturbs the recognition process.

The future work will focus on replacing text recognition module. It causes biggest issues as it was resented in the paper [Markowska-Kaczmar (2014)].

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