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ZASTOSOWANIE MODELI SIECIOWYCH W DRUKARKACH 3D

Streszczenie: Na podstawie analizy metody siatki wielokątów, podkreślono znaczenie użycia modeli gridowych (siatkowych) w drukarkach 3D. Analiza wielu alternatywnych metod, pozwala na wyciągnięcie wniosku, że to zagadnienie jest przedmiotem badań mających na celu podniesie jakości trójwymiarowych obrazów obiektów rzeczywistych. Poprawę jakości można uzyskać poprzez efektywne metody kompresji oraz kodowania obrazów video (sekwencji video) bez wzrostu ilości przesyłanych informacji gdy używa się modeli sieciowych dla drukarek 3D. Zaimplementowano wybrane programy do modelowania obiektów trójwymiarowych. Programy te mają różne konfiguracje dla wygenerowanych zbiorów, a zbiory/pliki (reprezentujące realny obiekt) mają różną zawartość. Opracowano tzw. standard MPEG-7, w którym można modelować/zapisywać obiektowo-zorientowane oraz iteracyjne sceny/obrazy dla poszczególnych obiektów, w oparciu o metodę siatek wielokątów.

Słowa kluczowe: drukarka 3D, metoda sieci wielokątów; obraz o wielkim rozmiarze, transformacja spektralna

USE OF NETWORK MODELS FOR 3D PRINTERS

Abstract: As a result of analysis of polygonal-net methods, the relevance of using grid models for 3D printers was determined. In turn, the analysis of methods has become one of the powerful directions in the study of the quality of three-dimensional images using effective compression and encoding methods of video sequences without increasing the amount of information transmitted when using network models for 3D printers. Implementing 3D printing programs is based on the models of three-dimensional objects. They not only have different configurations for constructing files, but also they are not the same in content. Moreover, the MPEG-7 standard has been developed, which provides object-oriented and iterative scenes from individual objects. This option provides polygonal-net methods.

Keywords: 3D printer, polygonal-net method; bulk image, spectral transformation

1. Introduction

Almost every model not prepared for 3D printing has to be prepared, and for this it is necessary to imagine how this 3D printing works. Implementing 3D printing programs means that we work with models of three-dimensional objects. They not only have

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different configurations for constructing files, but they are not the same in content. Models of volume objects are divided into two types of solid and surface. A solid object (Solid) is a vector model that describes a body completely using mathematical vectors. In it, each point has values (coordinates, weight, color, any other properties). Since the properties and coordinates are described using vectors, such an object has infinite detailing and a surface object (Mesh) is a model described by a “grid”. Mathematical vectors described only the "thread" of the grid, surrounding the surface of the object. The network has a step between the threads that determine the accuracy of the description of the properties of the model and its parts. Solid-state models contain a lot of information that requires a large amount of resources. Surface objects are much smaller in volume, but the accuracy of the display of their properties is limited by the grid parameters.

Some industrial printers, as well as complex CNC machines, “know how” to work with solid state arrays. However, all mass household and industrial printers are suitable only for work with surface (network) models.

Definitions that we need for grid models. Slicer is a program for translating a 3D model into a control code for a 3D printer (there are plenty commercial application to choose from: Kisslacer, Slic3r, Skineforge, etc.). It is necessary because the printer will not be able to eat immediately the 3D model. The model is cut (slipped) in layers. Each layer consists of a perimeter and / or fill. A model may have a different percentage of filling with a fill; there may also be no fill (hollow model). On each layer, displacements occur along the XY axes with the application of molten plastic. After printing one layer, the Z axis moves to a layer above, the next layer is printed, and so on. Intersecting faces and edges can lead to funny slice artifacts. Therefore, if the model consists of several objects, then they must be reduced to one.

The technology of printing by the method of layer-by-layer welding (FDM) has become widespread among individual users and small companies due to its wide capabilities, relative simplicity and good affordability.

The printing process consists of a number of steps: Creating or importing a digital three-dimensional model; digital model processing for printing with the addition of supporting structures; location and orientation of the digital model on the desktop; Slicing - cutting the digital model into separate layers with data conversion into instructions for the printer, called G-code; directly printing.

Polygonal-net methods of processing 3D objects began to apply in the XXI century. In other areas as a scientific direction are used from the 60's. In a short time, these methods have become one of the most powerful areas for reaching the quality of three-dimensional images in television production by using effective compression and encoding methods of video sequences without increasing the amount of transmitted information.

Polygonal - grid models are now beginning to be widely used for the representation of television objects of three - dimensional images in television production and post production. They are also used in computer-aided design, computer games, simulators, systems of virtual reality, in various fields of science and technology: mathematics, physics, medical research and geographic information systems in surface modeling and spatial problems.

At present, one of the topical problems in modern bulk television is the improvement of polygonal-net methods for creating and transmitting three-dimensional images.

Networking methods are laid down in MPEG-4 and MPEG-7 standards. Stereo TV requires 2 to 64 cameras to create bulky images and special glasses for viewing, which causes difficulties in setting up the system and in a comfortable viewing [1]. Networks require significant software costs, but are more acceptable for a comfortable and high-quality viewing. Moreover, the MPEG-7 standard has been developed which involves object-oriented and iterative scenes from individual objects, this option provides polygonal-net methods.

The development of methods for the transmission and exchange of television images created from three-dimensional network objects includes several areas, including, on the basis of a wavelet-progressive grid, into which a grid with a non-equidistant step is converted, and which is used to compress wavelet vectors in hierarchical coding.

The complexity of solving this problem is that the process of describing and restoring grid images is time-consuming, and thus it is necessary to restore the image with high accuracy.

The quality of three-dimensional polygonal-grid images is influenced by the important characteristics of the process of their visualization. One of the important characteristics is the signal-to-noise ratio and measurement error of the three-dimensional coordinates on which the image is rendered.

Classical spectral transformations of real three-dimensional grid images, which regularization is based on the Fourier transformation, can lead to inadmissible errors in images when they are transmitted over the communication channel with noise.

In this paper, we consider methods that improve the algorithms for the creation, transmission and restoration of polygonal networks with different resolution in television systems in order to improve the quality of television images. The basis of these studies is the spectral transformations of three-dimensional signals.

1.1. Development of the construction of three-dimensional objects

The development of the construction of three-dimensional objects in the television - the methods of describing surfaces and the process of creating three-dimensional objects based on polygons and nets are analyzed.

Based on the analysis of other works on the visualization of three-dimensional images, it was concluded that the polygons have a feature in the scaling of objects, and also have a small amount of data memory for describing simple geometric surfaces. It should be noted that it is necessary to calculate only the coordinates of the vertices, providing the required speed for the transmission of the video sequence.

The nets, in turn, also have features - they approximate the boundaries of the finite regions of the object to the smooth boundaries that describe the surface with simple geometric shapes, as well as provide an opportunity to quickly recognize the height of any point of the surfaces by simple interpolation.

In turn, comparing the methods of describing a three-dimensional object and considering which grid they are presented, it is necessary to pay attention to the importance and feature of the method in which there is a breakdown of the object into smaller details with great accuracy of restoration. The greater the density of the object being studied, the smaller the sampling rate of the grid (triangles).

Taking into account all the drawbacks of methods, we obtain the method of constructing a grid object with a non-equidistant step. And the main advantages of this method are less resource-consuming costs, high accuracy of the object's display,

as well as the receipt of a template in the template, namely, the object in the form of simple figures can be constructed in an order of magnitude faster than the object described using iterative and direct methods that are used in the study of complex images.
In turn, the polygonal-net method was further developed, which allows to keep the scale of triangulated objects in transition from a grid with an equidistant step to a grid with non-equidistant step. The method of interpolation on an equidistant mesh allows to improve the quality of a three-dimensional image with varying detail in one object, used in television production and the study of magnetic resonance imaging and 3D printers.
For the analysis of network methods for the construction of bulk images, it is necessary to conduct a comparative analysis of algorithms that visualize a given surface by approximating it with triangles.
When solving the problem of visualization of television objects, an important role plays the role of a function of a function that describes the desired surface, using the function of three arguments and the fixed value of this function - the level c represented by the formula (1)

$$\{(x, y, z) \ | f(x, y, z) = c\} \tag{1}$$

where *f (x, y, z)* is a given function, and *c* is a given level.

The set of points satisfying formula (1) is the desired surface of the object. However, it is not convenient to restore the surface itself, but the surface, which approximates the desired using triangles.
The stage of obtaining the initial triangulation of the surface is most important for surface imaging in television, since the end user needs the maximum accuracy of the image.

2. Visualization of three-dimensional objects

Visualization of three-dimensional objects in modern systems of television and 3D printers passes through a series of stages: - Obtaining the initial triangulation of the surface; - Simplification of triangulation if necessary; - Reorder triangles to form subbands to accelerate the data transfer process; - Construction of new vertices by means of interpolation or decimation to provide different levels of detail and compact data storage; - Compression data; - Visualization.
Non-manifold geometry - non-manifold 3D-model is a prerequisite for 3D printing. The essence of this concept lies in the fact that each edge of a 3D model must have exactly two faces.
The following errors are usually included in this concept: mesh with holes - the problem of “unclosed” polygonal mesh. Remember the basic rule of 3D modeling: your model must be "waterproof" or "airtight." If a hole is formed, it means that some edge lacks one face, therefore the model is non-manifold, which means it is not suitable for 3D printing. Another program that is widely used by Autodesk is MeshMixer. Most people who work in the field of ZD printing are clearly already familiar with Meshmixer, since this is one of the most popular STL file checking

programs. Meshmixer allow users to view, improve and correct their 3D models to as well as ensure that they are suitable for high-quality 3D printing. Also, Meshmixer is a powerful tool for designing and creating 3D models from scratch using triangles.
A comparative analysis of algorithms for constructing volumetric real objects with the help of various triangulation methods related to network methods is carried out - the method of "Marshiding Cubes"; method proposed by Guzesk (MT6); Canyear method; The method of Rock (Skala) according to the following criteria: speed; approximation error; number of generated triangles; "Quality" of the generated triangles.
In all the proposed network methods, the speed and error of approximation differ insignificantly. Therefore, it is enough to compare them in two parameters: the number of triangles and their "quality".
The vector of "quality" of triangles (SNF) is defined as follows:

$$SNF = \{a_1, a_2, ...a_{10}\}, \quad a_i \in [0, N], \quad \sum_i a_i = N$$

Numerous data confirm that network methods with non-equidistant step are actual in modern volume television, therefore, they allow to improve the quality of three-dimensional objects with less detail and better "quality" of triangles compared to a uniform grid.
Thus, it is shown that the grids described above can be successfully used when visualizing video images in three-dimensional areas, considering that triangulation algorithms are an integral part of almost all advanced binary object visualization software products [2].

Table 1. Results of comparison of grid algorithms with non-equidistant step

Explored object		Sphere	Thor	Plane
Results of comparison of grid algorithms with grid with non-equidistant step				
Number of triangles	Algorithm of the Rock	15000	13000	2000
	MT6 algorithm	10000	8000	1200
	Canyour algorithm	6000	6000	1200
	Algorithm "MK"	2500	1800	1200
"Quality" of the triangles	Algorithm of the Rock	0,52	0,52	0,5
	MT6 algorithm	0,48	0,48	0,5
	Canyour algorithm	0,52	0,52	0,5
	Algorithm "MK"	0,53	0,55	0,5

Consequently, for the construction of complex bulk objects, a grid with a non-equidistant step is used, which allows detailed objects with a higher accuracy.

3. Investigation of Wavelet transforms of network three-dimensional objects

The images described by the triangulation grid allow you to accurately describe the shape of the object for the sight of the eye, but in the literature, many algorithms require that triangles be small enough, and in our case we use a grid with a non-equidistant step. So, to simplify the triangulation, we use the detail of the triangulation.
The experiment was used to select the Spider object (Fig. 1) described by the grid. The study of the transition to a non-equidistant mesh with the help [3] of wavelet transformations with different sampling steps with the normalized values: 0,1; 0.3; 0.5; 0.7; 0.9, which satisfy the Kotelnikov theorem.

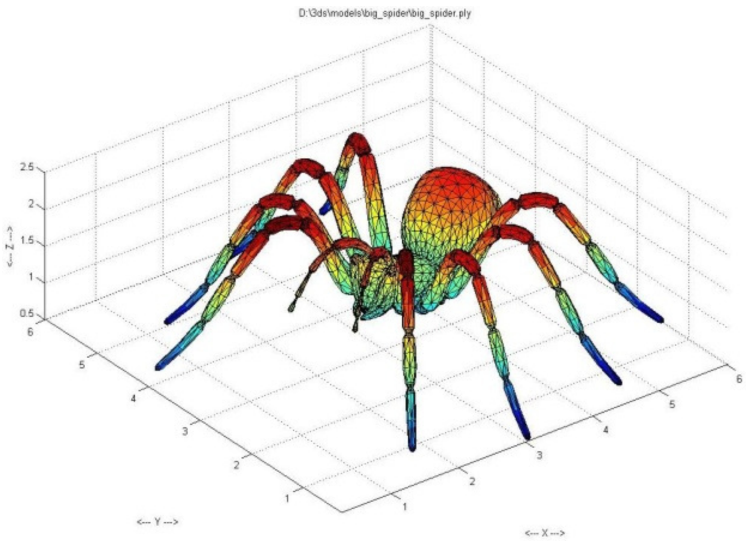

Figure 1. Big spider is described by 9286 triangles

Also in the study the threshold of acceptable error was chosen, where we choose the optimum normalized value of sampling step 0,3. From the selected threshold, one can conclude that the errors in the Wavelet-transformation of Dobeches of the 4th order and the Haar transform are more effective than in Dobechish's 6th order for several orders of magnitude, which also allows to increase the speed of visualization algorithms of three-dimensional objects with high accuracy of reconstruction with order their connection with the non-equidistant description step.

3.1. Hierarchical spectral transformation of objects

The use of hierarchical spectral transformation at selected thresholds allows to increase the speed of restored network objects obtained on the basis of the triangulation of Delone, which allows them to be used in television reproduction devices.
In order to reduce the computational complexity of the polygonal-net model, a transition to the spectral region is proposed, by splitting the object into subband areas,

followed by filtration using wavelet transformations. Consider the three-dimensional Object (Fig. 2) containing 1258 vertices and 3774 coordinates. Above the given object was deformation - a rotation around an arbitrary axis relative to the center of coordinates. To increase the processing speed of the real object, wavelet transforms such as Daubechies 4 were used. When Daubechies 4 is used, the output coefficients of decomposition are obtained - coefficients of approximation *by X, by Y, by Z*; - Coefficients of decomposition horizontally in *X, Y*, in *Z*; - Coefficients of decomposition vertically along *X, Y, Z*; - Coefficients of decomposition diagonally *by X, Y, Z.* To increase the speed of the algorithm, it is necessary to filter out insignificant coefficients (which do not actually affect the recovery of the object). Determine this threshold analytically, while getting the depth of wavelet transform $n = \log_2(\max(C_{i,j}))$ where $C_{i,j} \geq 2^n$ - this is the given threshold. Consequently, those coefficients that satisfy the threshold remain, and the rest are zeroed.

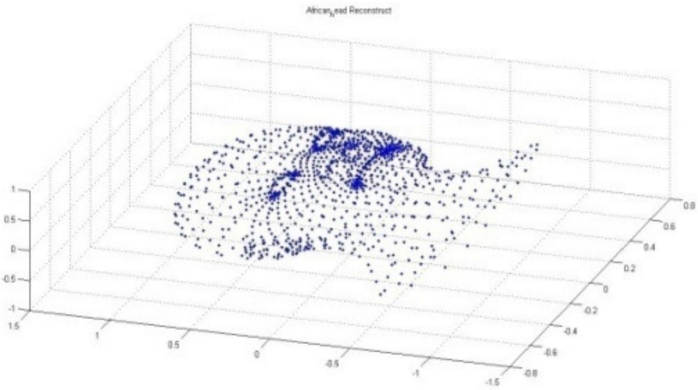

Figure 2. Recovered Facial Object

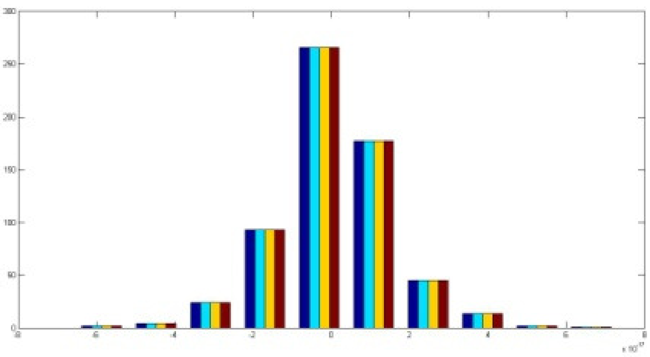

Figure 3. Graph of statistical distribution of elements of a three-dimensional image

When constructing histograms (Fig. 3) after the removal of insignificant coefficients of an image with different decomposition factors, it can be seen that changes in the brightness and quality of the image are insignificant and not noticeable to observers.

The histogram is a graph of the statistical distribution of elements of a three-dimensional image, in which the horizontal axis represents the probability of the elements falling into the array, and vertically - the number of elements of the image.
During the study, the samples of instantaneous values of the coordinates of the object were obtained, which show how the lengths of the object vectors are distributed over three coordinates.
In the case of backward wavelet transformation, all coefficients of decomposition, including zeroing, are taken into account, the number of elements of the restored object coincides with the initial data.
The calculation of the signal-to-noise ratio is carried out according to the formula:

$$PSNR = \frac{mn * \max_{W,H}(I_{W,N})^2}{\sum_{W,N}(I_{W,N} - K_{W,N})^2} \tag{3}$$

where *m, n* - image size;
$I_{W,N}$ - pixel value of the original image;
$K_{W,N}$ - Image pixel value after adding noise.

When transferring digital images it is extremely necessary to provide high quality image reproduction for the viewer. In DSTU 55696-2013 digital speech television. This standard stipulates that the value of the signal-to-noise ratio should not be below 35dB for comfortable viewing by the viewer. Therefore, for this study, the 35dB signal / noise ratio was taken as the minimum allowable for relatively comfortable viewing, the higher the signal / noise ratio, the better the image quality.
To study the transfer rate of selected 3D objects, we use two 4: 2: 2 and 4: 4: 4 sampling structures. The transfer rate for the selected structures 4: 2: 2 (2) and 4: 4: 4 (3), and with different parameters of the objects under study, are as follows

$$V_p = R * 2 * W * H * F \tag{4}$$

$$V_p = R * 3 * W * H * F \tag{5}$$

where *Vp* - the rate of data transfer of the object, bit / s;
W and *H* - the width and height of the frame in pixels;
R - bit for each component, bit;
F - frame rate, frames / sec.

Since we are exploring 3D objects, we need to move from a three-dimensional two-dimensional space. Coordinates in two-dimensional space are as follows:

$$X_c = x + k_x \times z \tag{6}$$

$$Y_c = y + k_y \times z \tag{7}$$

where *Xc* and *Yc* are coordinates on the plane;
x, y, z - coordinates in 3D space;
kx, ky - coefficients of depth projection, which are taken modulo and do not exceed the value of one. The coefficients are taken as 0.5.

In the transition from three-dimensional space into two-dimensional one, we should take into account the fact that used decimation of coordinates and clipping vertices of the object. This allows you to recover an object in two-dimensional space with high definition. Accordingly, the width and height of the frame of the investigated object are calculated by the formulas (6) and (7) as follows:

$$W = X_{\max} - X_{\min} \tag{8}$$

$$H = Y_{\max} - Y_{\min} \tag{9}$$

where X_{max} and Y_{max} are the maximum number of decomposition elements in two-dimensional space along the X and Y axes.
X_{min} and Y_{min} are the minimum number of expansion elements in two-dimensional space along the X and Y axes.
To study the speed of a digital stream from a three-dimensional object, we use the direct and inverse light transformations of the Daubechies 4th order, and we set the chosen threshold of the S / N ratio to 35dB.
It is shown that with a change in the flow of data allows for conducting of a spectral wavelet transform.
If you see small values of wavelet frequency, you can do it 5 times at a time when the number of images is presented to the signal / noise ratio of 32 dB - a virtual result of the display is acceptable and the distance is up to you. At the below view, the wavelet-type waveform is located at the two-dimensional space, where you can see the coordinates of the vertices of the site along the cob and the breeze type. For these which are, lower than 35 dB, it is not necessary to identify security requirements.
The numerical results on the speed of the digital stream and the compression coefficients of the three-dimensional network objects, the ratio of the signal / noise from the angle of rotation to the center of the coordinates of the object of the three-dimensional grid image after the spectral transformations and the allowable errors of the coordinates of the three-dimensional grid objects with the ordinal and interlacing scans, allow us to predict the quality of the image by the values of the ratio of signal / noise.

4. Final remarks

In conclusion, we note that at the selected error threshold we select the optimal normalized value of the sampling step of 0.3. From the chosen threshold, one can conclude that the errors in the Wavelet-transformation of the Doveeshi 4-th order and the Haar's transformation are more than in the Dobechy 6th order for several orders of magnitude, which also allows to increase the speed of the visualization algorithms of three-dimensional objects with high accuracy of restoration.
The implementation of complex bulky surfaces in the form of a grid, which consists of the coordinates of the vertices of this object and the order of their connection with the non-equidistant step of the description, is presented. Increasing the detail of three-dimensional images is achieved by reducing the sampling rate of the grid in complex areas, which, in general, indicates an efficient storage and rapid synthesis of three-dimensional objects.

The analysis shows the data on the speed of the digital stream for two real network objects, but it is possible to analyze the greater number of network real objects with a given signal-to-noise ratio of 35 dB, which allows them to be restored with high clarity and quality.
Moreover in conclusion, it can be noted that the creation of digital 3D models itself is not part of the 3D printing process. Common models of automated design ("CAD" or "CAD") are used to create models, including such 3D editors as SolidWorks, AutoCad and LightWave among many.
For the study, a universal 3D printing method was developed for three-dimensional data arrays obtained in digital form using various research methods. The proposed technique is based on converting data into a set of voxels, from which information on the mixing of various materials in print is then extracted. First, a three-dimensional image frame is built — the data is represented as a set of dots of various colors — which, based on information about the resolution of the printer, is divided into several layers of a certain size.
Then each pixel in each layer is assigned information about the "color" corresponding to a particular material, which is then converted into data on the ratio of this "ink" when mixed for each voxel. At the last stage, for each layer, the dithering technique is used - adding pseudo-random noise to the image to increase the color depth and preserve image details when using a limited palette.

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