Processing of thermographic images

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***Abstract*— The results from processing of thermographic images, obtained during a thermographic study of a pumping station electrical equipment, are presented in the paper.**

***Keywords*— thermographic study, processing of digital images, low-pass filter, high-pass filter.**

I. INTRODUCTION

Infrared (IR) thermal imaging, often referred to as thermovision or thermography, is a rapidly growing field in science as well as in various industrial fields.

Nowadays thermography is used as a tool for non-destructive control, condition monitoring and predictive maintenance, reducing energy costs for processes as well as for computer vision systems. In these areas, the requirements for high-quality infrared images are constantly increasing. However, due to the limited sensitivity and the high dynamic range of modern thermal imaging cameras, infrared images usually have some drawbacks such as low contrast and unclear contours and object features [1].

In thermography, the foundation of every processing program is a thermographic image or a sequence of thermographic images. Compared to the actual object picture in each thermographic image, a loss of information occurs due to the inevitable transformation of real object outlines into pixels (problem of discretization). The pixels in the detector matrix construct the signal matrix that is the basis of all subsequent mathematical steps for image processing. The purpose of image processing is to extract relevant information such as the identification of defects or distinctive patterns [2].

Modern methods, for processing of thermographic images, are examined in the paper. The results from processing of thermographic images, obtained during a thermographic study of a pumping station electrical equipment, are presented in the paper.

II. ADVANCED METHODS FOR PROCESSING OF THERMOGRAPHIC IMAGES OBTAINED WITH PASSIVE THERMOGRAPHY

Advanced methods, for processing of thermographic images, can be parted into three major steps: preprocessing of images (noise reduction), segmentation (detection of pertinent information) and feature extraction and reduction.

The digital implementation of low-pass and high-pass filters, in the spatial domain, is based on the convolution of the input image $f(x, y)$ and the filter function $A(m,n)$

$$\hat{f}(x, y) = f(x, y) \otimes A(m,n) \quad (1)$$

where $\hat{f}(x, y)$ is the output signal value after applying the filter function;

m and n are the dimensions of the filter function matrix.

The output signal, when using a filter function with dimension 3x3, is computed by using the formula:

$$\hat{f}(x, y) = tr\left\{ \begin{vmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{vmatrix} \times \begin{vmatrix} f(x-1, y-1) & f(x-1, y) & f(x-1, y+1) \\ f(x, y-1) & f(x, y) & f(x, y+1) \\ f(x+1, y-1) & f(x+1, y) & f(x+1, y+1) \end{vmatrix} \right\} \quad (2)$$

where

$\begin{vmatrix} a_{11} & a_{12} & a_{31} \\ a_{21} & a_{22} & a_{32} \\ a_{31} & a_{32} & a_{33} \end{vmatrix} = A$ - matrix of the filter operator,

$\begin{vmatrix} f(x-1, y-1) & f(x-1, y) & f(x-1, y+1) \\ f(x, y-1) & f(x, y) & f(x, y+1) \\ f(x+1, y-1) & f(x+1, y) & f(x+1, y+1) \end{vmatrix}$ - matrix of signal values.

The most important part of image processing for model and pattern recognition is preprocessing. Preprocessing of thermographic images has to provide reduction of noise and pixel distortion.

Low-pass filters are used to reduce noise in thermographic images. Filters must suppress high-frequency noises while preserving the features and geometric contours of objects.

The Gaussian smoothing operator is a two-dimensional convolutional operator used to "blur" images and remove noise. In this sense, it is similar to the mean filter but uses a different filter kernel that represents the shape of the normal (Gaussian) distribution. The Gaussian distribution in 2D has the form [3]:

$$A_{Gauss}(m,n) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{[(m-m_0)^2 + (n-n_0)^2]}{2\sigma^2}} \quad (3)$$

where σ is the standard deviation;

m_0 and n_0 are the mathematical expectations of m and n.

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The Gaussian smoothing operator, with dimension 3x3, is described with the following matrix [4].

$$A_{Gauss} = \frac{1}{16}\begin{vmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{vmatrix} \quad (4)$$

Usually, the first step after preprocessing is the segmentation of the input data, i.e. search for a region of interest (ROI). The main purpose of the segmentation process is to define the areas of the image in which the pertinent information is located. There are many methods for segmenting images, but the most common methods are region-growing segmentation, compression-based segmentation, dual clustering segmentation, histogram-based segmentation, and edge detection.

After defining the regions of interest (ROI), the procedure for extracting the features of these regions can begin. Pixels in the signal matrix which represent non-continuous jumps typify existing structures or edges in the image. To emphasize these discontinuities with sizes of the order of 1 pixel high-pass filtering is needed [2].

The methods, used for high-pass filtering, can be divided into two major groups: gradient and Laplacian. In gradient methods the distinctive features of the object are obtained by searching for the extreme (maxima and minima) values of the first derivative of the signal. The use of gradient methods leads to contrast enhancement only in certain directions. In many cases, this effect is undesirable and isotopic (all-symmetrical) operators are used to remove it. In principle, the Laplacian method, which searches for positions where the second spatial derivative of the image becomes zero, is equivalent. The Laplacian filtering method can be described, by using the following equation [5]:

$$\nabla^2 f(x,y) = \frac{\partial^2 f(x,y)}{\partial x^2} + \frac{\partial^2 f(x,y)}{\partial y^2}. \quad (5)$$

Most commonly used digital approximations of the second derivatives are:

$$\frac{\partial^2 f}{\partial x^2} = f(x+1,y) + f(x-1,y) - 2f(x,y) \quad (6)$$

$$\frac{\partial^2 f}{\partial y^2} = f(x,y+1) + f(x,y-1) - 2f(x,y) \quad (7)$$

High-pass filters implemented by using the Laplacian method are isotopic. The numerical value, of the second spatial derivative of the signal, is computed by using the following filter operators:

$$L_1 = \begin{vmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{vmatrix} \quad (8)$$

$$L_2 = \begin{vmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{vmatrix} \quad (9)$$

$$L_3 = \begin{vmatrix} -1 & -2 & -1 \\ -2 & 12 & -2 \\ -1 & -2 & -1 \end{vmatrix} \quad (10)$$

Extracting and enhancement of the distinctive features of the object, by using Laplacian filter is based on the equation:

$$\hat{f}(x,y) = f(x,y) + c[\nabla^2 f(x,y)] \quad (11)$$

where *c = 1*, if the center coefficient in the operator matrix is positive or *c = −1*, if the center factor in the operator matrix is negative [6].

III. Processing of Thermographic Images of Electrical Equipment

The processing of the thermographic images consists of the application of different low-pass and high-pass filters and observation of their effects on the thermographic images. The processing of the thermographic images is done, by using MATLAB.

The processed thermographic image is of a squirrel cage induction motor, whose rated parameters are, given in Table 1.

TABLE I. Rated Parameters of the Induction Motor

Parameter	Designation	Dimension	Value
Rated Power	P_r	kW	30
Rated Voltage	U_r Δ/Y	V	400/690
Rated RPM	n_r	min^{-1}	2950
Rated Current	I_r Δ/Y	A	54/31
Rated DPF	cosφ	-	0.87

The thermographic image, of the asynchronous motor before the start of the processing, is shown in Fig. 1.

Figure 1. Thermographic image before processing.

The thermographic image, after low-pass filtration, is shown in Fig. 2. The low pass filter is realized, by a Gaussian filter function of *5x5* size and a value of the standard deviation $\sigma = 1$.

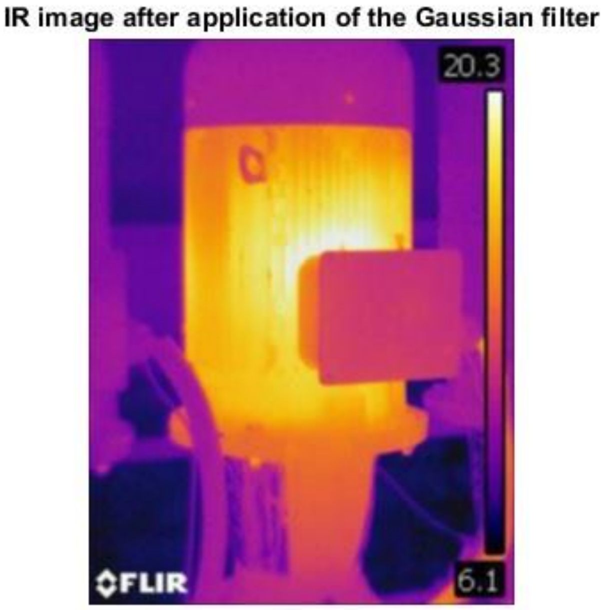

Figure 2. Thermographic image after application of the Gaussian low-pass filter.

The resultant thermographic image, from the application of the mean value low-pass filter, is shown in Fig. 3. The mean low-pass filter is realized with a *3x3* convolution kernel.

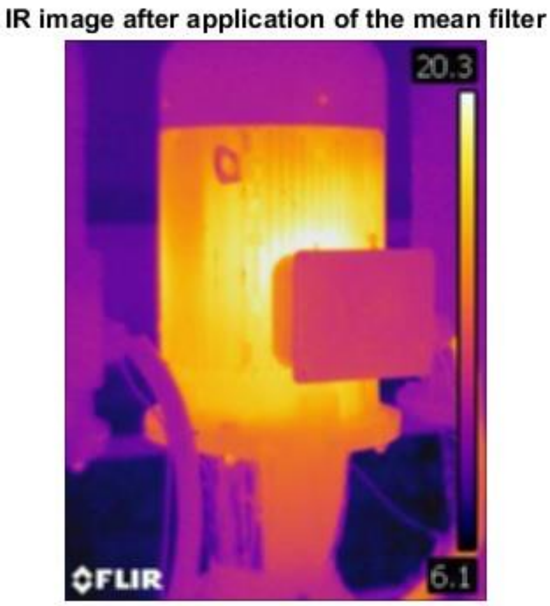

Figure 3. Thermographic image after application of the mean value low-pass filter.

The resulting image, from the application of a Laplacian high-pass filter that uses the filter operator matrix L_2, is shown in Fig. 4. The operator matrix L_2 takes into account only the horizontal and vertical derivatives of the signal.

Figure 4. Thermographic image after application of the Laplacian L_2 high-pass filter.

The resulting image, from the application of a Laplacian high-pass filter that uses the filter operator matrix L_1, is shown in Fig. 5. The Laplacian filter L_1 is isotropic and takes account of the signal derivatives in all directions.

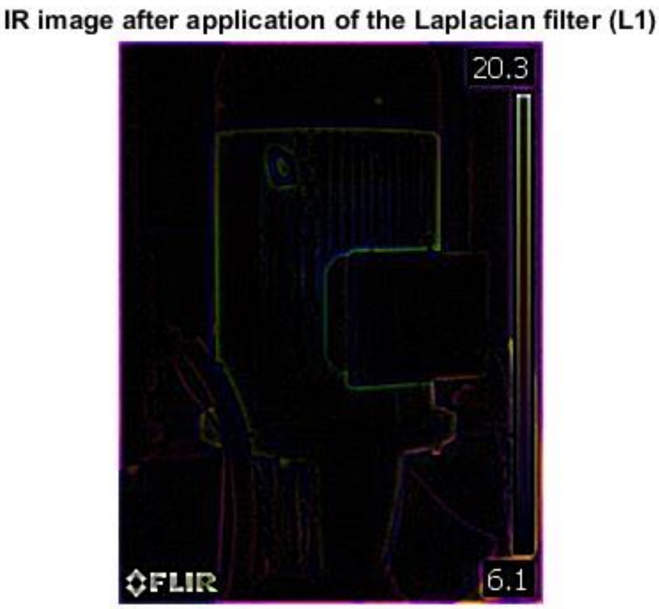

Figure 5. Thermographic image after application of the Laplacian L_1 high-pass filter.

The thermographic image, obtained after applying a Laplacian high-pass filter L_3, is shown in Fig. 6. The Laplacian filter L_3 takes account of the signal derivatives in all directions, with the derivatives in the horizontal and vertical directions being double weighted.

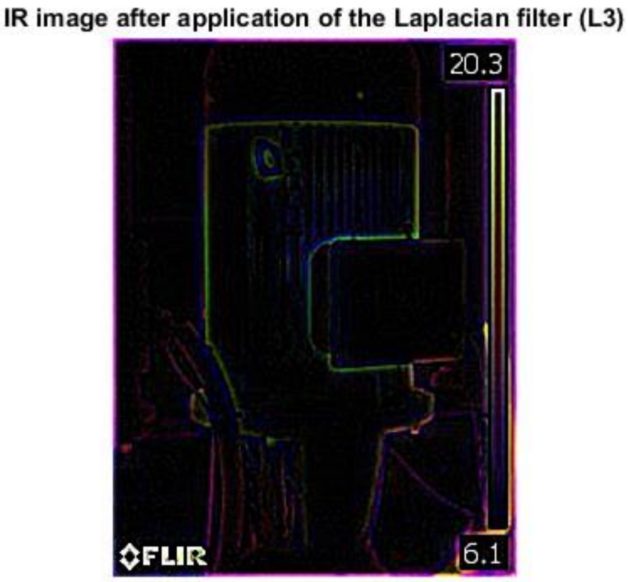

Figure 6. Thermographic image after application of the Laplacian L_3 high-pass filter.

The final step of the processing algorithm is to add or subtract, depending on the sign of the center coefficient in the filter operator matrix of the high-pass filter, the original image and the image obtained after the high-pass filtration.

Fig. 7 shows the original thermographic image and the image obtained by subtracting the original image and the image obtained after application of the Laplacian L2 filter.

The results, from the processing of the thermographic image by using a high-pass Laplacian filter L_1, are shown in Fig. 8.

The results, from the processing of the thermographic image by using a high-pass Laplacian filter L_3, are shown in Fig. 9.

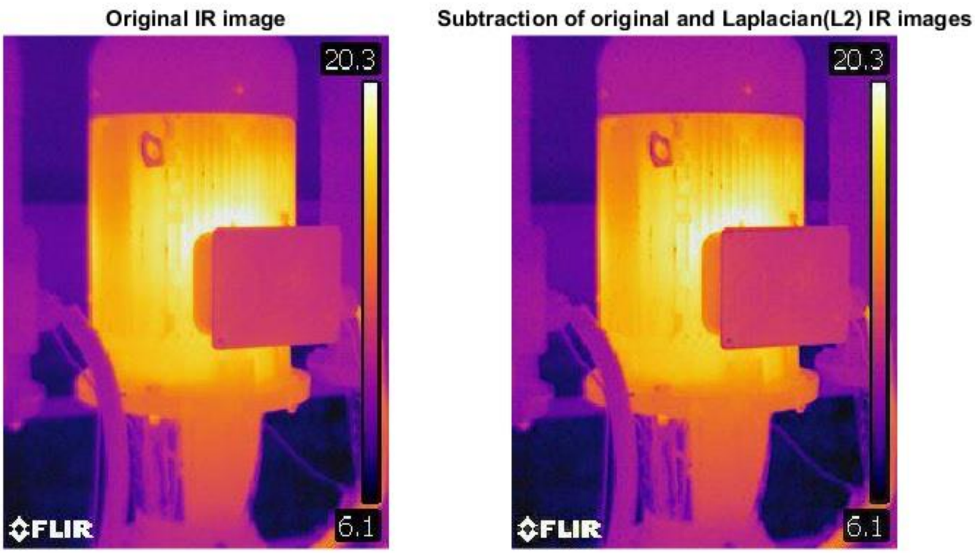

Figure 7. Original thermographic image and resultant image obtained by using Laplacian L_2 high-pass filter.

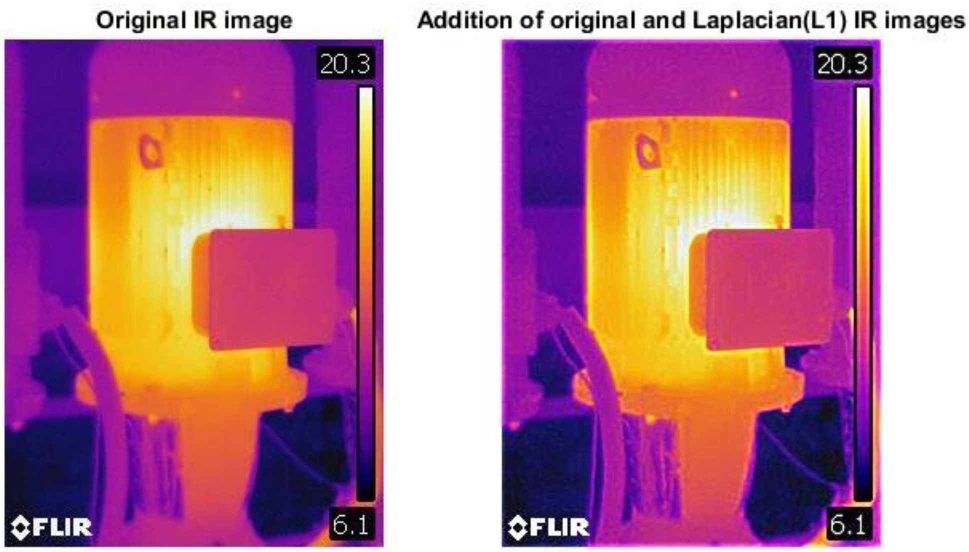

Figure 8. Original thermographic image and resultant image obtained by using Laplacian L_1 high-pass filter.

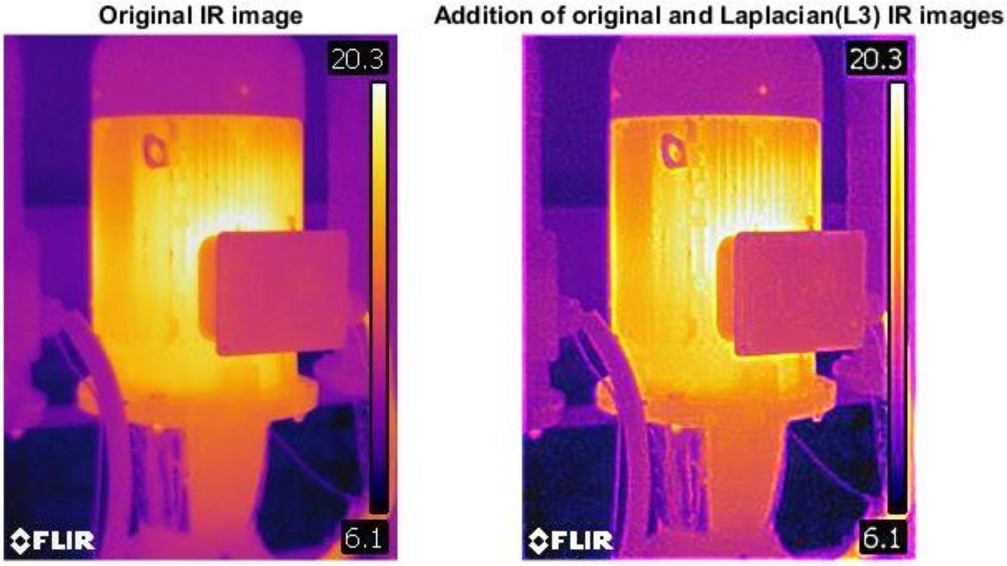

Figure 9. Original thermographic image and resultant image obtained by using Laplacian L_3 high-pass filter.

Numerical description, of the processing of a thermographic image, can be done by using the histograms of the image at the various stages of the processing algorithm.

Figures 10 to 13 represent the histograms of the thermographic image at the different stages of the processing algorithm.

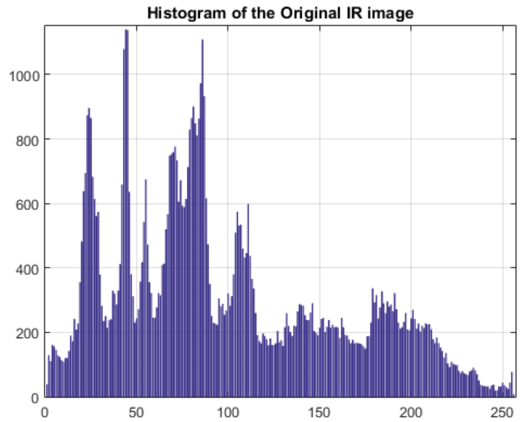

Figure 10. Histogram of the original thermographic image.

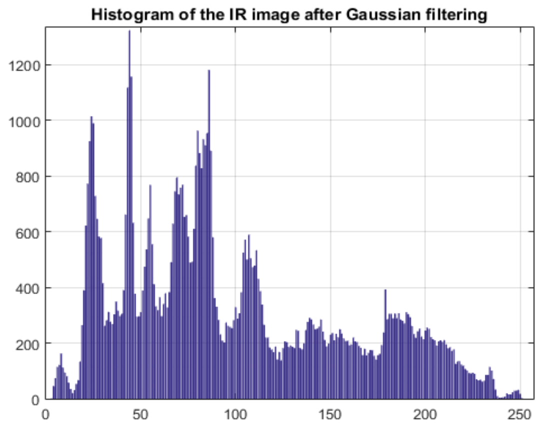

Figure 11. Histogram of the thermographic image after application of Gaussian low-pass filter.

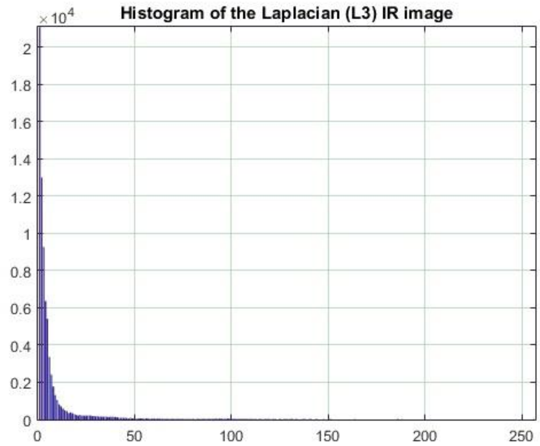

Figure 12. Histogram of the thermographic image after application of Laplacian high-pass filter.

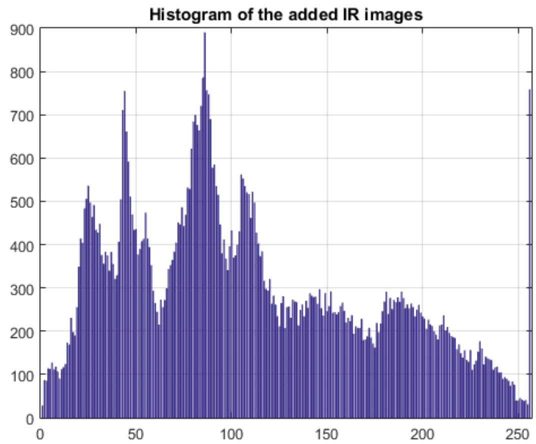

Figure 13. Histogram of the resultant thermographic image.

The resultant image histogram shows that the increase of the image contrast, in order to extract the features of the objects, is associated with achieving a more even distribution of signal values.

IV. CONCLUSION

The great importance of the coefficients in the filter matrices for the final processing result is clearly visible, in the processed thermographic images.

The results show that there is no generally valid method for processing the thermographic images. The choice of the method for processing depends on the particular application for which the thermographic image, will be used.

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