DIAGNOSTYKA, 2016, Vol. 17, No. 2

ISSN 1641-6414
e-ISSN 2449-5220

APPROACH TO AUTOMATED HOT SPOT DETECTION USING IMAGE PROCESSING FOR THERMOGRAPHIC INSPECTIONS OF POWER TRANSMISSION LINES

Angelika WRONKOWICZ
Institute of Fundamentals of Machinery Design, Silesian University of Technology
Konarskiego 18A, 44-100 Gliwice, Poland, email: angelika.wronkowicz@polsl.pl

Summary

The paper deals with detection of hot spots in thermograms acquired during infrared inspections of power transmission lines. The author proposes an approach to automated selection of a threshold value for image segmentation using several methods of image processing and analysis. The algorithm is based on finding the steepest growth of successive gradients of sorted values of input image after certain image pre-processing steps. Several post-processing procedures were applied for proper visualization of detected regions in the resulting images. The results have brought satisfying effects and the algorithm, owing to its fast performance, could be also used on-line, during vision inspections.

Keywords: hot spot detection, image processing, power transmission lines, thermographic inspections

PODEJŚCIE DO AUTOMATYCZNEGO WYKRYWANIA GORĄCYCH OBSZARÓW PRZY UŻYCIU PRZETWARZANIA OBRAZU NA CELE INSPEKCJI TERMOGRAFICZNYCH PRZESYŁOWYCH SIECI ELEKTROENERGETYCZNYCH

Streszczenie

Artykuł dotyczy wykrywania gorących obszarów w termogramach uzyskanych podczas inspekcji termograficznych przesyłowych sieci elektroenergetycznych. Autor proponuje podejście do automatycznego doboru wartości progowej dla segmentacji obrazu przy użyciu kilku metod przetwarzania i analizy obrazu. Algorytm opiera się na znalezieniu najbardziej stromego wzrostu wśród wartości kolejnych przyrostów posortowanych wartości obrazu wejściowego po pewnych krokach wstępnego przetwarzania. Pewne procedury przetwarzania końcowego zostały zastosowane dla prawidłowej wizualizacji wykrytych regionów w wynikowych obrazach. Wyniki przyniosły zadowalające efekty i algorytm, dzięki swojemu szybkiemu działaniu, może być zastosowany również on-line, w trakcie inspekcji wizyjnych.

Słowa kluczowe: wykrywanie gorących obszarów, przetwarzanie obrazu, przesyłowe sieci elektroenergetyczne, inspekcje termograficzne

1. INTRODUCTION

Power transmission lines belong to ones of the most important branches of industry nowadays. Their damage, or even adjacent vegetation, may cause serious consequences like disruption in energy supply, big financial losses or even disasters, like fires [1]. The most common types of damage appearing during power lines operation are mechanical failures (fractures, collapses of elements of pylons [2]), cracks or degradation of insulators (depending on their type – a glass, ceramic or polymer one), breaks of electrical conductors and corrosion propagation. Another major problem are electrical discharges (the so-called corona discharges), which result in energy losses and accelerated aging of insulators. Requirements related to power lines operation, which are high reliability, efficiency and safety, lead to a need of performing their technical diagnostics. Furthermore, since these lines are permanently exposed to the influence of environment, as well as vandalism or thefts, they are needed to be inspected regularly. Numerous diagnostic methods are applied, these are among others techniques based on electrical parameters measurements [3,4], vibration and acoustic measurements [5,6], and vision-based procedures – often with use of regular, infrared (IR) and/or ultraviolet cameras. Another methods are applied for monitoring of vegetation encroachment, such as aerial video surveillance, LiDAR (light detection and ranging) scanning and aerial multispectral imaging [7]. The vision-based methods are of a significant importance since it is highly needed to notice destruction or symptoms of aging at their earliest possible stage to avoid damage propagation and its serious after-effects. Ones of the most widely used tools in this application are infrared cameras [8] because of high effectiveness in detecting damage using them. They allow performing thermal measurements in non-contact manner using the infrared radiation. Changes in temperature may indicate presence of a failure, which can be of an electrical nature (e.g. loose connections, overloads, open circuits, harmonics, inductive heating), mechanical (e.g. cracks of insulators) or electrochemical one (e.g. corroded joints or parts of foundations and pylons). Such failures can be identified by e.g. excessive local heat generation or uneven temperature distribution.

For proper interpretation of acquired thermograms (IR images) the hot spots, i.e. regions with the highest temperature, should be detected and then analyzed. Numerous researches in various applications have been reported, which targeted at a problem of proper detection of hot spot or any thermal irregularities. In the study of Tsanakas and Botsaris [9], IR images of an operating photovoltaic array were analyzed by means of temperature line profiles and image histogram features. Kafieh et al. [10], for defects detection, used several image processing techniques with different clustering methods. Another examples of multistep algorithm for damage detection can be found in [11], where the authors used edge detection and clustering, convex hulls and active contours; or in [12], where the template for comparative analysis was applied. The authors of [13] used the reference temperature, calculated as the average surface temperature, whereas the authors of [14] used several methods for detecting anomalies in thermograms, e.g. statistical image analysis such as contrast, variance, and standard deviation as well as image thresholding. Another approaches to defects detection using thermal imaging can be also found in [15,16,17].

However, several of the above mentioned methods require employing manual operations and the majority of them were adjusted strictly to the considered, individual problem. Using such approaches would not be appropriate for detecting hot spots in thermograms of power transmission lines because of significant influence of a background of images and a lack of reference temperature values or templates. Since thermographic measurements performed in field conditions are related to the risk of a high measurement error because of a problem of changeable emissivity and reflection of radiation from other elements surrounding power lines, using a reference temperature could be invalid. For this reason, the author of this paper proposes an approach to universal, automated hot spots detection without a reference temperature value for the purpose of computer analysis of IR images after vision inspections of power transmission lines. The algorithm is very fast so that it could be used also on-line, during infrared inspections of power transmission lines.

2. ALGORITHM DESCRIPTION

In general, the proposed algorithm is based on automated selection of a threshold value for image segmentation by finding the steepest growth of a gradient of sorted values of input image after several image pre-processing steps. It was implemented and tested in Matlab®, the subsequent steps are as follows. Firstly, the original IR image (see example in Fig. 1) is loaded into the workspace. The representation of IR image is the matrix of pixels corresponding to the temperature values. For the purpose of better visualization, this one as well as other IR images in this paper were displayed with a colour map instead of the monochromatic one. Values of temperatures corresponding to colours of pixels, given in Celsius degrees (after conversion from originally obtained Kelvin degrees), are shown in a colour bar next to the IR image.

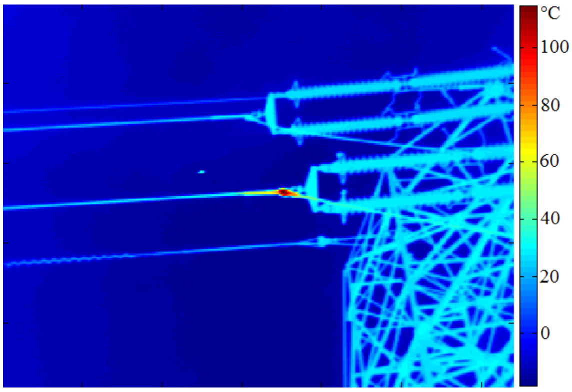


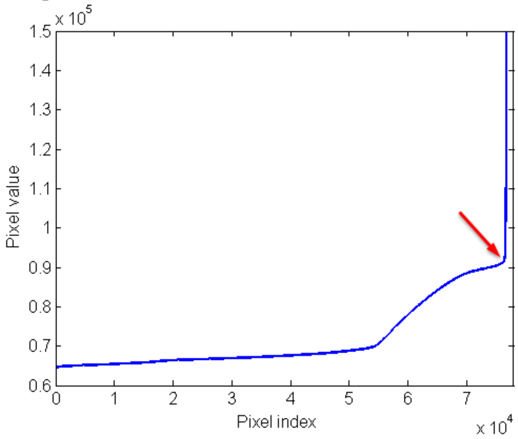
Fig. 1. The exemplary thermogram of a power line

The next step is to raise the values of this image to the power of 2 in order to enhance the differences between them. Afterwards, the obtained values were transformed into a vector and then sorted ascendingly (Fig. 2(a)). The idea of the proposed method is to find a threshold value for image binarization, which corresponds to a point where a gradient (difference) of neighboring values starts significantly increasing, i.e. this is a threshold above which a background and undamaged elements disappear from the image and a damage (significant temperature increase) remains. Such the target point was indicated by the red arrow in Fig. 2(a). The gradients of these values were plotted and depicted in Fig. 2(b), where also the red arrow indicates the desirable location of a rapid growth.

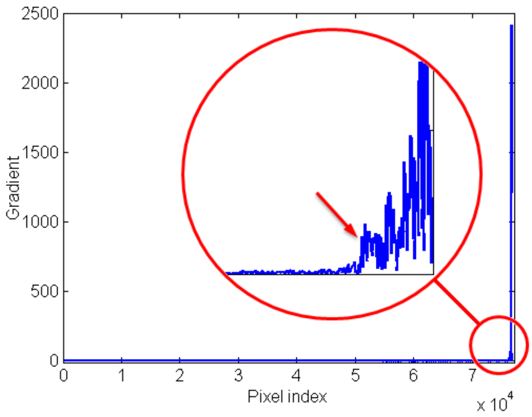
In order to obtain the index of a pixel p automatically, which value is to be the chosen as a threshold, the author proposes an experimentally selected measure:

$$p = \frac{n}{i_2 - i_1} \sum_{i=i_1}^{i_2} grad(i), \quad (1)$$

where i_1 is a value of index calculated as 0.1% and i_2 as 10% of a total length of pixel indices (Fig. 2(a)) and grad*(i)* are the nonzero values of calculated gradients. The principle of Eq. 1 is that a threshold is a number of n times greater than the average gradient of a selected section of nonzero gradients. The specific values of ranges of indices $[i_1,i_2]$ were chosen since they are assumed to be the low-values from the environment (seen as background). In other words, even if a damage is very big, it is not expected to exceed a 10% area of a whole image. Several first values were also excluded since in the considered IR images in this range some steepest growth was also observed (rapid changes of low values of temperature). In the considered problem, n equal to 8 was selected experimentally (this is a “safe” value, however, similar values also returned the same results). This value can be substituted by another number depending on the type of analyzed thermograms and possible variability of temperature values.



a)



b)

Fig. 2. Analysis of values of IR image and their gradients: a) sorted pixel values, b) gradients of pixels values (with zoomed view)

Having the calculated index, a threshold value from the sorted image values corresponding to this index is obtained. The next step is the image binarization by thresholding with the calculated threshold value T, i.e. the pixels of the IR image I which values are higher than T become white and the lower – become black (Fig. 3(a)). Such operation can be expressed by:

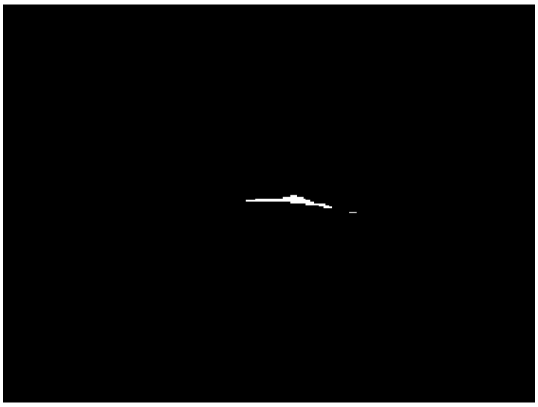
$$J_{i,j} = \begin{cases} 1 & for \quad I_{i,j} > T, \\ 0 & for \quad I_{i,j} \le T. \end{cases} \qquad (2)$$

At this stage, all separate regions visible in the resulting image are identified as separate hot spots. In order to merge regions that are close located, the morphological dilation is performed. The binary dilation is the operation that “thickens” or “grows” objects visible in a binary image. The dilation of A by B, denoted $A \oplus B$, is defined in terms of set of operations:

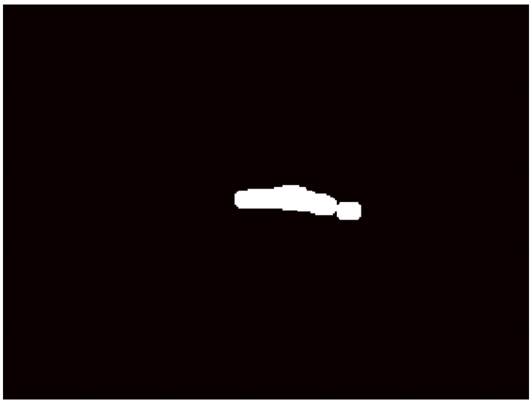
$$A \oplus B = \{ z | (\hat{B})_z \cap A \neq \phi \} \qquad (3)$$

where: B is the structuring element, $\hat{B}$ is the reflection of B.

The dilation is therefore a set of pixels locations z, where $\hat{B}$ overlaps with foreground pixels in A when translated to z [18]. As the structuring element, a flat, disk shape was chosen with a radius of 6 px.



a)



b)

c)

Fig. 3. Hot spot detection: a) image after thresholding, b) image after morphological dilation, c) resulting image

The exemplary results are shown in Fig. 3(b), where one can observe that owing to this procedure the two separate objects visible in Fig. 3(a) were connected.

The last step is a visualization of the detected hotspot and, using region properties function (finding the smallest rectangle containing the region), this region was captured in a red rectangle on the original IR image. The resulting image of the discussed example is presented in Fig. 3(c).

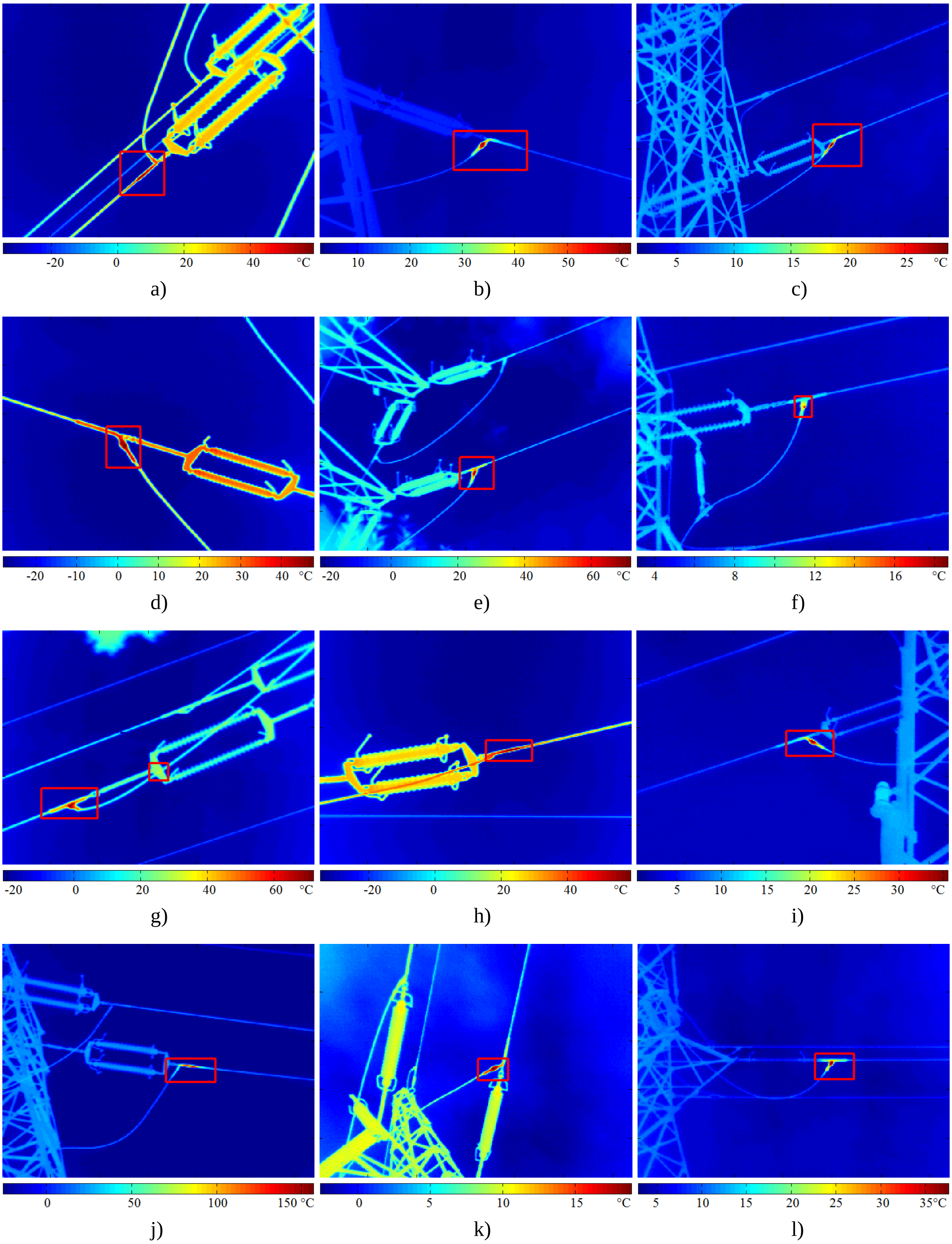


Fig. 4. Exemplary results of hot spots detection

3. RESULTS

For testing the algorithm a set of IR images taken from real inspections of 110 kV high voltage power transmission lines in Poland were used. The algorithm described in Section 2 was applied and the examples of the resulting images are presented in Fig. 4. From the obtained images one can observe that in most cases the hot spots were detected properly. In one of the figures (Fig. 4(g)) two hot spots were detected, however in this case the first hot spot is of much higher temperature comparing to the second one, thus the number of *n* from (1) could be substituted by a higher number in order to extract only the highest growth of temperature.

The proposed method could be used in vision inspections of power transmission lines as well as other applications with adjusting the *n* parameter in the proposed measure to the individual problem.

4. CONCLUSIONS

The aim of this paper was to detect hot spots automatically from IR images using image processing and analysis methods. The author proposed an algorithm by which the threshold level for image binarization is selected automatically basing on the steepest growth of a gradient of sorted values of input image after certain image pre-processing steps. Several mathematical operations on images were performed, including morphological transformation and the proposed, experimentally selected measure. The algorithm was tested on a set of IR images taken from vision inspections of 110 kV high voltage power transmission lines. The results turned out to be very effective so that the algorithm can be used for computer analysis of thermograms acquired after infrared inspections as well as during them, owing to the fast performance of the algorithm.

ACKNOWLEDGEMENT

The author would like to thank the Power Research "Testing Company "ENERGOPOMIAR—ELEKTRYKA" Ltd. for providing the thermograms of power lines elements.

REFERENCES

[1] Mitchell JW. Power line failures and catastrophic wildfires under extreme weather conditions, Engineering Failure Analysis, vol. 35, 2013, pp. 726-735.
[2] Prasad Rao N, Samuel Knight GM, Mohan SJ, Lakshmanan N. Studies on failure of transmission line towers in testing, Engineering Structures, vol. 35, 2012, pp. 55-70.
[3] Silva KM, Souza BA, Brito NSD. Fault detection and classification in transmission lines based on wavelet transform and ANN, IEEE Transactions on Power Delivery, vol. 21, 2006, pp. 2058-2063.
[4] Bockarjova M, Sauhats A, Andersson G. Statistical algorithms for fault location on power transmission lines, IEEE Russia Power Tech, St. Petersburg, 2005, pp. 1-7, 2005.
[5] Saadabad NA, Moradi H, Vossoughi G. Semi-active control of forced oscillations in power transmission lines via optimum tuneable vibration absorbers: with review on linear dynamic aspects, International Journal of Mechanical Sciences, vol. 87, 2014, pp. 163-178.
[6] Tadeusiewicz R, Wszołek T, Izworski A, Wszołek W. Recognition of defects in high voltage transmission lines using the acoustic signal of corona effect, Proceedings of the 2000 IEEE Signal Processing Society Workshop, Neural Networks for Signal Processing X, 2000. Sydney, NSW, vol. 2, pp. 869-875, 2000.
[7] Ahmad J, Malik AS, Xia L, Ashikin N. Vegetation encroachment monitoring for transmission lines right-of-ways: A survey, Electric Power Systems Research, vol. 95, 2013, pp. 339-352.
[8] Bagavathiappan S, Lahiri BB, Saravanan T, Philip J, Jayakumar T. Infrared thermography for condition monitoring – a review, Infrared Physics & Technology, vol. 60, 2013, pp. 35-55.
[9] Tsanakas JA, Botsaris PN. On the detection of hot spots in operating photovoltaic arrays through thermal image analysis and a simulation model, Materials Evaluation, vol. 71, 2013, pp. 457-465.
[10] Kafieh R, Lotfi T, Amirfattahi R. Automatic detection of defects on polyethylene pipe welding using thermal infrared imaging, Infrared Physics & Technology, vol. 54, 2011, pp. 317-325.
[11] Usamentiaga R, Venegas P, Guerediaga J, Vega L, López I. Automatic detection of impact damage in carbon fiber composites using active thermography, Infrared Physics & Technology, vol. 58, 2013, pp. 36-46.
[12] Senni L, Ricci M, Palazzi A, Burrascano P, Pennisi P, Ghirelli F. On-line automatic detection of foreign bodies in biscuits by infrared thermography and image processing, Journal of Food Engineering, vol. 128, 2014, pp. 146-156.
[13] Cotič P, Kolarič D, Bosiljkov VB, Bosiljkov V, Jagličić Z. Determination of the applicability and limits of void and delamination detection in concrete structures using infrared thermography, NDT & E International, vol. 74, 2015, pp. 87-93.
[14] Sreedhar U, Krishnamurthy CV, Balasubramaniam K, Raghupathy VD, Ravisankar S. Automatic defect identification using thermal image analysis for online weld quality monitoring, Journal of Materials Processing Technology, vol. 212, 2012, pp. 1557-1566.
[15] Guzmán E, Baeten V, Pierna JAF, García-Mesa JA. Infrared machine vision system for the automatic detection of olive fruit quality, Talanta, vol. 116, 2013, pp. 894-898.
[16] Zhao J, Fengn H, Xu Z, Li Q, Peng H. Real-time automatic small target detection using saliency extraction and morphological theory, Optics & Laser Technology, vol. 47, 2013, pp. 268-277.
[17] Florez-Ospina JF, Benitez-Restrepo HD. Toward automatic evaluation of defect detectability in infrared images of composites and honeycomb structures, Infrared Physics & Technology, vol. 71, 2015, pp. 99-112.

[18] Gonzalez RC, Woods RE, Eddins SL. Digital image processing using MATLAB, 2nd ed., Pearson Prentice Hall, 2003.

Received 2016-03-30
Accepted 2016-05-25
Available online 2016-06-04

Angelika WRONKOWICZ is a PhD student at the Institute of Fundamentals of Machinery Design of Silesian University of Technology in Gliwice, Poland. Her areas of research focuses mainly on vision-based diagnostics, non-destructive testing methods and advanced signal and image processing techniques.