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## MODELING OF DEFECTS DETECTION BY ANALYZING THERMAL IMAGES

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**Abstract.** *In this paper a contactless method for the detection of an object's defect by applying the thermovision camera is proposed and implemented. The thermal image processing is realised in two perpendicular directions and the analysis of the results is presented. An advantage of the proposed method is a simple and efficient application of the standard techniques, which are not specially designed for thermal image processing. By comparing the analysis of results obtained by this method with those obtained by already known methods, the applicability of this method could be confirmed. Using the powerful software packages and applications the thermovision images are being transformed into digital records that can be processed on personal computers. The conducted experiments show that this contactless method is very efficient in the detection of the defects in forms of cavities and damages caused by overload or by material fatigue.*

**Key Words:** *Thermovision Image, Kernel Operation, Rangefilt Method, Thresholding, Defect Detection*

### 1. INTRODUCTION

In the 1980s, Vavilov and Taylor took into consideration the non-destructive thermal methods for material testing (TNDT methods) and pointed out their ability to provide quantitative information about the hidden defects in the material [1]. There are several significant thermal and spectral features of the materials which need to be considered during the testing of the compactness of their structure and the detection of a possible defect. If a solid material possesses a defect in its structure in the form of cavity, aperture or damage of any shape, the density of the material changes at that very place. The density change affects the process of thermal transmission and thermal conductivity of the material. These changes cause surface discontinuity, which is possible to record with a thermovision camera. The functional dependence of the specified values is described by equation (1):

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$$\alpha = k / \rho \cdot C_p \quad (1)$$

where:  $\alpha$  - heat diffusion [ $m^2/s$ ],  $k$  - thermal conduction [ $W m^{-1} K^{-1}$ ],  $\rho$  - specific density of the material [ $kg m^{-3}$ ],  $C_p$  - specific thermal capacity [ $J kg K^{-1}$ ].

Thermal resistance  $e$  [ $W s^{1/2} m^{-2} K^{-1}$ ] is the parameter that represents the characteristics of the material and it can be calculated with equation (2):

$$e = (k \cdot \rho \cdot C_p)^{1/2} \quad (2)$$

The materials of the lower thermal resistance value will heat up more and have higher temperatures, compared to the materials with higher thermal resistance values. The thermal difference is defined with equation (3):

$$\Delta T = Q / \sqrt{e \cdot \pi \cdot t} \quad (3)$$

where:  $\Delta T$  – temperature increase of the surface [ $K$ ],  $Q$  – amount of energy that has been brought through the material [ $J$ ],  $t$  – time [ $s$ ].

The inner and outer defects of the material are capable of easily transmitting heat because of the lower thermal resistance values. By heating, a higher thermal difference compared to the environment can be achieved in these areas. The result of that effect is that defects on the thermovision image will be 'warmer' surfaces. The temperature increase depends on the amount of the accumulated energy and the thermal features of the material. By using a special thermovision camera, it is possible to record thermal radiation from the surface of an object to determine its conditions and features. By detecting energy anomalies it is possible to determine and define the defects that can be noticed during the production process [2]. Thermovision is a method of preventive maintenance that can be successfully applied to monitoring and diagnostics of the conditions of industrial equipment, facilities, systems and products. Thermovision cameras of the new generations have an increased resolution and sensitivity comparing to the previous generations, which makes the detection of the anomalies more accurate. For the display and analysis of the thermal images in colour personal computers are used. The images are being formed by means of three basic colours: red, blue and green. A thermogram can display only 65536 different temperatures, which means that by using the combinations of the shades of three basic colours, it is possible to display a thermogram in an adequate manner (one temperature - one colour). Most often the colour scales in which higher temperature is represented by a lighter colour nuance are used. The relative spectral characteristics of a huge amount of thermal sources can be approximated by the spectral characteristics of the black object heated to a certain temperature. When it is heated, the black object transmits radiations, whose spectrum depends only on the radiation temperature. Max Planck showed that this dependence is defined by Eq. (4):

$$M_{e\lambda} = C_1 \cdot \lambda^{-5} / e^{C_2/\lambda T} - 1 \quad (4)$$

where  $T$  is temperature,  $C_1$  and  $C_2$  are constants. For each temperature it is possible to calculate RGB coordinates of the colour lights. These colours are approximate to those radiated by steel during heating and melting and can be formed by applying Planck's formula (4).

That is how the defect analysis process is reduced to that of defect detection, i.e. the detection of a characteristic shape in a thermovision image. The defect detection process is based on the process of image segmentation. An image, by segmentation, gets divided into meaningful regions. The aim is to separate the pixels which form the objects of interest from all other pixels in the image. Image segmentation, usually, comprises three subsystems [3]. The first subsystem is binary classification (binarization) of pixels which is applied to each pixel and which assigns one of the two possible values to it: 0 – not an object or 1 – an object. These values are joined by a black and white pixel, respectively. Classification is always a specific application. The basic tendency is to realise homogeneous regions related to a certain pixel characteristic. This phase is imperfect and pixels may end up unclassified. The second subsystem is the determination of the availability of neighbouring pixels of the same class and their interconnectedness. They define the spatial adjustment. These groups can be represented by defining a certain property of each pixel individually or by a list of pixel coordinates which define the boundary of a homogeneous region. The third subsystem is the description of the considered characteristic (size, position or shape) in terms of a scalar or vector quantity.

## 2. THE METHOD AND MATERIALS

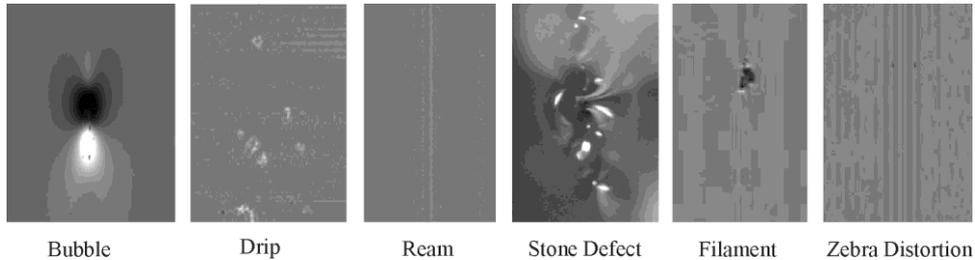
The control of the product is a significant phase of the serial production. The human visual control, which is represented in the greater part of industry, presents the roughest form of elimination of badly produced pieces. The need for creating new and more precise forms of control and safety of products, considering the development of science and technology, has evolved and the demands for accuracy have increased. In the last decades, the method of non-destructive testing has stood out as the primary method of examination and testing of defects in materials [4].

The thermovision methods are contactless measuring methods and, as such, they have become the basic, necessary methods for controlling most of the production and exploitation phases [5]. They enable the detection of defects in a material on a very big surface in a very short period of time. This type of testing has become a standard during the testing in high-tech systems, aerospace and aeronautics. The requirement to use the thermovision methods is the existence of a specific thermal difference between the object which is being tested and its environment. The thermovision methods are defined as passive or active, depending on the existence of an additional source of infrared radiation.

Passive methods enable the recording of the material surfaces and structures, whose temperatures are significantly different from those of the environment, and that do not require an additional source of infrared radiation [6], [7], [8]. The applications of the passive methods are multiple; the most important areas where they can be applied are: control of industrial processes [9], maintenance of machines and equipment, traffic monitoring, detection of forest fires [10], applications in medicine, biology and agriculture, detection of gases and non-destructive testing of electronic printed circuit boards, etc.

Active methods of the thermovision examining require the use of additional sources of infrared radiation in order to achieve a specific thermal contrast. Based on the knowledge of the parameters of the outer impulse, the quantitative estimation of the temperature of the tested object is accomplished [11]. In Ref. [12], the implementation of a measurement system for thermovision examining of solar cells and modules during the period of their exploitation is shown, which is included in the methods of active thermovision.

In the experiment presented in this paper, the thermovision system is applied in combination with a personal computer. The research is conducted in order to diagnose the state of the product in the glass industry. Typical glass structure defects come in the form of bubbles, little bubbles, drops and defects in the form of stone, fibre or railroad (Fig. 1).



**Fig. 1** Typical defects of glass panels

In the interior of the product, unknown objects and dirt can be detected or the discontinuity of the density can be spotted as a result of disturbance of the production process. The external defects come in the form of physical damages of various shapes.

### 3. THE EXPERIMENT

The goal of the research is to confirm the possibility of applying non-destructive methods of examining and detecting material defects. The conducted experiment employs a thermovision system in combination with a personal computer. The research is performed with the aim to diagnose the state of glass industry products. The material of the used samples is glass. Such a manner of testing allows for the detection of defects in the material on a big surface and in a relatively short period of time. The system is conceived in such a way so as to perform the process of product control without human presence. The used glass samples are rectangular in shape and positioned on an assembly line. The assembly line oscillations and external influences are neglected, thus the speed could be considered constant. The applied method belongs to the group of active methods because it requires an additional source of energy in order to achieve the needed thermal difference between the object and its environment. The infrared lamp is used for that purpose. It provides the needed amount of heat for the samples, so the thermovision camera can record them. An IC lamp is positioned above the assembly line. Samples are heated up by its effect. The uneven distribution of temperature is the consequence of the assembly line motion. A thermovision camera is set up next to the IC lamp so that their visible areas do not overlap. The process of recording the object and the formation of the thermogram is shown in the scheme in Fig. 2.



**Fig. 2** Block diagram of the process of thermography recording

Once the object is recorded, the signal is transmitted from the thermovision camera to the computer where it gets adequately transformed. The transformed signal is then being processed by means of appropriate software and a thermogram is formed. The obtained results can be displayed on the screen in the form of a 3D presentation or a 2D diagram. With the aim of detecting possible defects in the material, first the recording of the reference sample without defects is performed in the state of inaction. The analysis of the reference model thermogram yields the values of temperature dilatations which are caused by surface roughness. After that, the mobile reference sample without defects is recorded in the process of motion and its thermogram is formed. The analysis of this thermogram provides for the distribution of temperature dilatations which are the consequences of the object surface roughness and its motion. By recording the unexamined object, forming its thermogram and analyzing it in comparison to the previously obtained thermograms of the reference model, one can observe the existence of a defect in the material and determine its shape and position.

The process of examining can be divided into two phases: the recording and the analysis of the thermogram.

### **3.1. The capture of the thermogram**

The heat that an object radiates goes through the atmosphere, passes through the camera lens and gets to the detector. The detector transforms the received signal into an electrical one. The transformed signal is then transferred to the computer system and shown on the screen in the form of a colour image–thermogram. The camera registers the simultaneous radiation from the surface of the object and the radiation of the atmosphere. It is necessary to perform compensation for atmospheric effects, as the only thing that is relevant for the research is the energy that is transmitted from the object. As it passes through the atmosphere, the intensity of the infrared light is reduced due to the absorption from the unknown particles that are in the air. The compensation is accomplished with the help of the correction parameters, which include:

- The distance between the object and the camera. The greater distance causes higher atmospheric absorption and greater reduction of radiation intensity.
- The relative environment moisture. A higher percentage of moisture leads to a higher collapse of radiation intensity.
- The environment temperature. With the increase of the environment temperature, the atmospheric radiation increases as well.

In order to minimize the atmospheric effects, the experiment is carried out in the laboratory conditions.

### **3.2. The analysis of the thermogram**

The *Matlab* software is used for the analysis of the thermogram. Filtering is performed in two mutually perpendicular directions. The obtained results show the presence or absence of defects. A defect can be detected if its shape and direction of distribution are at a random angle or match the direction of the filter kernel movement. If the defect is in the direction perpendicular to the direction of the filter kernel movement, there is no possibility for it to be detected. With the aim of solving this problem, filtering is conducted in both directions simultaneously. This enables the detection of defects regardless of their

shape and position. The height (width) of the filter kernel is in line with the dimensions of the processed image and it is defined using equation (7) (equation (8)). The value of the other dimension of the kernel is minimum possible value (3) with regard to achieving the most accurate results. If the adopted value is higher than the minimum, the area encompassed by the filter kernel would be too large, thus reducing the possibility of detecting smaller dimension defects.

The process of filtering is done by applying several different filters and the comparative analysis of the obtained results is performed. **Max-min method filtering** (*rangefilt*) is based on the assessment of local extreme values in the region defined by a filter kernel. The assessment of minimal and maximal values is carried out using the morphological functions of dilatation and erosion. In the boundary regions, the padding behaviour of morphological functions is applied. To be realised, these functions imply a certain basic environment. If necessary, it is possible to create structural elements and use the extraction method to generate the environment of a desired shape and dimensions. The result of such filtering is image J, in which the value of each output pixel corresponds to the difference of the estimated maximal and minimal value within the previously defined environment of the appropriate input image I pixel. The dimensions of the output image are the same as those of input image I. **Entropy filtering** (*entropy filtering*) is based on the calculation of the value of the entropy of the current pixel neighbouring environment. The one-dimensional entropy of the grey image ( $H$ ) represents the measure of the average amount of contained information generated by the source which sends  $n$  independent messages, each with possibility  $p_i$ . In the sense of image analysis, entropy represents the sharpness of the image. Accordingly, the images which have blurred edges have lower values of entropy than those with sharp and clearly defined edges. In this case, the homogeneity of the material is analysed, along with the absence of defects and unknown objects contributing to the temperature discontinuity. Thus, it is more favourable if the values of entropy are lower, since they indicate the absence of great temperature dilatations and the absence of defects in the tested material. The mathematical relation used to describe image entropy is:

$$H = -\sum_{i=0}^{L-1} p_i \cdot \log_2 p_i \quad (5)$$

The processing of edge pixels is performed by adding pixels symmetrically. The values of added pixels are symmetrically mapped around the edge pixel of input image I. Apart from the default neighbouring environment, it is possible to form an environment of a desired shape and size. The application of appropriate functions leads to the creation of a structural element, upon which the desired environment is generated by extraction. The result of such a type of filtering is image J, in which the value of each of the input pixels corresponds to that of entropy within the previously defined environment of the appropriate input image I pixel. The dimensions of the output image are the same as those of input image I. **Statistical filtering** (*stdfilt*) implies the determination of standard deviation ( $\sigma$ ) in the previously defined local environment around the appropriate input image I pixel. The mathematical relation used to describe the standard deviation is:

$$\sigma = \sqrt{\sum_{i=0}^{L-1} (i-m)^2 p_i} \quad (6)$$

where  $p_i$  represents the probability of appearance of the  $i$ -th shade of grey colour, and  $m$  is the mean value of the image and the level of saturation. Images are commonly in the 8-bit format, thus the number of possible shades of grey is  $L=256$ . Standard deviation represents the measure of the average image contrast and it points to the dispersion of the pixel intensity values in the defined environment. A higher value of standard deviation implies the existence of contrast, and thus the existence of temperature discontinuity and defect in the material. The calculation of the standard deviation of edge pixels is carried out by adding pixels symmetrically. The values of the added pixels are mapped symmetrically onto the image  $I$  edge pixel. The default neighbouring environment can be altered if necessary. The application of appropriate functions defines the structural element which is used for generating the desired neighbouring environment by the extraction method. The result of such a type of filtering is image  $J$  in which the value of each output pixel corresponds to that of the standard deviation within the previously defined environment of the appropriate input image  $I$  pixel. The above functional dependences differ significantly in the speed of realization. If time interval  $\Delta t$  is needed to perform a single basic mathematical operation, to calculate the difference between extreme values and carry out filtering which is based upon it time interval  $\Delta t$  is also needed. The mathematical operation (equation (5)) for calculating requires time interval  $5 \Delta t$ , while the mathematical operation (equation (6)) for calculating standard deviation requires time interval  $7 \Delta t$ . A comparative analysis of the mentioned ways of filtering points to the fact that filtering based on the assessment of extreme values and their differences can be conducted most easily and quickly; thus, it is applied in the analysis of the recorded thermovision images.

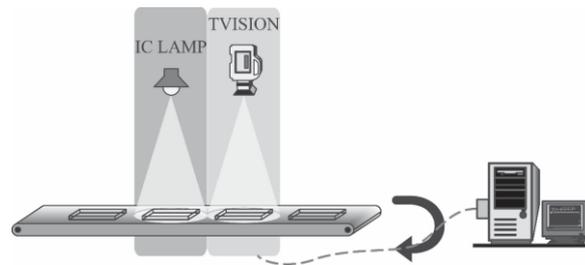
Filtering is performed using the *rangefilt* function and the differences of the extreme values of intensity within the filter kernel are defined. Filter kernels are, with their size, customised to the image dimensions. The process of filtering is realised in the direction of  $x$ -axis,  $y$ -axis and in both directions simultaneously. Low values indicate the homogeneity of the structure. By analysing the obtained results their maximum value is determined and approved as the reference parameter. The reference and examined samples are exposed to the same working conditions. After the capture of the non-examined object, the analysis of its thermogram is made. The existence of the defect could be established by comparing the obtained results with the reference parameters.

### 3.3. The system proposed for defect detection

The system that is proposed (Fig. 3) consists of an infrared lamp, a glass panel on the assembly line, thermovision camera, and the computing system for data processing. The position of the infrared lamp and the thermovision camera is determined in such a manner that the areas of their effect do not overlap. The moving of the assembly line causes uneven heating of the glass panel. When one end of the glass panel comes out of the range of the infrared lamp effect, the other end is still under its thermal influence. When the glass panel finds itself completely in the position of the recording of the thermovision camera, the front end which left the heating area earlier has lower temperature than the rear end. This thermal difference cannot be excluded and it has to be considered when it comes to larger objects. When dealing with smaller objects, the difference between colder and warmer end is negligible.

After the capture, the signal goes from the thermovision camera to the computing system, being transformed in an appropriate manner and shown as a video on the display. The analysis of the thermogram is conducted by using the Matlab software and it consists of the next steps:

- image input of the unheated sample without damages and defects in the state of inaction,
- pre-processing and adjusting the image to the demands of the applied filters,
- filtering,
- the analysis of the temperature dilatations,



**Fig. 3** Computer - controlled thermovision system

- the estimation of the parameters in the state of inaction,
- image input of the heated and moving sample with damages and defects - the reference sample,
- pre-processing and adjusting the image to the demands of the applied filters,
- filtering,
- the analysis of the temperature dilatations,
- the estimation of the extreme temperature values of the reference sample on the moving assembly line,
- image input of the examined object - the image is in colour and in .bmp format,
- pre-processing of the input image means the conversion of the data to a suitable format. A colour image is being converted into a grey 8-bit image (uint8),
- the analysis of the image parameters - the size of the image in pixels ( $m \times n$ ),
- forming filter kernel  $h$  that is necessary for the analysis and the process of filtering and which defines the local environment of the pixels,
- local filtering over the previously defined environment. The filtering process is conducted in a way similar to the convolution. The filter kernel is moving linearly on the image. The start position of the filtering kernel is the upper left corner, and the process ends when the kernel of the filtering is in the lower right corner. In comparison with the convolution, the mathematical operation that is conducted over the selected pixels is simpler and requires less time for realization, so the process of filtering goes a lot faster. The local filtering is made with the `rangefilt` function, which can be used to calculate the absolute difference of the maximal and minimal intensity value of pixels of kernel  $h$ . The calculated difference is approved as a criterion for testing homogeneity of the surface texture. If the intensity difference is equal to zero, or negligible, the analysed environment can be considered as a homogeneous one. Otherwise, when the results show a significant

difference of the pixel intensity, the surface cannot be considered as homogeneous, which is the result of the existence of the defects. The result of applying the rangerfilt function on the input image is the forming of matrix J which is made of calculated differences of the local environment intensity. By experimenting, two filterings are realised in two perpendicular directions.

- *The first filtering* is realised in the direction of  $x$ -axis, using kernel  $h_1$ , dimensions  $3 \times m_{1h}$ . Size  $m_{1h}$  is determined from the conditions of the filter kernel centre with the initial (1,1) and last pixel ( $m,n$ ) matching equation (7). The applied kernel is:

$$\begin{aligned} m_{1h} &= 2m + 1 \\ h_1 &= \text{ones} (3, 561) \end{aligned} \quad (7)$$

The obtained results form matrix  $J_1$ .

- *The second filtering* is realised in the direction of  $y$ -axis, using kernel  $h_2$ , dimensions ( $n_{1h} \times 3$ ), defined by equation (8):

$$\begin{aligned} n_{1h} &= 2n + 1 \\ h_2 &= \text{ones} (783, 3) \end{aligned} \quad (8)$$

The obtained results form matrix  $J_2$ .

- *The third filtering* is realised in both directions simultaneously, using kernel  $h_3$ . The dimensions of this kernel are ( $3 \times 3$ ). The obtained results form matrix  $J_3$ .
- The determination of the size and the position of the global maximum is being achieved by applying the max function in the *Matlab* program software. The function analyses each column separately and detects maximum values of each column. As a result there is a row composed of local maximums of all columns. By applying the same function to the obtained row, the obtained result is the global maximum. The defining of the column, row and size of the global maximum is achieved by applying the functions:

$$[J_{max}, col] = \max (\max (J, [ ], 1)) \quad (9)$$

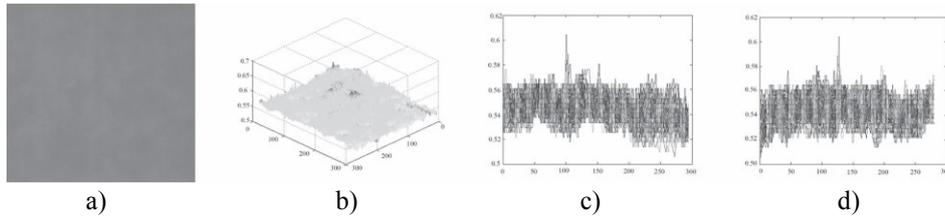
$$[J_{max}, row] = \max (\max (J, [ ], 2)) \quad (10)$$

#### 4. RESULTS AND DISCUSSION

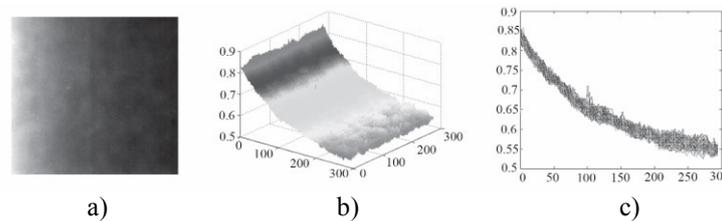
The analysis of thermal images enables continuous monitoring of the thermal changes of the surface. Since it is not possible to present all thermograms and all the measuring results, this paper presents only characteristic samples. Fig. 4a shows a sample without defects in the state on inaction. The thermal distribution is shown in Fig. 4b. What can be seen is relatively even distribution as a result of the homogeneity of the structure. The deviations that can be seen are caused by surface roughness. Figs. 4c and 4d present graphical representation of all thermal changes in the directions of  $x$ -axes and  $y$ -axes. The difference of extreme values is on a relatively small scale.

Fig. 5a presents the thermal layout of the samples on the moving assembly line. The darker area corresponds to the lower, and the lighter area to the higher temperature. The three-dimensional presentation of the temperature distribution is given in Fig. 5b, and the layout on  $x$ -axis in Fig. 5c. With respect to the previously obtained results, the changes in

the temperature distribution can also be seen. A thermal difference on the edges of the object is in the direction of the assembly line movement. The thermal values oscillations are caused by surface roughness and motion. The thermal layout in the direction perpendicular to the direction of moving is approximately constant.



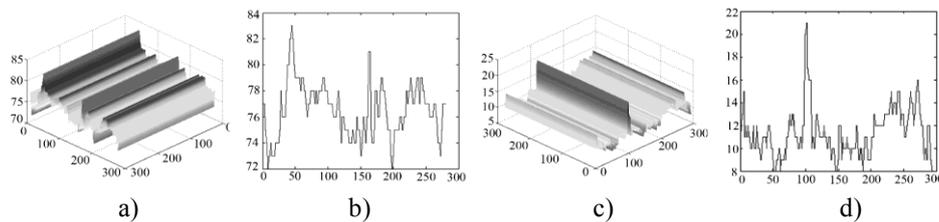
**Fig. 4** Temperature distribution of the reference model in the state of inaction



**Fig. 5** Temperature distribution of the reference model in the moving process

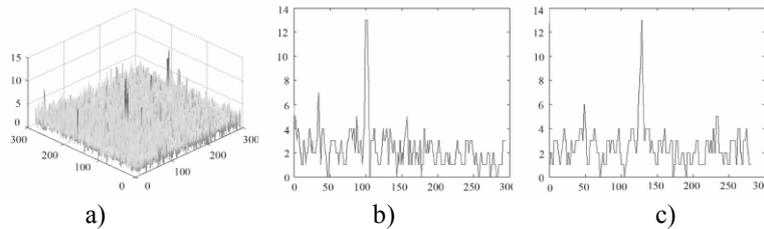
For the estimation of the parameters of the reference model the filtering in two perpendicular directions is conducted. The applied coordinate system is adjusted to the experiment conditions. The direction of the moving object on the assembly line is in the direction of  $x$ -axis. A three-dimensional presentation of the results obtained by filtering in the direction of  $x$ -axis is given in Fig. 6a. The filtering kernel is formed in such a manner, so that it registers only the changes on  $x$ -axis. The detection of the defect in the direction of  $y$ -axis is not possible. Fig. 6a shows the changes of the thermal differences on  $x$ - $z$  plane. In the direction of  $y$ -axis the values of the changes are constant.

The detection of the defects in the direction of  $y$ -axis is achieved by using the same process, but in the direction perpendicular to the previous one. The three-dimensional presentation of the results obtained by filtering in the direction of  $y$ -axis is given in Fig. 6c and the thermal changes in  $y$ - $z$  plane in Fig. 6d. The detection of the defects in the direction of  $x$ -axis is not possible by using this filter. In  $x$ -axis direction the values of these changes are constant.



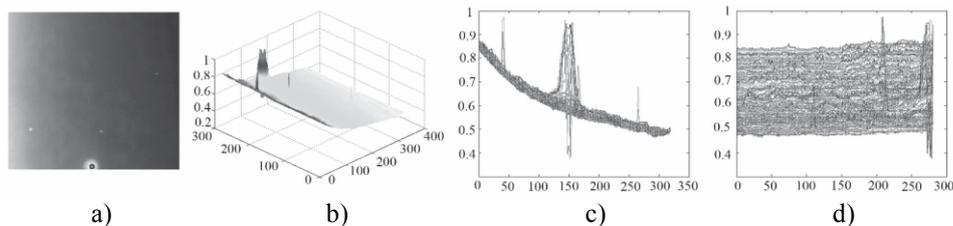
**Fig. 6** Filtered thermograms reference model in the direction of  $x$ -axis and  $y$ -axis

A reliable detection of defects, regardless of their shape and size, can be realised by using the simultaneous filtering in two perpendicular directions. The most reliable results are obtained by applying the filtering kernel with dimensions  $(3 \times 3)$ . The three-dimensional presentation of this filtering is shown in Fig. 7a. The distribution of the thermal changes in the plane  $x-z$  is given in Fig. 7b, and the distribution of these changes in plane  $y-z$  is given in Fig. 7c.



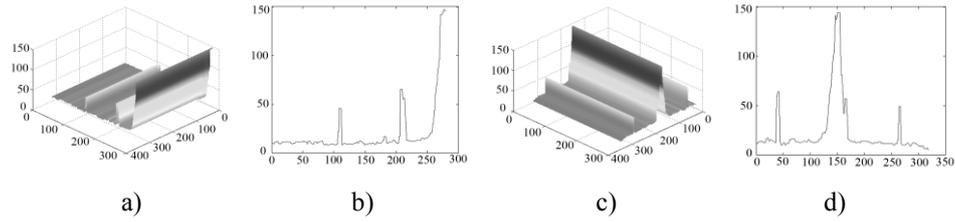
**Fig. 7** Two-dimensional filtering thermograms reference model

The change in the numerical values of the two-dimensional filtering results is in the dependence of the current filtering kernel position. This change is the result of surface roughness of the reference sample. The criterion in the process of defect detection is the maximal value of thermal deviation. This value is considered to be the threshold value. By analysing the thermogram of the untested object and comparing its parameters with the approved threshold value, the data about the existence of defects on the object can be obtained. If thermal deviations are greater than the threshold value in some points, it means that the distribution of the heat in those spots is significantly increased. Discontinuity of the thermal distribution is the direct result of the existence of defects. Fig. 8a shows a sample with the defect in the process of moving. The heat distribution is shown in Fig. 8b. A significant deviation can be seen in certain domain, which is the result of the defect in the structure. Figs. 8c and 8d give graphical presentations of all thermal changes in the directions of  $x$  and  $y$ -axes.



**Fig. 8** Temperature distribution of the tested object

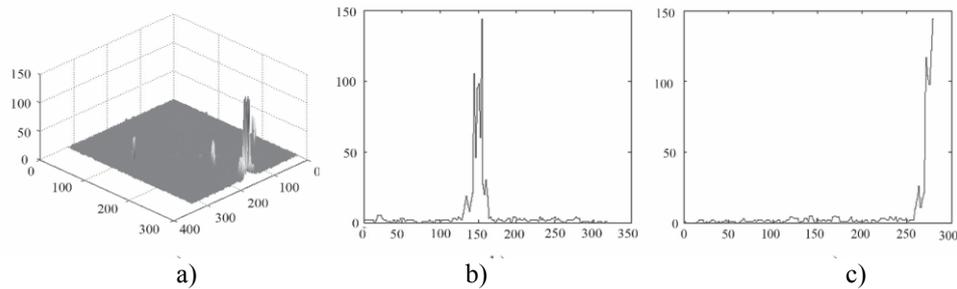
The three-dimensional presentation of the thermogram filtering results of the tested object moving in the direction of the moving assembly line ( $x$ -axis) is given in Fig. 9a, and the layout of the thermal differences in  $x-z$  plane in Fig. 9b. Comparing with the results obtained by analysing the thermogram of the reference sample, a significant deviation from the threshold value can be seen in several positions. This proves the existence of the defect in the direction of  $y$ -axis.



**Fig. 9** Filtering the thermogram of sample in  $x$ -axis and  $y$ -axis direction

By filtering the same thermogram in the direction perpendicular to the previously considered direction, the given results show the existence of the defect on  $x$ -axis. These three-dimensional results are given in Fig. 9c, and the layout of the thermal differences on  $y$ - $z$  plane in Fig. 9d.

By two-dimensional filtering of the thermogram in  $x$ - $y$  plane, the defects in both directions are detected. A comparison of the obtained results with the reference values is enabled by applying the same filtering kernel which was used for the filtering of the reference model. The results of the analysis indicate the existence of defects. The three-dimensional presentation of the obtained results is shown in Fig. 10a. The distribution of the thermal changes in  $x$ - $z$  plane is given in Fig. 10b and the distribution of these changes in  $y$ - $z$  plane is given in Fig. 10c. By using appropriate algorithms, the position of the largest detected defect on the tested object is determined. The numerical extreme values and their positions are given in Table 1.



**Fig. 10** Two-dimensional filtering of the thermogram of a sample

**Table 1** Numerical extreme values and their positions

	object without defect in sleep mode	moving object without defect	moving object with defect
max. temp. difference	0.0510	0.0510	0.5647
row <sub>max</sub> (pix)	128	128	275
col <sub>max</sub> (pix)	99	99	150
min. temp. difference	0	0	0
row <sub>min</sub> (pix)	1	1	1
col <sub>min</sub> (pix)	1	1	1

#### 4. CONCLUSIONS

The presented principle of thermography, the procedure for testing, and the obtained results show that this method of indirect testing is very useful when it comes to assessing and discovering defects with the possibility of monitoring the development of defects. Due to the described values, the testing by thermography and the method for estimation of the usage suitability are accepted. Determination of the existence and the location of defects in products after a certain exploitation period is the subject of much experimental research. There are various diagnostic methods based on the usage of thermovision systems. The presence of defects causes undesirable changes in product features. Defects most often occur during the production or exploitation processes. The implemented system presents an original solution which increases the possibilities of testing and product quality control in exploitation. Based on the presented research results it is possible to achieve an increase in efficiency and expand the basic possibilities of the thermovision system application. With the research presented in this paper, the conditions are created for the contactless determination of defects or the presence of unknown objects in the structure of a product.

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## **MODELIRANJE DETEKCIJE DEFEKTA ANALIZOM TERMOVIZIJSKIH SLIKA**

*U ovom radu predložen je metod detekcije defekta primenom termovizijske kamere. Obrada slike je ostvarena u dva perpendikularna pravca i obavljena je analiza dobijenih rezultata. Prednost predložne metode ogleda se u jednostavnoj i efikasnoj primeni standardnih tehnika koje nisu specijalno namenjene za obradu termalnih slika. Uporednom analizom rezultata ostvarenih ovom metodom sa rezultatima dobijenim već poznatim metodama može se potvrditi njena primenljivost. Moćnim softverskim paketima i aplikacijama termovizijske slike se transformišu u digitalne zapise koje je moguće obrađivati i na personalnim računarima. Realizovani eksperimenti su pokazali da je ova beskontaktna metoda vrlo efikasna u detekciji nedostataka u obliku šupljina, oštećenja usled preopterećenja ili zamora materijala.*

*Ključne reči: termovizijska slika, kernel operacija, rangefilt metoda, metoda praga, detekcija defekta*