TEXTURE IMAGE ANALYSIS

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Abstract: The paper deals with investigation of stomata images of the picea abies leaves. The leaves are taken from trees observed on a long-term basis in selected regions distinguished by a low or high pollution level, respectively. Research of stomata of spruce leaves, or to be more accurate, of structural signs of the stomata wax, represents a manner of evaluation of the given locality load by pollutants. Stomata images, obtained upon previous modification of the leaves using an electron microscope at the Department of Solid State Engineering, Prague Institute of Technology, Czech Republic, are classified into the selected number of classes according to structural changes of the stomata wax. In their evaluation, the leaves age must be considered, as well, for the leaves wax is subject to ageing in the course of its life. Visual evaluation of the stomata images is performed, and the images are modified using suitable mathematical means to obtain a better visualization of the structure. The current goal in this area of interest is to find an algorithm of automatized classification of the images into classes.

Keywords: Image Processing, Wavelet Transform, Edge Detection, Environmental Pollution, Data Classification

1 INTRODUCTION

The paper falls into the category of image processing, applied to investigation of one aspect of environmental pollution - namely accelerated damage of stomata on picea abies leaves. The stomata are subject to natural ageing, i.e. natural damage, however, due to air pollution their damage may be accelerated and significant pollution levels can mean serious, even fatal consequences for the trees mentioned.

The leaves are observed by means of long-term monitoring of selected trees in selected regions of the Czech Republic, see Table 1. The identical regions are shown in Fig. 1, providing a clearer idea of their distribution.

The stomata images acquired are processed subsequently and evaluated according to the damage extent found. As ways of automatic evaluation have been sought, the goal of the paper lies in examination of selected classification methods and their application to a control subset of stomata images, classified subjectively as well as automatically. The classification results are then compared and their application to more extended image data sets is discussed briefly.

1.1 Input Data Characteristics

The paper deals with pictures provided by the Department of Analytical Chemistry, Prague Institute of Chemical Technology and dealt with e.g. in [5]. They are 16bit gray scale images of

Table 1 - SELECTED MONITORED REGIONS OF PICEA ABIES LOCATIONS

Region Id.	**Locality**
CR01	Svratouch
PU12	Býšť u Pardubic
PZ04	Trnová u Jíloviště
ST06	Řepice u Strakonic
UH02	Újezd u Boršic
ZR09	Velké Losenice

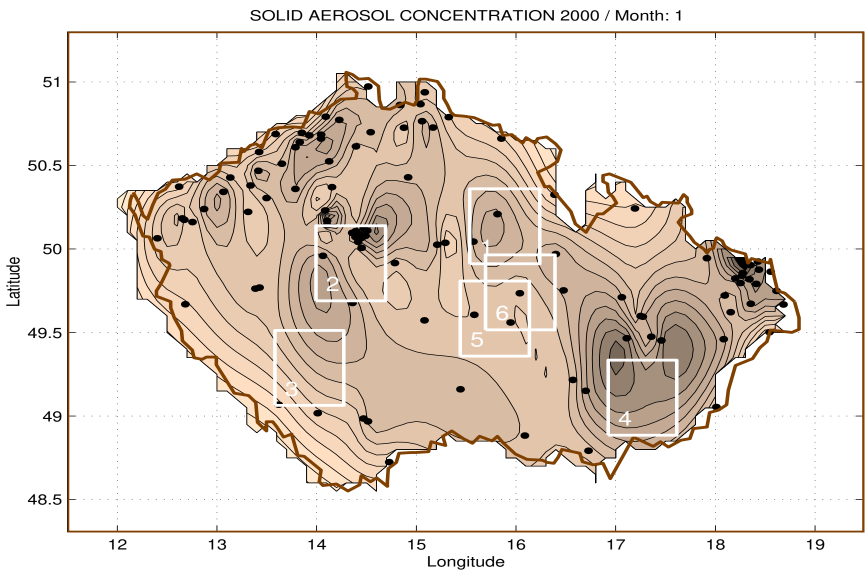

Figure 1 - Selected localities for evaluation of the spruce leaves taken for the purpose of monitoring; other environmental pollution parameters are observed in these localities, among them the dust particles concentration (the measurements are shown using the contours and were obtained in January, 2003), shown in the figure, which the reader may thus find more interesting perhaps.

the size 1024x768 pixels. One pixel corresponds with 0.063 μm to 0.116 μm. Their quality differs significantly, and their processing is burdened by e.g. varying sharpness or varying angle of the stomata view - both factors introduce an error in the image evaluation. A significant problem is represented by presence of various anorganic as well as organic particles of various dimensions and shapes on the stomata surface. These are very small impurities which cannot be removed from the leaves before the image acquisition; their influence on the resulting image processing can only be suppressed by means of digital filtering methods. In a number of images, these impurities cover a small part only, it can be thus assumed that in spite of their presence proper classification can be obtained; however, the image sets do include a non-negligible number of images with impurities covering a significant part of the leaf surface, making the classification very difficult.

To provide a better idea of the image nature, Fig. 2 (a) shows one leaf image with very few impurities and also very low damage, and another one, see Fig. 2 (b), with quite a few and large impurities and significant damage.

The images were processed in the Matlab environment [7]. To verify the image data processing methods proposed, a set of testing images was selected, containing the minimum amount of impurities and disturbing elements. These images were classified subjectively, based on materials and instructions provided by the Department of Analytical Chemistry, Prague

Institute of Chemical Technology. Automatized classification methods were designed using this testing set, and these methods were implemented in the Matlab environment and verified in the first step on the set mentioned.

(a) **(b)**

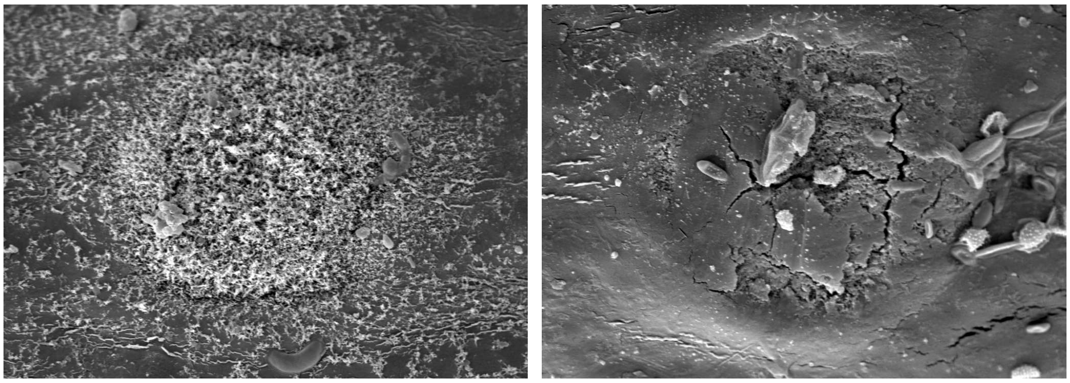

Figure 2 - **(a)** - Selected image for illustration - stoma image from the tree no. 532 in the region CR01 - Svratouch. This image would be classified in the best class (the stoma is damage free virtually). **(b)** - Selected image for illustration - stoma image from the same tree as above and would fall in the worst class, the stoma shows severe damage namely. (At the same time, this image illustrates what kind of interesting shapes can be formed on the stomata surface by organic and anorganic particles.)

2 MATHEMATICAL METHODS

Mathematical methods of image processing [1, 9, 6] were chosen and designed according to how well they allowed to classify the images investigated into proper classes. In this respect, the following items needed to be performed to achieve proper classification:

1. Image preprocessing, i.e. unification of the scale and noise removal, present in a various extent in all images;
2. Delimiting of the stoma area and determining of the appropriate criterion value using the method selected;
3. Definite assignment of class 1 to 5 to criteria values.

Item 1 cannot be always performed due to missing data on the pixel size. For noise removal, in respect of the following item 2 it is suitable to use non-linear filtering. In unification of the image scale related with resampling, various 2D interpolation methods can be applied [10]. The most simple and fastest one is represented by the nearest neighbour method. To remove noise in the images having the form of isolated light points, median filtering was applied.

Realization of item 2 is based on the fact that images falling in classes defined by lower criteria values (meaning that the stomata damage is less profound) show a high number of steep edges, while stomata images with greater damage, thus images classified in higher classes show a low number of steep and rather slow edges. To consider this fact, possibilities of wavelet analysis and edge detection were investigated in greater detail.

2.1 Wavelet Transform in Image Processing

From the viewpoint of signal processing, wavelet functions can be used to transform a given series of values using complementary low-pass, high-pass half-band filters [4]. According to the wavelet function type selected, the relevant tree structure resembles a complete filter bank with signal decomposition into partial frequency bands. Coefficients of this wavelet transform can then be used further for the original signal analysis or reconstruction [8].

Continuous wavelet functions are usually derived from the initial mother wavelet $w(t)$, with the selected dilatation parameter $a = 2^m$ and translation parameter $b = k\ 2^m$ according to the following relationship:

$$W_{m,k}(t) = \frac{1}{\sqrt{a}}\ w(\frac{t-b}{a}) = \frac{1}{\sqrt{2^m}}\ w(2^{-m}\ t - k) \tag{1}$$

where m and k are integral constants. Initial wavelets can be defined either as the appropriate dilatation equation solution or analytically.

From the viewpoint of digital signal processing, the initial wavelet can be considered as a high-pass, half-band filter. The dilatation parameter $a = 2^m$ of the continuous wavelet functions then corresponds with the spectrum compression level. This general property is well apparent for the harmonic wavelet $w(t)$ first stated by Newland [3], defined together with the corresponding scaling function $s(t)$ by the following relationships:

$$w(t) = \frac{1}{j\pi/2\ t}(e^{j\pi\ t} - e^{j\pi/2\ t}) \tag{2}$$

$$s(t) = \frac{1}{\pi/2\ t}(e^{j\pi/2\ t} - 1) \tag{3}$$

Both of these functions are modified by the parameter (scaling index) $m = 0, 1, ...$ according to Eq. (1), while the wavelet dilatation leads to the spectrum compression, as well. A similar approach can also be applied for other wavelets, defined analytically or by means of the recurrent formula.

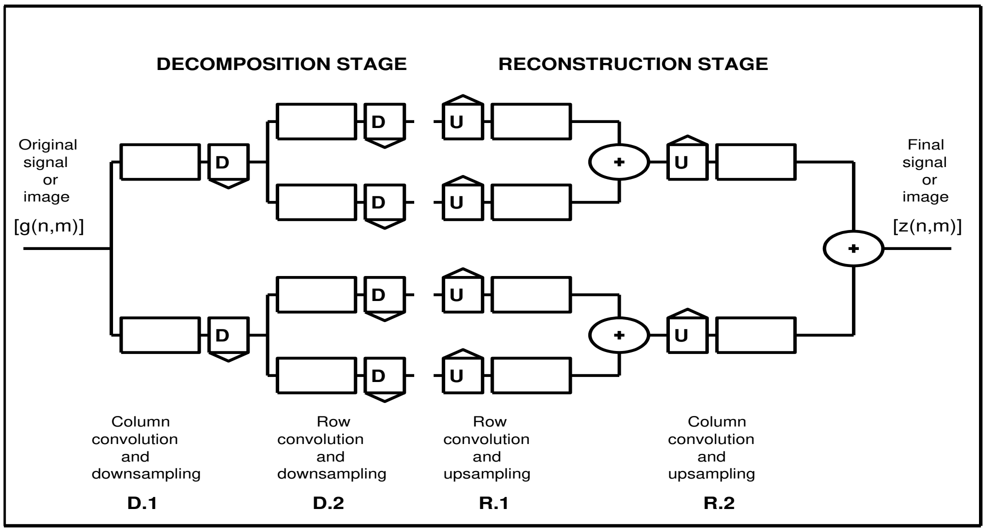

Figure 3 - Mallat's image decomposition scheme into the first level and its subsequent reconstruction

In this particular image analysis, image decomposition is performed according to the scheme shown in Fig. 3. An example of the given image decomposition in the second level is shown in Fig. 4, together with its reconstruction to suppress its noise components for the given threshold levels. Using real wavelet functions, the image is then characterized by the mean square value of the wavelet coefficients.

2.2 Edge Detection Methods Using the Sobel Detector

An edge is defined in the image as a location where the image (brightness) function changes suddenly. It is apparent that image edges are defined by the sudden nature of such a change in

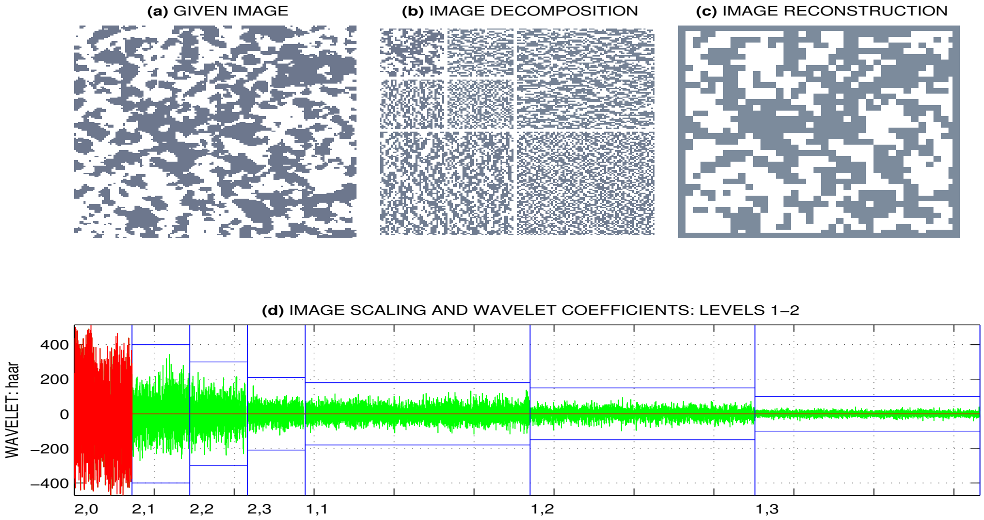

Figure 4 - Decomposition of the selected microscopic image part: **(a)** original image, **(b)** image decomposition components, **(c)** reconstructed image, and **(d)** decomposition coefficients including threshold levels for their modification

the selected direction. Some of the commonly used edge detection methods are of directional nature, others perform estimation even in their basic form in all directions [2]. At present, the Canny edge detector is considered to belong among the highest-quality edge detectors. However, in many cases more simple methods suffice, e.g. the Sobel filter characterized by the matrix:

$$M_{Sobel} = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \tag{4}$$

The matrix shown above allows for edge detection in the horizontal direction; by partial turning of the matrix, detectors for other directions can be obtained.

The resulting image is defined by convolution of the image matrix and the edge detector matrix, providing information on presence of edges in the image - the image assumes local maximum values in areas where edges exist. The advantage of this method lies in its simplicity. Another advantage is represented by the fact, that this method cancels partially the effect of disturbing components, thus eliminating the need of median filtering. The detailed algorithm applied, as well as the Sobel detector criterion used, are described in Section 3.

3 RESULTS

Two algorithms were designed to classify the images into predefined classes; these algorithms were compared using the testing image set with known values of subjective classification, see Table 2. The correlation coefficient was applied as the criterion to evaluate the quality of the method selected, also see Table 2. Both correlation coefficient values are very high (> 0.9).

The weighted wavelet analysis criterion C_W (see Table 2) computation algorithm is as follows: 1. Identical pixel size in the given (μm) units is ensured by means of resampling, using the corresponding interpolation method. 2. Digital filtering is applied due to rather frequent presence of disturbing components in the image, namely median filtering. 3. In classification, the fact must be considered that the stoma does not cover the entire image area in most cases. The algorithm of the stoma boundary delimiting can be subject of further research. For the purpose of the initial automatized classification proposal, it is assumed that the stoma is located especially in the middle of the image. Four more areas were delimited in the images, as well, namely above, below, left and right of the central part; in these four areas marginal parts of the

Table 2 - RESULTS OF WEIGHTED WAVELET ANALYSIS AND THE SOBEL DETECTOR APPLICATION IN THE TESTING SET CLASSIFICATION. SE = SUBJECTIVE EVALUATION; C_W = WEIGHTED WAVELET ANALYSIS CRITERION; AC_W = AUTOMATIC CLASSIFICATION ACCORDING TO C_W; C_S = SOBEL DETECTOR CRITERION; AC_S = AUTOMATIC CLASSIFICATION ACCORDING TO C_S

Locality	Set	Resolution [$\mu m/pixel$]	SE	C_W	AC_W	C_S	AC_S
128	b2_1b	0.0906	1	1.0422	1	10,5	1
605	b2_1p	0.0906	1	1.0982	1	9,9	2
532	a3_1c	0.0868	1	1.1333	1	9,3	2
533	a1_1c	0.1096	1	0.9271	2	13,1	1
533	b2_1b	0.0868	1	1.0981	1	13,4	1
128	a3_1b	0.0947	2	0.9038	2	9,6	2
128	a3_1p	0.0868	2	0.9412	2	9,2	2
128	b1_1p	0.0694	2	0.9602	2	7,3	3
625	a2_1b	0.0906	2	0.9683	2	7,6	3
633	b1_1c	0.0868	2	0.9173	2	7,3	3
128	b3_1c	0.0718	3	0.8585	3	8,4	3
145	a2_1b	0.0801	3	0.8252	3	8,9	2
618	a3_1c	0.0801	3	0.8066	3	7,9	3
649	a1_1p	0.0718	3	0.9282	2	9,1	2
615	a2_1b	0.0833	3	0.8980	3	7,4	4
145	b2_1b	0.0772	4	0.7871	4	6,8	4
532	b1_1b	0.0718	4	0.8104	3	5,9	4
612	a1_1b	0.0906	4	0.7069	4	6,1	4
618	a1_1c	0.0947	4	0.5521	5	5,3	5
640	a3_1p	0.0906	4	0.7594	4	6,6	4
128	a1_1c	0.1042	5	0.6045	5	5,3	5
145	a3_1p	0.0992	5	0.6517	5	4,5	5
532	b1_1c	0.0992	5	0.6956	5	4,0	5
633	a2_1b	0.0868	5	0.6777	5	5,0	5
658	b1_1p	0.0744	5	0.6512	5	5,8	4
Correlation coefficients calculated between the subjective and automatized classification							
					0.96		0.92

stoma occur only. The remaining part of the image is neglected. Sizes of these five areas are identical, upon performing the wavelet transform, the number of wavelet coefficients obtained is thus the same, as well. 4. The C_W criterion, corresponding with the stoma condition, is computed as the weighted sum of absolute wavelet coefficient values. 5. Images are classified in classes 1 to 5 according to C_W.

The Sobel detector criterion C_S (see Table 2) is as follows: 1. Sobel detector application to the image in the horizontal direction. 2. Depiction of the resulting image histogram and its medium value. 3. Recording of the histogram medium value. The medium value is used as the quality criterion C_S of the stoma; the higher this value, the more edges the image contains and the less damaged it is. 4. Based on the medium values found for the testing set, intervals were determined for image classification in classes.

4 CONCLUSION

Results obtained seem very promising, although some characteristics of the images investigated clearly make proper classification difficult. This concerns especially the presence of disturbing components or organic and anorganic particles, respectively, on the stomata surface. Another problem is represented by difficult automatic selection of the stomata area which could be resolved partially only in the current work.

The weighted wavelet analysis method provides slightly better results and it can be expected that in respect to many variable parameters of this method, such as the wavelet choice, the decomposition level choice, its further marked improvement can be achieved. Also the Sobel detector method can be improved, especially by variation of the detector kernel size and by application of edge detection in all directions. Modification of the image acquisition methods can be considered, as well, as it is very desirable to work with bitmap images in automatized processing, without any previous compression, to acquire stomata images taken under the same angle and with the same sharpness.

Further work is focused on improvement of the methods described and on their application to more extended image data sets.

References

[1] GONZALES R. C. and WOODS R. E. *Digital Image Processing.* Prentice Hall, second edition, 2002. 795 pages, ISBN 0-201-18075-8.

[2] WATKINS Ch., SADUN A., and MARENKA S. *Modern Image Processing: Warping, Morphing, and Classical Techniques.* Academic Press, Inc., London, 1993. 235 pages, ISBN 0-12-737860.

[3] NEWLAND D. E. *An Introduction to Random Vibrations, Spectral and Wavelet Analysis.* Longman Scientific & Technical, Essex, U.K., third edition, 1994.

[4] DAUBECHIES I. The Wavelet Transform, Time-Frequency Localization and Signal Analysis. *IEEE Trans. Inform. Theory*, 36:961–1005, September 1990.

[5] NÁHLÍK J. Studium imisního poškození mikrostruktury voskové vrstvy jehličí užitím elektronové řádkovací mikroskopie, ve zprávě "Hodnocení stavu životního prostředí: Monitoring cizorodých látek v potravních řetězcích"(Projekt MR/14/95, část 5.). Technical report, Vysoká škola chemicko-technologická, Praha, ČR, 1996.

[6] PETROU M. and BOSDOGIANNI P. *Image Processing: The Fundamentals.* John Wiley and Sons, Inc., UK, 2000. 335 pages, ISBN 0-471-99883-4.

[7] THE MATHWORKS. *Matlab Image Processing Toolbox.* The MathWorks, Inc., Natick, Massachusetts 01760, 1997.

[8] RIOUL O. and VETTERLI M. Wavelets and Signal Processing. *IEEE SP Magazine*, pages 14–38, October 1991.

[9] HLAVÁČ V. and SEDLÁČEK M. *Zpracování signálů a obrazů.* Vydavatelství ČVUT, Praha, 2000. 221 pages, ISBN 80-01-02114-9.

[10] ŽÁRA J., BENEŠ B., and FELKEL P. *Moderní počítačová grafika.* Computer Press, 1998. 450 pages, ISBN 80-7226-049-9.

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