An Automatic System to Detect Thermal Leakages and Damages on Building Facade Using Thermal Images

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***Abstract*—In recent years, very high energy consumption is the major problem of the big cities. Most of the energy of the cities are disbursed to warm and cool buildings. Thus, detecting heat leakages on building walls is a new research problem. In this study, we propose a novel system to detect thermal leakages automatically from thermal camera images. To this end, we use sequential thermal images of buildings. First, we start with fusing thermal image sequences to obtain rectified building facade with higher resolution. Then, we detect L-shaped features using a set of steerable filters. We use L-shaped features and perceptual organization rules to detect windows and doors from rectified thermal image. After eliminating detected doors and windows from building facade, we detect problematic regions.**

One of the advantage of proposed system is that, it can also be used to detect building damages automatically even in night time. Therefore using proposed system, it may be possible to detect thermal leakages and also damages by only using images taken from a vehicle which is moving around interested buildings.

I. Introduction

Most of the budget of the economy has been spending on energy consumption in residential and commercial buildings. Most of the energy has been using for heating and cooling purposes. If walls, windows, doors, and roofs of these buildings are not insulated, warm air or the cool air in the building is distributed to the outside which causes energy and money lose. The classical optical cameras captures only visible bands of light, so it is not possible to detect energy loses using them. Advent of the thermal (infrared) cameras offered solutions to solve these problems easily. In Fig. 1, we provide an optical camera and thermal camera views of a building belong to Technische Universitaet Muenchen to illustrate power of infrared imaging to detect energy loses. On the left hand side, we provide an optical image which can not give information about energy loses. On the right hand side, we provide thermal image of the same building facade where bright regions indicate high energy (heat) loses. In this figure, we present thermal image with false colors on it in order to increase visibility of thermal leakages. Thermal cameras record electromagnetic radiation in the invisible infrared spectra. It is possible to monitor surface characteristics of objects which can not be seen with naked eye. Thermal cameras generate an image showing heats of the objects. This information very amazingly gives a different sense to humans. In this way it is possible to visualize the hot and cool air loses with eye. These images can also give information to detect cracks, moisture, water damages. Using this information, it is possible to fix the building walls with a very few effort and very low cost before having bigger problems. It is also possible to detect damaged buildings automatically even in night time. To detect and locate these problems, it is very important to extract building facade and classify the window and doors automatically. Classification of doors and windows automatically is important since these problems generally occur around the doors and windows. Classification results also can be fused with optical images, or they can be mapped on the three-dimensional building model. Detected doors and windows can be used in image registration when a mapping is applied to three-dimensional building model.

In the previous work, Pu and Vosselman [8] fused laser data and close-range images to reconstruct building facade details. For this purpose, they extracted hough-edges in laser data and close-range images and they applied a novel matching process. Burochin et al. [3] proposed an unsupervised segmentation method to detect repetitive structures like windows in closerange building images. In [2], Ali et al. gave summary of the researches on window detection. They also proposed a window detection system based on cascade classifiers. In a following study [1], proposed a system to detect windows in laser scanner data. The laser distance information shows high variability in windows region. Therefore, they use these variations to detect windows. Lee and Nevatia [7] proposed a robust system to detect windows in ground view images. They extracted window boundaries searching for structures that satisfy regularity and symmetry rules. In addition to that, they extract three-dimensional models of windows by searching for image features.

In literature, very few researches has been done for window detection purposes in thermal images. In a past work, Hoegner and Stilla [6], [5] developed novel systems to generate three-

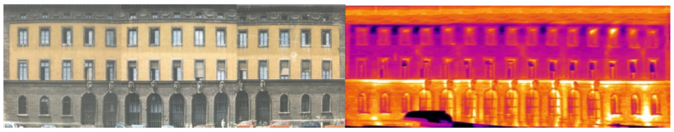

Fig. 1. Optical image and thermal image of a building in Technical University of Munich on the left and right sides respectively

dimensional building models using infrared image sequences. They used region growing algorithm on these models to locate heat leakages on building facade. They claimed that, further improvements in leakage detection can be made if windows and doors are removed from this texture. Therefore in this study, we propose a novel system to detect doors and windows in thermal images automatically. For this purpose, first we extract L-shaped geometrical features using a steerable filter set. After detecting L-shaped features, we use perceptual organization rules to group them. This grouping process let us to detect doors and windows in building facade. After removing detected doors and windows from building facade, we obtain only building walls. By thresholding this wall, and by using region growing algorithm we detect thermal leakages on buildings. If building facade is damaged, there will be similar heat leakage. Therefore, proposed system can also be used to detect damaged buildings automatically using a vehicle taking images around building. Besides, system can work even in night time.

II. Detecting Windows and Doors on Building Facade Automatically

To detect thermal leakages on building facade, we will use thermal images of buildings which are taken sequentially. These images are obtained by a moving car which carries a thermal camera on its top and captures 50 new image of the building both in forward and backward direction in each second. To minimize holes in the textures due to occlusion caused by the oblique view, every facade was recorded with a view forward looking and a view backward looking. The viewing angle related to the along track axis of the van was constant. An example of a recorded sequence is shown in Fig. 2. The position of the camera was recorded with GPS and, for quality measurements from tachometry measurements from ground control points.

Fig. 2. Example images from one sequence along a building

In our study, we use method proposed by Hoegner and Stilla to fuse and rectify sequential images[6], [5]. Unfortunately, thermal images are not in very high resolution and they contain noise effects. Therefore, we use median filter with 3×3 window size to eliminate noise [12]. This non-linear filter helps to remove small noise without giving damage to edges. Next, we describe L-shaped geometrical feature detection step in detail.

A. Detection of L-Shaped Geometrical Features

Unfortunately, classical edge detection methods do not give stable responses on thermal images which are generally in very low resolution. Therefore, we use a set of steerable filters for robust detection of window and door properties in thermal images. Using steerable filters, it is possible to detect straight line segments and discriminate geometrical object features in low resolution and noisy data. Using these straight line segments, we can detect L-shaped features which will indicate window or door appearance.

Steerable filters provide directional edge detection since they behave as band-pass filters in particular orientations. They can be synthesized as a linear combination of a set of basis filters. Herein, we use steerable filters introduced by Freeman and Adelson [4]. In their study, they defined their steerable filters as follows. For a symmetric Gaussian function $G(x,y) = \exp(-(x^2+y^2))$, it is possible to define basis filters G_0 and $G_{\frac{\pi}{2}}$ as follows,

$$G_0 = \frac{\partial}{\partial x} G(x,y) = -2x \exp(-(x^2+y^2)) \tag{1}$$

$$G_{\frac{\pi}{2}} = \frac{\partial}{\partial y} G(x,y) = -2y \exp(-(x^2+y^2)) \tag{2}$$

Freeman and Adelson prove that, the derivative in arbitrary direction θ can be obtained using the filter

$$G_\theta = G_0 cos(\theta) + G_{\frac{\pi}{2}} sin(\theta) \tag{3}$$

After obtaining the steerable filter in θ direction, we convolve it with the median filtered image ($I(x,y)$) to detect edges in θ direction as

$$J_\theta(x,y) = I(x,y) * G_\theta \tag{4}$$

Here $*$ stands for the two dimensional convolution operation. Since our building facade images are rectified, we filter image in only four directions as $\theta \in [0, \pi/2, \pi, 3\pi/2]$. In all these four filter responses, we expect to obtain high responses in window and door edge locations perpendicular to the filtering direction. Therefore, we obtain horizontal and vertical linear features after thresholding $J_\theta(x,y)$ filter responses. To obtain an adaptive method, we pick threshold value as equal to the median value of the thermal image. We picked this value after extensive testing. After thresholding four filter responses, we obtain four different binary images with pixel locations having value one representing possible window or door characteristics. We apply connected components analysis to the thresholded images to obtain each linear feature separately. We assume these four binary images as $B_1(x,y)$, $B_2(x,y)$, $B_3(x,y)$, and $B_4(x,y)$ which contain linear features laying perpendicular to the $[0, \pi/2, \pi, 3\pi/2]$ filtering directions respectively.

After detecting linear features, we use them to detect L-shaped features. For this purpose, first we pick $B_1(x, y)$ binary image which contains vertical linear features extracted in $\theta = 0$ filtering angle. We know that $B_2(x, y)$ and $B_4(x, y)$ binary images contain horizontal linear features. For endpoints of each vertical linear feature in $B_1(x, y)$ matrix, we check if there are intersecting horizontal features in $B_2(x, y)$ and $B_4(x, y)$ binary images. If there is an intersecting horizontal feature, we put both the feature from $B_1(x, y)$ matrix and intersecting linear feature to the new binary matrix $L_1(x, y)$. After applying this process to each feature in $B_1(x, y)$, we obtain all possible L-shaped features in $L_1(x, y)$ binary matrix. We apply the same process for the vertical linear features in $B_3(x, y)$ binary image. Again, we check if endpoints of linear features are intersecting with horizontal features in $B_2(x, y)$ and $B_3(x, y)$ binary images. We store obtained L-shaped features in $L_2(x, y)$ binary image. In the next step we benefit from perceptual organization rules to group these L-shaped geometrical features.

B. Perceptual Grouping to Detect Windows and Doors

Similar to Shaw and Barnes [11], after detecting possible window edges in thermal image, we want to group edges which can be indicate a window appearance. Perceptual organization refers to ability of human visual system to form meaningful groupings of low level (primitive) structures detected in an image based on proximity, similarity, good continuation, connectedness, common region, symmetry, and closure laws. Sarkar and Boyer [10] gave a nice survey of perceptual organization research in both humans and computer vision. In computer vision applications perceptual grouping work has been used to identify and group meaningful structures in the images [9]. Since, window edges always form a closed shape, we propose to benefit from perceptual grouping idea to group detected edges for locating determining window locations in very fast and robust manner.

We use L-shaped features which are extracted in previous step to detect windows and doors. L-shaped features are stored in $L_1(x, y)$ and $L_2(x, y)$ matrices. We pick each L-shape feature from $L_1(x, y)$ binary image one by one, and check if perceptual grouping rules can be satisfied. We check three properties to detect windows and doors. For each L-shaped feature in $L_1(x, y)$ binary image, we start with checking if there is an intersecting L-shaped object in $L_2(x, y)$ test image. We assume that $L_1^m(x, y)$ binary feature contains only mth L-shaped feature in $L_1(x, y)$ test image. That means, $L_1(x, y) = \bigcup_{m=1}^{M} L_1^k(x, y)$ where M is the total number of L-shaped features in $L_1(x, y)$ binary image. To find intersecting L-shaped features, we control intersection of $L_1^m(x, y)$ feature with $L_2(x, y)$ matrix. If $L_1^m(x, y) \cap L_2(x, y)$ contains two connected components, then we assume that arms of $L_1^m(x, y)$ feature is intersecting with the arms of an L-shaped feature in $L_2(x, y)$ matrix. We pick intersecting feature in $L_2(x, y)$ binary matrix and assume it as $L_2^n(x, y)$.

After verifying connection of $L_1^m(x, y)$ and $L_2^n(x, y)$ L-shaped features, now we need to check other perceptual grouping laws to ensure window or door appearance. We check if union of $L_1^m(x, y)$ and $L_2^n(x, y)$ features form a closed shape which separates inside region from the outside. If their union form a closed shape, we check size of their union as the third verification step. If their size is larger than a_{min} (smallest window and door area) and smaller than a_{max} (largest window and door area), we assume that union $L_1^m(x, y)$ and $L_2^n(x, y)$ L-shaped features give a window or a door shape. In this study, we assumed $a_{min} = 50$, and $a_{max} = 500$ pixels considering resolution of our test images. Unfortunately, if a mutual L-shaped feature can not be detected, we can not detect this window or door object.

Our results on automatic window detection can be seen in Fig. 3. In this figure, we present our detection results on fused and rectified grayscale thermal image. Red boxes indicate automatically detected windows. In future studies, we will work on having better fitted window and door shapes.

Fig. 3. Automatic window detection result

III. DETECTING THERMAL LEAKAGES AUTOMATICALLY

In thermal images, regions which radiates more heat seems brighter. Both cracks and windows radiate more heat than healthy building walls, therefore both of them seem brighter. We can detect both window regions and regions at the wall which have leakage or crack by an automatic approach. We detect all blobs in building facade image, which have a high pick value, by detecting local maximum points (x_p, y_p) in building facade. Even if the temperature of the facade itself is changing in different times of the day, healthy wall still will have lower heat value than window, crack, and leakage areas. Therefore, detecting local maximum values of the facade surface can help us to detect windows, cracks, and other leakage areas at all times of the day.

To detect only problematic areas at the wall surface, we remove the (x_p, y_p) local maximum points which lay inside of the previously detected windows. We assume that, rest of the local maximum points represent the problematic areas. To extract boundaries of these areas, we apply region growing method to the rest of local maximum locations. We assume the boundries of this detected region as problematic area. In this step, unfortunately window regions which could not be detected in the previous step are also labeled as problematic regions.

As a final step, we represent detected windows, doors, and problamatic areas (leakages, cracks) by mapping them on Hoegner and Stilla‘s previously obtained three-dimensional

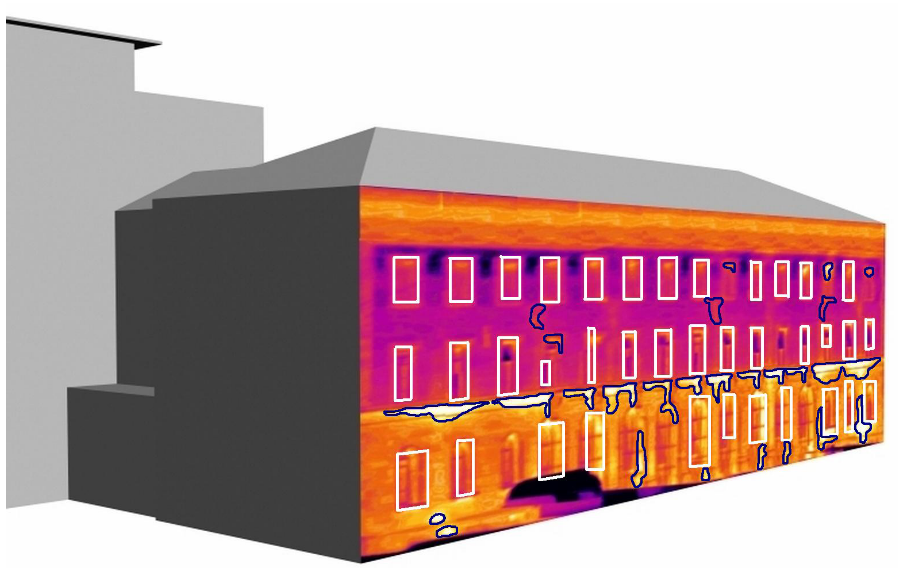

Fig. 4. Sample result of proposed method. Detected windows are labeled with white color, and detected thermal leakages are labeled with dark blue color

building models [6], [5]. We present an example of proposed result in Fig. 4.

IV. Conclusions and Future Work

Herein, we proposed a novel system to detect problematic areas (thermal leakages, cracks) of building facade from thermal images. However thermal images provide very important information, these images have special characteristics that lead to many problems. The physical behavior of the IR spectrum causes camera systems with lower resolution than normal video or photo cameras. Besides, they can also provide very important information to detect problematic regions on buildings even in night time. Therefore, advanced techniques are needed to detect problematic areas automatically. To solve the problem, first we developed an intelligent system to detect windows and doors in building facade. For this purpose, we extracted geometrical features using a set of steerable filters, and we detected window and door shapes based on perceptual organization rules. After removing door and window regions from building facade, we detected local maximums which indicate high heat lose. Then, we applied region growing algorithm to the locations of local maximum points to extract boundaries of problematic regions. Finally, we mapped detected windows, doors, and problematic regions on three-dimensional models of buildings.

Proposed system can be used to detect thermal leakages of buildings which can not be seen by naked eye. This determination may help to solve high energy consumption problems. Study can also be used to detect damaged buildings in an area in a robust manner, independent from illumination conditions of region. System can be developed to be used in unmanned aerial vehicles to detect damaged or problematic buildings automatically.

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