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TWO APPROACHES TO REPRESENTING AGRI-FOOD PRODUCT GEOMETRY – AN ORIGINAL SOFTWARE FOR CONSTRUCTING FINITE ELEMENT MODELS AND THE 3DS MAX APPROACH

Summary

Adequate representation of agri-food product properties in mathematical models of heat and water transport is necessary to simulate the behavior of the products, and to be able to explain and predict agri-food processing operations such as drying, cooling, and heating. Heat and water transport processes affect the final product quality and it is important to provide designers of agri-food processing and storing systems with tools for virtual prototyping and performance prediction. A lack of sufficient knowledge on product complex geometry represents a major obstacle in many computer predictions. Therefore two original approaches, one based on the finite element mesh generation and the other on the 3ds Max modeling were constructed and implemented in the paper to represent geometry of agri-food products. The approaches were used to model corn kernel geometry, in the intention of modeling grain drying and storing processes.
Key words*: geometry modeling, FE mesh generation, 3ds Max modeling, software development*

DWA PODEJŚCIA DO MODELOWANIA GEOMETRII PRODUKTÓW ROLNO-ŻYWNOŚCIOWYCH – ORYGINALNE OPROGRAMOWANIE DO BUDOWY MODELI MES I TWORZENIE MODELI W 3DS MAX

Streszczenie

Odpowiednie odwzorowanie właściwości produktów rolno-żywnościowych w matematycznych modelach transportu ciepła i wody jest niezbędne do symulacji zachowania tych produktów oraz umożliwia wyjaśnianie i prognozowanie operacji przetwórstwa rolno-żywnościowego, takich jak suszenie, schładzanie czy podgrzewanie. Procesy transportu ciepła i wody wpływają na jakość końcowego produktu, jest zatem ważne, by projektantom systemów przetwarzania i przechowywania żywności dostarczać narzędzi do wirtualnego prototypowania i prognozowania wydajności tych systemów. Brak dostatecznej wiedzy o złożonej geometrii produktów stanowi główną przeszkodę w wielu komputerowych symulacjach. Dlatego też skonstruowano i zastosowano w pracy dwa oryginalne podejścia, jedno oparte na tworzeniu siatki elementów skończonych, a drugie na modelowaniu w środowisku 3ds Max, przeznaczone do odwzorowywania geometrii produktów rolno-żywnościowych. Podejścia te zastosowano do modelowania geometrii ziarniaków kukurydzy, z zamiarem modelowania procesów suszenia i przechowywania ziarna zbóż.
Słowa kluczowe*: modelowanie geometrii, tworzenie siatki elementów skończonych, modelowanie w 3ds Max, wytwarzanie oprogramowania*

1. Introduction

In order to design and control agri-food processing systems comprising heating, drying, cooling and storing operations it is necessary to develop appropriate heat and water transport models to be able to simulate the product behavior. As all the processes affect the final product quality, its properties should be adequately represented in a corresponding mathematical model. Attempts to measure and/or identify material properties of agri-food products, and to enhance the heat and water transport models by inserting acquired data are well described in the literature [1, 13, 14]. However, there is a little information about the role of inaccurate representation of the product geometry, and it is a major obstacle in computer predictions of the agri-food product behavior. Simplification of complex shapes of agri-food products into shapes of basic solids significantly decreases quality of modeling, and thus poses a barrier in explaining, predicting and designing investigated processes [13, 15].

Recent developments in image analysis applied to measurement and modeling of geometry [2, 3, 6, 10, 12], and in numerical methods of representing geometry within finite element models [4, 15, 16] are a good starting point to construct original algorithms to detect, measure and represent complex 3D geometry of biomaterials. The geometry data acquired can be used to map and visualize product geometry in the 3D domain, and to improve consistency in modeling and predicting the heat and water transport processes in agri-food products.

The objective was to develop and implement two original approaches to represent agri-food product geometry in the mathematical model of the heat and water transport, and to develop software supporting geometry modeling. The approaches were exemplified by modeling geometry of corn kernels. The resulting geometry models will be used in future for enhancing temperature and moisture content predictions in agri-food products, and for estimating effects of various approximated geometry representations on the accuracy of such predictions.

2. Material and methods

The two original approaches, one based on the finite element mesh generation and the other on the 3ds Max modeling were constructed and implemented to represent geometry of agri-food products. The approaches were used to approximate geometry of a corn kernel, and kernels of a hybrid variety FAO 280 (Pioneer) were investigated.

The approach based on the finite element mesh generation consisted in 3D geometry measurement from imaging data, FE meshing and visualization [3, 4, 6, 10, 15, 16]. The following procedures were designed and performed: a sample material cutting with a microtome, acquisition of digital photographs, processing and analysis of images of consecutive object layers, detection of external edges and internal boundaries between the product components, construction of a geometry model in a form of a mesh of 3D isoparametric finite elements, and, for visualization reasons, enhancing the model with NURBS, textures and illumination. In order to automate the procedures a software package was developed. Software development methods were based on software engineering standards [5, 11], with the use of UML 2.4.1. The Visual Studio 2012 programming environment was used to implement software in C# v. 5.0 [9].

The approach based on the 3ds Max modeling was framed by methods available in the Autodesk 3ds Max version 12 [7, 8]. One technique was based on the chamfer box modeling, an extremely useful modeling technique offering huge possibilities dedicated to constructing complex shapes. The other technique consisted in modeling with NURBS curves and surfaces, useful in creating models with high flexibility and small amount of data describing geometry of a solid.

3. Results and discussion

### 3.1. Method based on the finite element mesh generation

The approach was based on image processing and analysis, 3D geometry measurement from imaging data, and FE meshing and visualization. The designed procedures were performed for corn kernels. A sample kernel was cut into layers with a microtome, and digital photographs of the consecutive layers were acquired. Next, the images were processed and analysed - external edges and internal boundaries between the product components were detected. According to the FE mesh parameters the primary mesh was automatically generated in 3D. Location of nodes was manually refined, and finally all the nodal coordinates were written to an output table. The kernel geometry model was constructed using 3D isoparametric finite elements. Structure parameters of the 3D FE mesh were the input data, and the global array of 3D nodal coordinates was the output. For visualization reasons the model was smoothed by NURBS and enhanced with a texture and illumination. To perform all the procedures original software was developed (Fig. 1, Fig. 2).
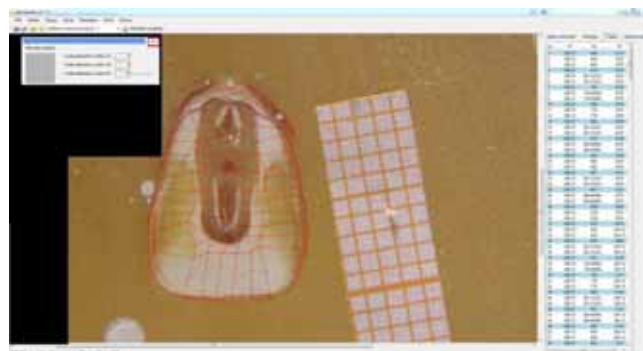
Source: own study / Źródło: opracowanie własne

Fig. 1. Software package for detecting external and internal edges of a product from images of its consecutive layers, generating FE mesh, and measuring and saving all nodal coordinates
Rys. 1. Pakiet oprogramowania do wykrywania zewnętrznych i wewnętrznych krawędzi produktu na podstawie obrazów kolejnych jego warstw, tworzenia siatki MES oraz mierzenia i zapisywania współrzędnych wszystkich węzłów
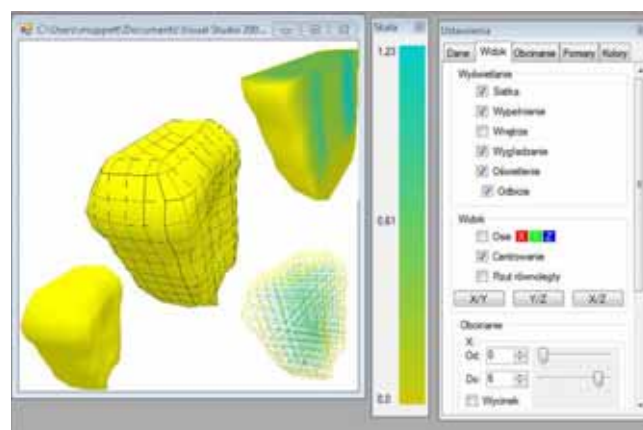
Source: own study / Źródło: opracowanie własne

Fig. 2. Software package for visualization of the geometry model. Available functions: NURBS smoothing, texture and illumination enhancement, moving, rotating, scaling and plane-cutting
*Rys. 2. Pakiet oprogramowania do wizualizacji modelu geometrycznego. Dostępne funkcje: wygładzanie NURBS, nakładanie tekstury i oświetlenia, przesuwanie, obracanie, skalowanie i odcinanie płaszczyzn*

3.2. Method based on the 3ds Max modeling

Geometry modeling techniques were described with the use of Autodesk 3ds Max version 12. Among modeling techniques available in 3ds Max the following two ones were chosen, used, and described in detail: 1) chamfer box technique, i.e. chamfered cuboid equipped with the Fillet Segs property, with the possibility to set the number of segments, curves, and their width. It is extremely useful as it offers many editing possibilities, especially for modeling original composed shapes; 2) NURBS curves and surfaces modeling, useful for creating complex projects due to the high flexibility in creating models and a small amount of input data necessary to describe the solid geometry.

NURBS is one of the tools available for designing in 3ds Max. It covers both the NURBS curves and NURBS surfaces. There are two kinds of NURBS curve objects:

point curves, the points of which must lie on the curve, and CV curves, the curves controlled by control vertices (CVs), and the CVs don't lie on the curve. To create a corn kernel, in the front window a half of the kernel contour was drawn by NURBS CURVE CV. Then, from the MODIFY panel, with the use of the *select* and *move* transformation tools (Fig. 3), the contour checkpoints were moved to correct possible errors made during the contour drawing. To make it possible, the *selection* option should be chosen within the CV rollout.
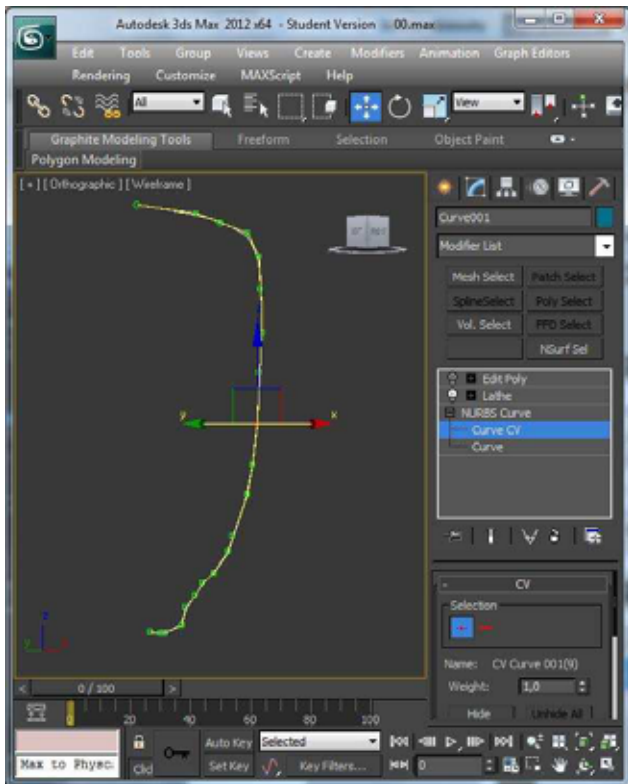
Fig. 3. Select and move transformation tools
*Rys. 3. Narzędzia transformacji - wyboru i przesuwania*

In the next step the lathe modifier was applied to wrap the previously created contour. As the result of the modifier action the rotary block was attained, assuming that the *degrees* parameter was set to 360, it is the number of angular degrees by which the basic object is rotated. Next, by using the *select* and *scale* transformations, the corn kernel was flattened as it was unacceptably round, and scaled to a suitable size. After scaling the model dimensions were 12 mm × 8 mm × 4 mm. It can be determined by the *measure distance* tool, available in the *Tools* command on the menu bar.

The next step was to impose the *edit poly* modifier (Fig. 4). This solution is better than converting to *editable poly,* as the object remains the NURBS curve, but it gains editing capabilities. The shape of the kernel can be clarified by generating appropriate distortions after selecting the *Vertex* sub-object.

When the shape of the corn kernel is ready, we can move to the next step of designing in 3ds Max 12. Chamferbox is an easily editable object. Its advantage is in shape which provides a suitable basis for creating a corn kernel. At the beginning an object was created: *Create / Extended Primitives / ChamferBox.* In the *Parameters* rollout the *length, width, height* and *fillet* were set. Then the *Segs* pa-

rameters – the division number for each length – was set to 9. Thus we obtained the chamfered box similar to the size of the corn kernel.

In the next step a *taper* modifier was imposed (Fig. 5), and it was used to taper the bottom part of the ChamferBox object. This modifier is available in the *modify* tab in the *Modifier List* rollout. After entering data into the *Taper Amount* the rectangle changed into a trapezoid. In the *Taper Axis* we chose the axis along which the transformation was to be performed.
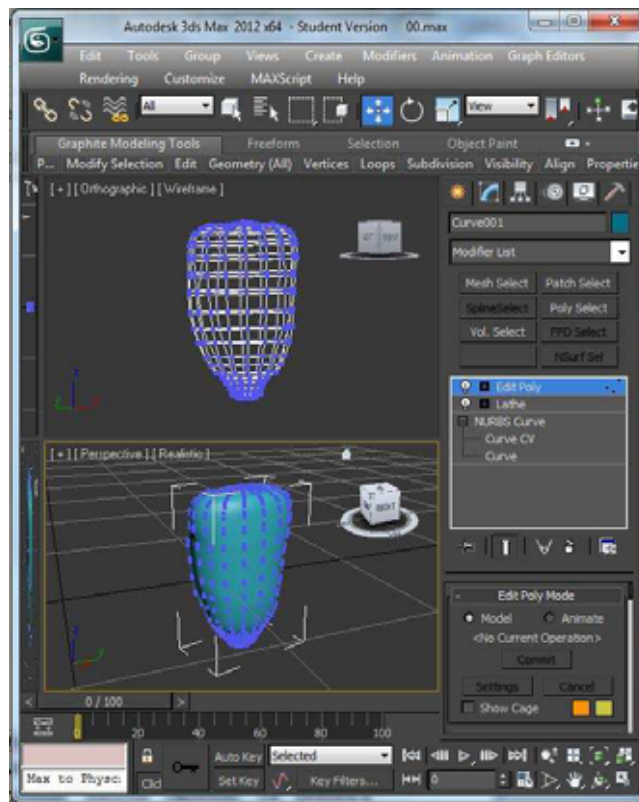
Fig. 4. Edit Poly modifier
Rys. 4. Modyfikator Edit Poly
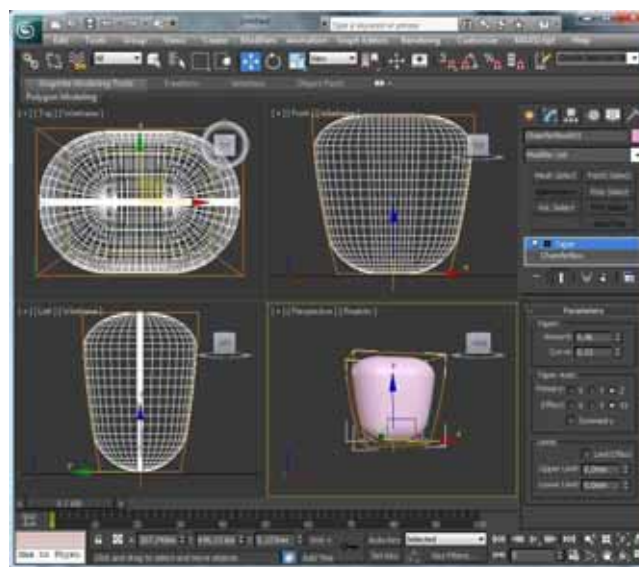
Fig. 5. Taper modifier
Rys. 5. Modyfikator Taper

As in the case of the model developed with the use of the NURBS curves we imposed the *Edit Poly* modifier (Fig. 6).
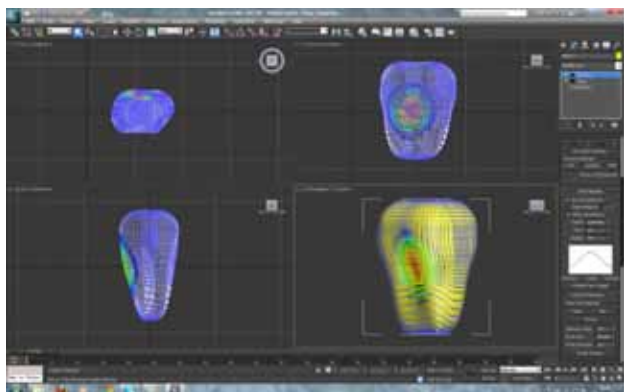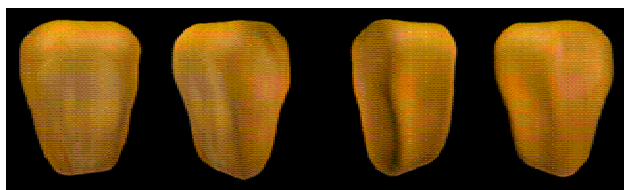

Source: own study / Źródło: opracowanie własne

Fig. 6. Edit Poly modifier
Rys. 6. Modyfikator Edit Poly

Application of materials – now the model can be covered with a color surface selected from a sample palette available in the program or by a previously prepared texture. In the case of the model of a corn kernel the texture was created from a high resolution photograph of a modeled kernel with the use of Adobe Photoshop CS2, and then applied to the model of the corn kernel in a realistic manner.

The effect of the imposition of texture is presented in Fig. 7, and the model is shown in different positions.

Source: own study / Źródło: opracowanie własne

Fig. 7. Effect of the texture imposition
Rys. 7. Efekt nałożenia tekstury

After completing the model an illumination was imposed, and an animated camera was introduced, in order to view exactly the corn kernel from any angle due to the constant movement of the model.

Rendering, as the process of transforming the computer appearance of a project into the appearance close to reality, improved the corn kernel modeling result, taking into consideration the details. Rendering is also necessary in creating visualization of the whole project, when individually rendered frames, progressive scans are saved in .avi file and pieced together in a video editor.

4. Conclusions

The geometry model of an agri-food product constitutes a significant part of a mathematical model used to simulate heating, cooling, drying and re-wetting operations in agri-food processing. Two approaches to geometry modeling of complex biomaterials were developed and implemented to represent geometry of any agri-food product, and the approaches were exemplified by modeling geometry of corn kernels. Appropriate software packages were developed to support the procedures, and the software was used to model and visualize corn kernels. The resulting models, both the isoparametric finite elements model, and the 3ds Max model, fulfilled the requirements of having geometric shape and dimensions similar to realistic products, and thus they can be used to improve temperature and moisture content predictions in examined products subjected to heat and water transport in agri-food industrial processing. It is only then that effects of various approximated geometry representations on accuracy of temperature and moisture content predictions can be estimated.

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