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IMAGE ANALYSIS, 3D GEOMETRY MODELING AND INVERSE FEA IN INVESTIGATING PROPERTIES OF AGRI-FOOD AND FOREST PRODUCTS

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ABSTRACT In designing and managing thermal and mechanical processes in the agricultural, food and forest industries, to be able to assess quality, it is important to know product properties at all stages of processing. Recent advances in image analysis, both for neural classification and for 3D geometry data acquisition, enhanced by 3D geometry modeling and inverse finite element analysis, extend our possibilities in predicting product behavior and performing quality classification. In this paper original procedures and software earlier developed by the authors to solve a variety of quality analysis problems were analyzed and integrated into software of higher functionality, usability and efficiency. The problems were as follows: 1) image analysis measurement and product geometry representation in a form of 3D isoparametric finite element meshes, enhanced with NURBS and appropriate textures, 2) identification of unknown model coefficients (inverse FEA) and prediction of heat and moisture transport (direct FEA), 3) visualization of prediction results for 3D objects in time and space, 4) neural classification of products with respect to quality factors based on analysis of selected image features. The procedures were exemplified by analysis of dried vegetables and cereal grain kernels. Effective algorithms of image analysis enhanced with neural modeling procedures, edge detection and 3D geometry modeling approaches, and original inverse and direct finite element analysis software resulted in increased accuracy of prediction of thermal and mechanical behavior of investigated biomaterials and classification of product quality.

Keywords: 3D geometry data acquisition, Geometry representation and visualization, Inverse coefficient problems, FEM, Heat and mass transport, Neural classification.

INTRODUCTION Knowledge of properties of agricultural, food and forest products is crucial in understanding and predicting behavior of investigated biomaterials during thermal and mechanical processes. It is also important for designing and managing corresponding processing technologies. Recent advances in the area of agricultural, food and forestry engineering with respect to image analysis in acquiring 3D geometry data (Weres, 2008), object geometry modeling (Weres, 2008), inverse finite element analysis (Olek and Weres, 2007, Weres and Olek, 2005, Weres et al., 2009), and image analysis and neural-based object classification (Boniecki et al., 2006, 2009, Koszela et al., 2004, Koszela and Weres, 2005, Nowakowski et al., 2007, Nowakowski, 2008, Nowakowski et al., 2009, Nowakowski et al., 2010) extend our possibilities in predicting behavior of investigated products and in classifying products.

The objectives of the paper were to review procedures earlier developed by the authors and to analyze them and integrate into software of improved functionality, usability and efficiency in the following specific areas: 1) image analysis for 3D geometry data acquisition and generation of 3D isoparametric finite element meshes; 2) 3D geometry modeling enhanced with NURBS and appropriate textures, and visualization of changes in thermal and mechanical properties of investigated products in time and space domains; 3) identification of mathematical model coefficients by inverse finite element analysis (FEA), evaluation of optimization algorithms used to estimate coefficient values, and prediction of changes in thermal and mechanical properties of investigated objects in time and space domains by direct FEA; 4) neural-based image analysis for assessing quality and classifying investigated objects.

METHODS AND RESULTS

Image analysis for 3D geometry data acquisition and generation of 3D isoparametric finite element meshes Image analysis procedures based on edge detection were analyzed and implemented to acquire 3D geometry data for investigated agri-food and forest products. The finite element mesh generation procedure, applicable to 3D isoparametric elements, was based on collecting 3D coordinates of external and internal nodes, acquired from image analysis for photographs of consecutive layers of a product, selected either along all three axes or only along one axis of the Cartesian coordinate system. The procedure was started by entering input parameters for 3D mesh generation, and the first image was preprocessed. Preprocessing results were automatically applied to all remaining images of layers. Next, edge detection was performed, approximate structural FE mesh was proposed and manually corrected, and coordinates of all nodes were automatically measured separately for each layer. Coordinate values were stored, at appropriate positions in a global table of 3D mesh node coordinates (Figure 1). Original software was developed to meet such requirements. Alternative approach based on photogrammetry was examined to collect 3D coordinates of external nodal points from photographs taken at different angles. This 3D point cloud processing procedure, more effective for shape modeling, lacked information on internal structure of a product.

3D geometry modeling enhanced with NURBS and appropriate textures, and visualization of changes in thermal and mechanical properties of investigated products in time and space domains Algorithms were developed to improve 3D geometry modeling and visualize changes in thermal and mechanical properties of investigated products, in time and space domains (Figure 2). Mapping of shapes with the use of curvilinear isoparametric finite elements was enhanced by applying selected parametric surfaces. Due to characteristics of such surfaces it was possible to achieve a higher level of smoothness for the models. The 3D geometry representation of agricultural, food and forest products was used as input to our original inverse and direct finite element analysis software to estimate thermo-mechanical properties of products and to predict their behavior. It resulted in increased accuracy of predictions.

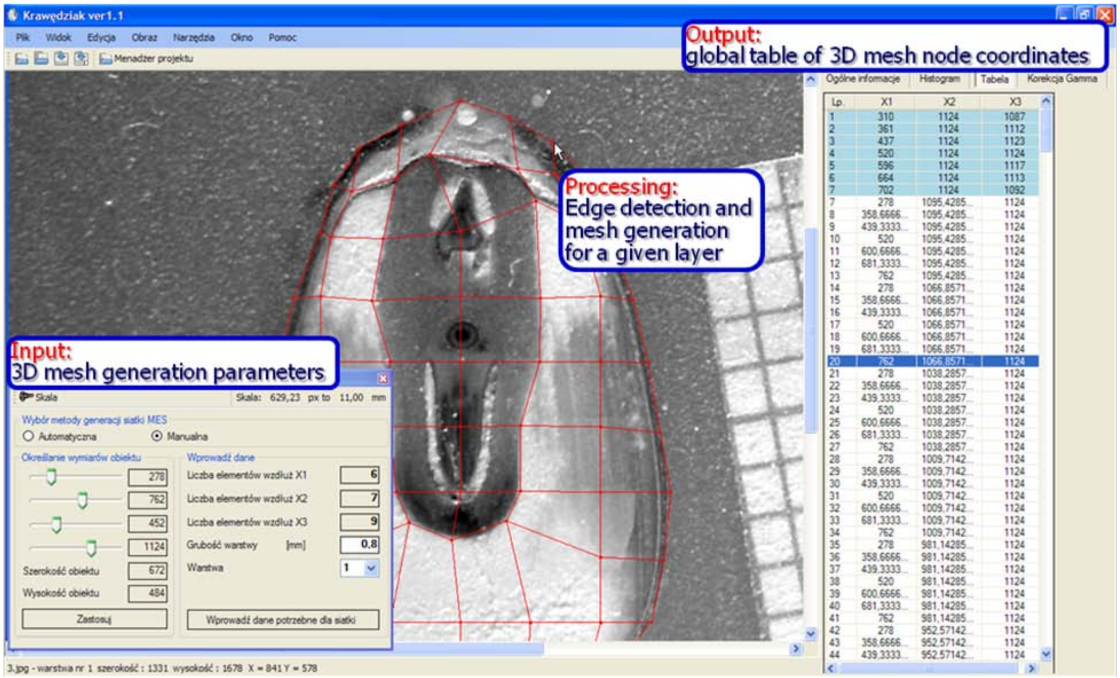

Figure 1. Software for image analysis for 3D geometry data acquisition and generation of 3D isoparametric FE meshes

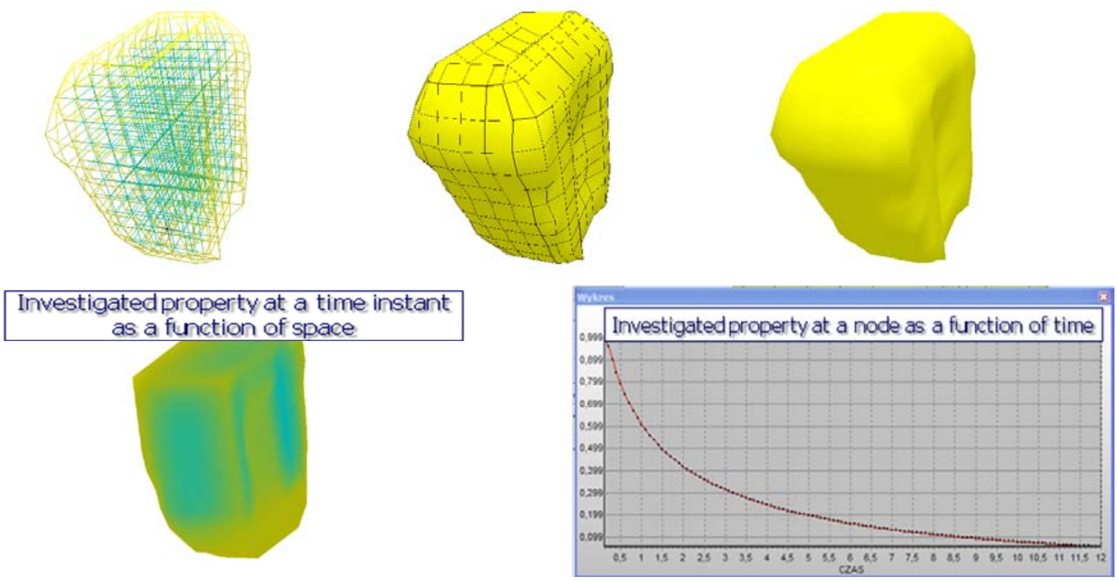

Figure 2. Software for 3D geometry modeling enhanced with NURBS and textures, and for visualization of changes in investigated product properties in time and space

Identification of mathematical model coefficients by inverse FEA, evaluation of optimization algorithms used to estimate coefficient values, and prediction of changes in thermal and mechanical properties of investigated objects in time and space domains by direct FEA Redeveloped and newly added algorithms for identifying unknown or dubious values of mathematical model coefficients concerned the following stages of inverse FEA approach (Figure 3): 1) experimental measurements of investigated quantities, e.g. temperature, moisture content; 2) computer simulation based on coefficient starting values (direct FEA); 3) minimization of objective function with respect to coefficient values sought, with the use of metaheuristic algorithms: simulated annealing, tabu search and genetic algorithm, and, for local optimization: trust region and variable metric algorithms; 4) prediction of investigated quantities based on estimated coefficient values; 5) evaluation of prediction quality on the basis of experimental data not used in coefficient identification; analysis of quality of optimization algorithms.

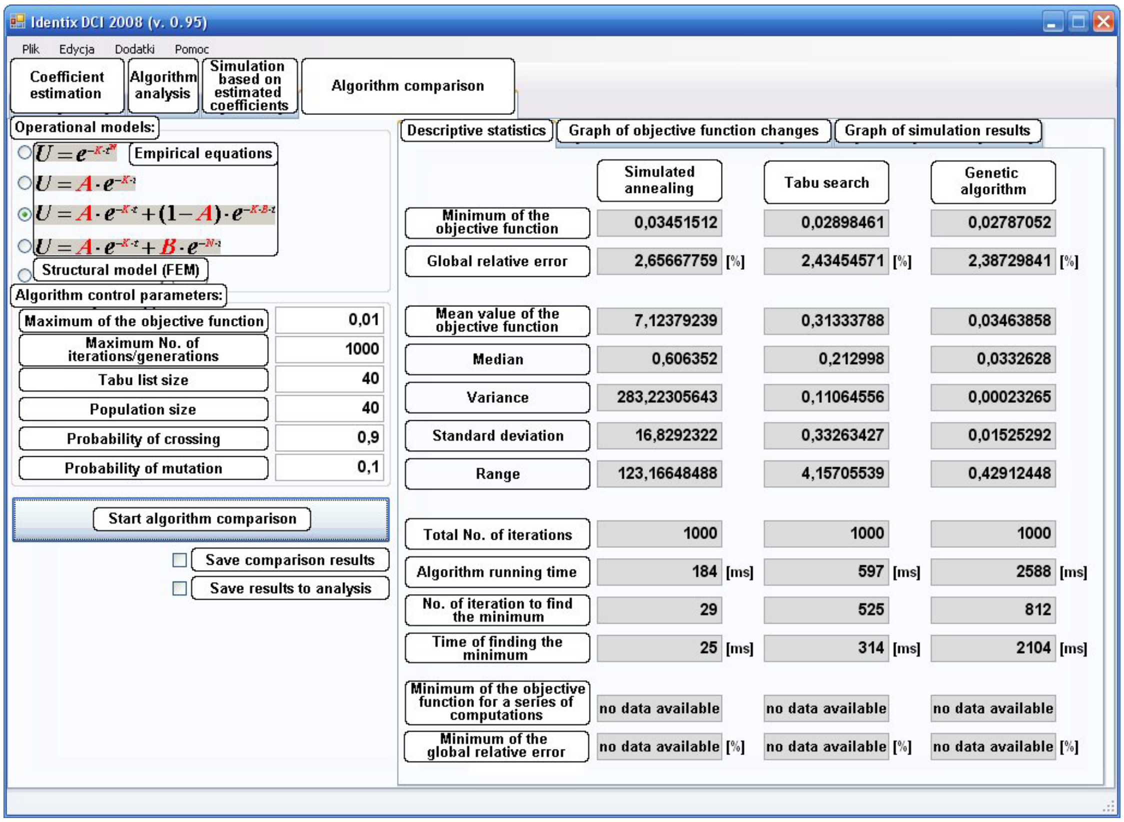

Figure 3. Software for estimating coefficient values by inverse FEA, for evaluating optimization algorithms, and for direct FEA predictions

Neural-based image analysis for assessing quality and classifying investigated objects Information from image analysis often requires human participation for unambiguous interpretation. This task can be performed by artificial neural networks. A significant stage in neural modeling approach was to choose characteristic tags, indispensable in correct inferring (Figure 4). The next important issue was to find an appropriate method to prepare learning files, and it was fundamental for effective image transformation to a form acceptable by a neural network for its correct operation. The original software was developed to convert an image to learning files on the basis of color and shape criteria. The learning process was designed and conducted to guarantee correctness of the operating model (Figure 5).

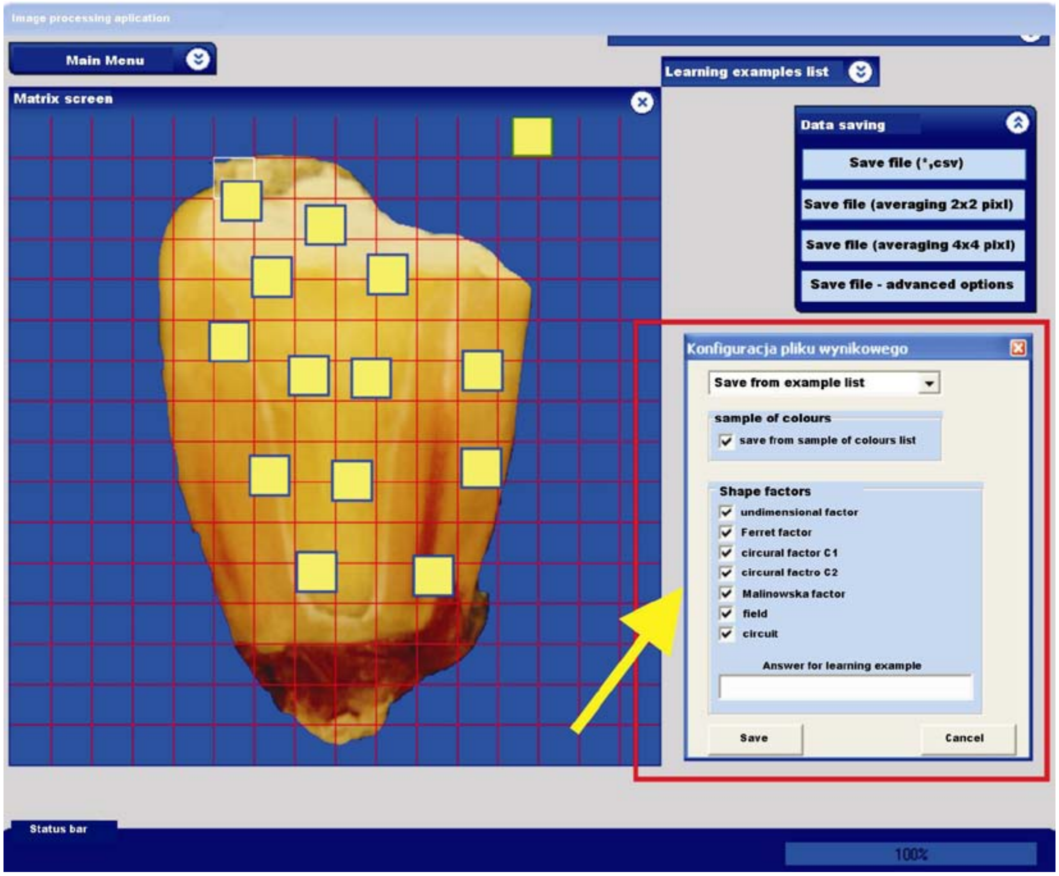

Figure 4. Software for neural-based image analysis for assessing quality and classifying investigated products

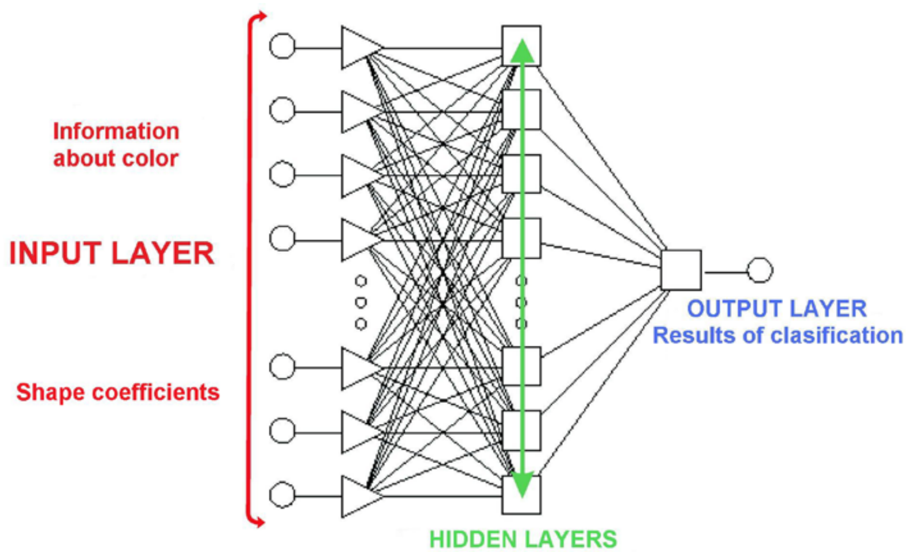

Figure 5. Topology of neural classifying model for selected agri-food and forest products

Such combination of the two approaches: image analysis and neural networks enlarged the range of possible applications for the two methods. It also brought in a complete level of automation to the processes of identification and classification, and can be applied for much larger number of investigated agri-food and forest objects. However, a constraint was found in image acquisition and processing - due to limitations in the hardware performance.

Another image analysis and neural classification software, earlier developed by the authors, was reconstructed to improve functionality and efficiency in classifying and assessing quality for selected agricultural, food and forest products. The software was applied to analyze images of dried carrot cubes (Figure 6 and Figure 7). The developed procedures resulted in selecting color and shape as specific features important for quality assessment.

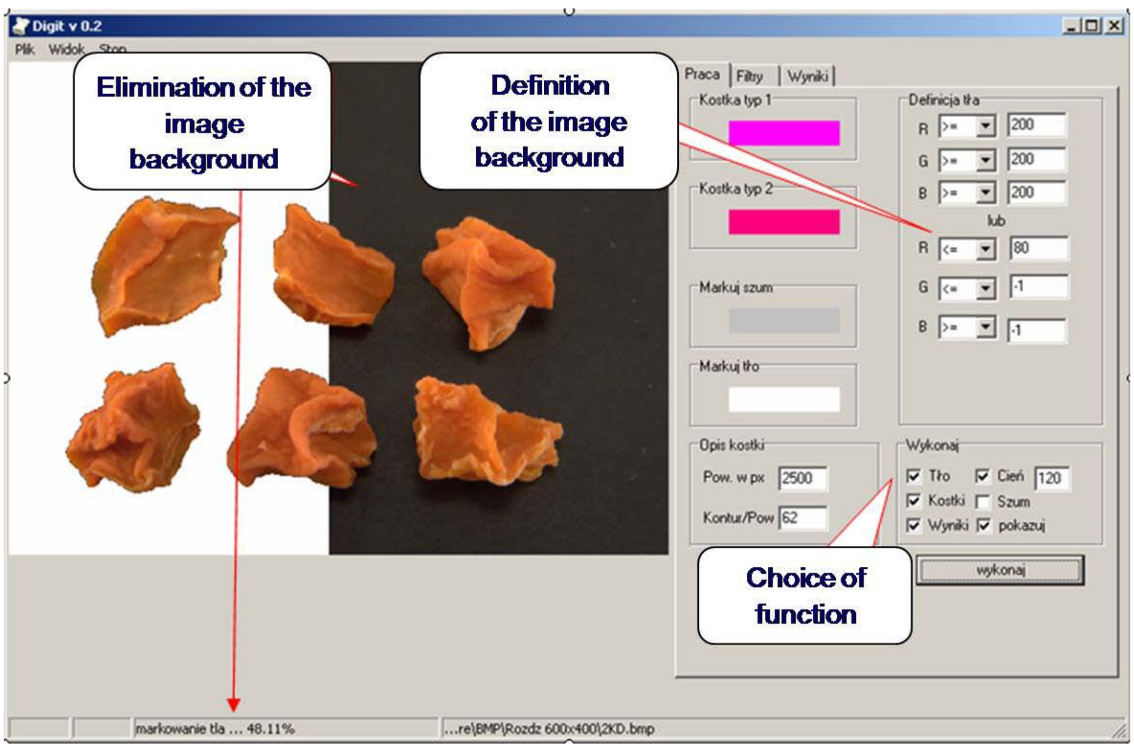

Figure 6. Software for neural-based image analysis for assessing quality and classifying dried vegetables – stage 1

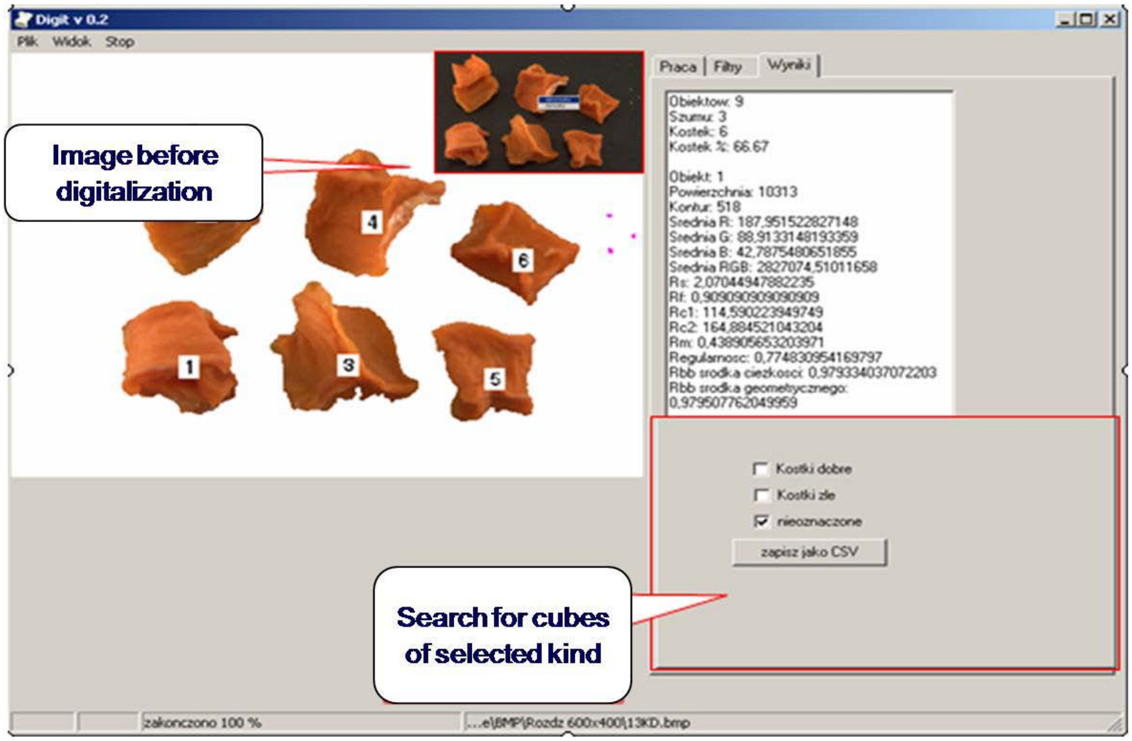

Figure 7. Software for neural-based image analysis for assessing quality and classifying dried vegetables – stage 2

Methods of software development The software depicted in the paper was developed to support edge detection-based image analysis, 3D geometry modeling, inverse finite element analysis, and neural network-based image analysis. It was elaborated according to software engineering standards at all phases of software development process. Functional requirements and UML 2.2 diagrams were redesigned to represent enhanced functionality, structure and behavior corresponding to the problems domains. The software code was implemented in Visual Studio 2008, in C++/CLI and C#. Microsoft programming framework was supplemented with the OpenGL library to model effectively product geometry. Test cases were designed to cover all functional requirements, and testing results were used to improve the software. Finally, the software showed improved functionality, and also usability and efficiency as compared to older versions developed by the authors.

CONCLUSION The original software developed in the paper was applied to represent 3D geometry of agri-food and forest products, to visualize variations in their properties during thermal and mechanical processing, to identify mathematical model coefficients by inverse FEA, to predict variations in thermal and mechanical properties of investigated products, and to assess quality and to classify products. The approach was exemplified by the analysis of corn kernels and dried carrot cubes. Implementation of image analysis in acquiring 3D geometry data, object geometry modeling, inverse and direct FEA, and image analysis combined with neural-based object classification, provided a highly functional and effective tool for increasing accuracy in predicting behavior of examined products and assessing their quality.

REFERENCES

Boniecki, P., J. Weres, A. Krysztofiak, and W. Mueller. 2006. NEURALNET2005: Education computer system supporting the use of artificial neural networks in agriculture. Journal of Research and Applications in Agricultural Engineering 51(1): 10-13.

Boniecki, P., K. Nowakowski, and A. Przybylak. 2009. Neural compression of graphical data in a process of identifying selected agricultural objects (in Polish). Journal of Research and Applications in Agricultural Engineering 54(2): 19-24.

Koszela, K., P. Boniecki, and J. Weres. 2004. Neural predicting of the farm product distribution exemplified by the marjoram and carrot. Journal of Research and Applications in Agricultural Engineering 49(1): 22-23.

Koszela, K., and J. Weres J. 2005. Analysis and classification of dried vegetable images with the use of artificial neural networks (in Polish). Inżynieria Rolnicza 2(62): 77-82.

Nowakowski, K., P. Boniecki, J. Weres, and W. Mueller. 2007. Processing graphical data for teaching artificial neural networks in modeling selected problems of agricultural engineering (in Polish). Inżynieria Rolnicza 2(90): 243-248.

Nowakowski, K. 2008. Neuronal image analysis (in Polish). In: Weres, J. et al. (eds.) Elements of Agricultural Systems Engineering (in Polish). Wyd. UP Pozn., Poznan, Poland, pp. 183-192.

Nowakowski, K., P. Boniecki, J. Dach. 2009. Neural image analysis in identification process of mechanical damages of kernels. Journal of Research and Applications in Agricultural Engineering 54(2): 77-81.

Nowakowski, K., P. Boniecki, A. Przybylak. 2010. Effects of color compression on performance of the neural identification model (in Polish). Inżynieria rolnicza (in press).

Olek, W., and J. Weres. 2007. Effects of the method of identification of the diffusion coefficient on accuracy of modeling bound water transfer in wood. Transport in Porous Media 66(1-2): 135-144.

Weres, J., and W. Olek. 2005. Inverse finite element analysis of technological processes of heat and mass transport in agricultural and forest products. Drying Technology 23(8): 1737-1750.

Weres, J. 2008. Computer aided analysis of selected properties of agricultural and forest products (in Polish). In: Weres, J. et al. (eds.) Elements of Agricultural Systems Engineering (in Polish). Wyd. UP Pozn., Poznan, Poland, pp. 205-218.

Weres, J., W. Olek, and S. Kujawa. 2009. Comparison of optimization algorithms for inverse FEA of heat and mass transport in biomaterials. Journal of Theoretical and Applied Mechanics 47(3): 701-716.