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RESEARCH OF PRODUCTION TECHNOLOGIES OF PHYSICAL OBJECTS PROTOTYPES BASED ON VIRTUAL 3D MODEL USING 3D PRINTING

Розглянуто теоретичні та практичні проблеми побудови тривимірних моделей реальних об'єктів і наведено оригінальне розв'язання науково-технічної задачі вдосконалення доступної технології тривимірного сканування.

Ключові слова: 3D технології, безконтактне сканування, віртуальна модель

This paper reviews theoretical and practical problems of constructing three-dimensional models of real objects and shows the original solution of scientific and technical problem of improving the available three-dimensional scanning technology.

Key words: 3D technologies, noncontact scanning, virtual model

Introduction

The modern world is impossible without information technologies. They get deeper and deeper in our life, covering more and more sciences such as computer science and IT, math, physics, and are used in education, business and entertainment.

Information society needs the latest developments, as alternative to last century. 3D-technologies help to cope with this. Three-dimensional printing technology is still exotic not only for Ukraine but also for many other countries. However, experts assure that adaptation to these devices will occur very quickly. Moreover, today 3D printers are widely used in medicine, aviation, space building and even food industry. This is an extremely promising technology which is increasingly growing. Over time, 3D printers will be in every home, performing various tasks.

Printing requires a model, and today there are many ways to get it. But the most popular among them are manual modeling of objects in the program-editors and scanning the necessary objects using 3D scanner with further processing in the same editors. In different times different ways were dominated. It depended on the appearance of new technologies of digitization, visualization algorithms, new software which allows to process 3D objects easier and more efficient.

Now we can say that scanning and modeling are equally popular, but this equality is gradually reducing, due to continuous improvement of technologies of three-dimensional scanning. Also demand of three-dimensional printers and introduction of 3D technology into movies, television and video games contributed to spreading of 3D scanning. In addition, the average user does not have skills of 3D modeling; theoretical and practical knowledge base and experience are needed for this. Therefore, to facilitate the task and saving time you can use the method of scanning three-dimensional objects. The only problem is that the creation of high-quality 3D model requires professional 3D scanners, which are quite expensive. But simple and budget analogue of 3D scanner can be created. Using this kind of creating three-dimensional models you cannot expect a very high quality and accuracy, but if the details are not critically needed, then 3D scanning can become a budget solution. It is important to pay attention to specifications and compliance of scanner components, and to control all important factors for maximum improvement of quality of the scanned model and successful prototyping [1].

The main task of the paper was investigation of the 3D printing technologies and available methods of manufacturing of computer 3D models of real objects. Using results of previous researches, one method of prototypes manufacturing was implemented and a physical object was further received using

3D printing. Using data of research, conclusions were made regarding to the optimal technical characteristics of the components of the scanner and the environment, which make scanning process as qualitative as possible.

3D technologies as a part of modern scientific and technological progress in the world and in Ukraine

3D printing is a technology of additive manufacturing that transforms virtual three-dimensional model to its physical copy. Using different materials and printing techniques, high-quality prototype can be obtained. Printing process starts from passing the prepared model to a specialized program called Slicers. In this program, the object is literally cut to layers, which are overlapped each other using a specific material that melts or softens. After material hardens, we get ready real three-dimensional model. This process distinguishes 3D printing among traditional mechanical treatment techniques, most of which are based on the removal of material by cutting down or drilling (subtractive process). The most popular material is plastic (PLA, ABS). It is the most convenient for use and the cheapest. Also metal, photopolymer, nylon and other materials that may be in liquid or solid state can be used. Even living cells, for example epithelium and bone matter, and foods like chocolate can be used now. There are many 3D printing technologies. They differ in possibilities to use materials, dimensions, print quality, and automation process.

3D printing is a future. Nowadays this technology is not developed enough and does not allow to typical user to print a preferred object just by pressing a button. A preliminary preparation and processing of images, which requires skills and knowledge of 3D modeling, is an important and often time-consuming process.

3D modeling is the process of manual creating of three-dimensional mathematical model of scene and objects in it by using specialized software. 3D model could be represented as a program code or displayed on the screen as well as by using two-dimensional image created by rendering (visualization), in other words there is going on construction of a projection according to the chosen physical model. After that the resulting image can be displayed on output device – a printer or a display. 3D models are built as a set of points in 3D space, connected by various geometric objects as triangles, lines and so on. The model allows to precisely present shape, size, texture of the object, evaluate its look and ergonomics.

There are many applications for three-dimensional modeling and editing, using which 3D models of any accuracy and with any characteristics can be created. The modeling of complex structures requires training and practice, but during last few years a lot of simple, easy-to-use programs were created. They are all suitable for modeling and for further 3D printing. Typically, programs include function of preparation model for printing or there are plugins that allow you to perform this task. Before embark to modeling phase in this work, I did review of some 3D modeling software to choose the most appropriate. According to the site i.Materialise, the most popular 3D Editor is a program Blender [2]. This free open source software that runs on Windows, Mac and Linux has plenty of fans due to professional developer team, competing with major commercial analogs [3]. This program can function even on the computers with very weak configurations up to netbooks. However, there are some drawbacks, for example, its overloaded interface and its constant work with keyboard shortcuts [4].

All of the most popular programs have their advantages and disadvantages. It is also worth to mention such programs as 3Ds Max, Maya, ZBrush. They are good for creating models for further submission on 3D printing.

The editor of 3D Studio Max is oriented on architectural visualization, there are a large number of tools that are necessary for modeling a variety of architectural projects, beginning with pieces of doors and windows and ending with different forms of vegetation, stairs and railings.

With all of its complexity, the 3Ds Max is easy to study and the lack of any specific tool offsets the large base of additions called plugins that greatly extend the standard capabilities of the program [4].

Maya is used for a work not only by lovers of three-dimensional graphics modeling but also professional companies such as DreamWorks, Pixar, Walt Disney and this is not the end of the list of the supporters of this editor. This program is needed thanks to the ability to implement all the stages of 3D creation. In addition to this, it copes with preparing models for printing and exporting models.

ZBrush is the program for digital painting and design. It has 30 original brushes to paint and models are created by making a 3D-mesh. Then the brush is used to add volume and texture. ZBrush models can be extremely detailed but there are free plugins that allow to convert them into resolution which is suitable for using it on a consumer 3D printer. There are a lot of available resources for learning ZBrush that are helpful at the beginning of the work, including the official site [3].

The SolidWorks program has problems with importing of STL files (files for the submission to the 3D printer). As a result, it is better to use another program for editing of the loaded model.

A 3D scanning is another way to fix physical objects. With the help of this technology you can digitize real-word objects and create their virtual copies. The 3D scanner analyzes the information and collects data about the shape and, if it is possible, the color of the object. These scanners can be created by using different technologies. It usually depends on the purpose of the scanner, the physical properties of the scanned object and requirements for the initial model. The essence of the scanning technology is to determine the spatial coordinates of the object and to create a cloud of such points. The process is implemented by measuring the distance to all the points that are determined with the help of the phase or pulse laser rangefinder reflectionless. The measurements are carried out with a very high speed – thousands, hundreds of thousands, and sometimes millions of measurements per second [5, 6].

Creating of virtual model be means of 3D noncontact scanning and creating its prototype by means of 3D printing

The method of noncontact scanning was chosen to do a job. The noncontact scanners have two types of scanning: active and passive. Passive scanners use available light reflection in the visible range of the spectrum. Then the analysis is carried out on the basis of its reflection from the object. Active 3D scanner has the ability to generate its wave signal which can be directed light, laser, sound, infrared. The principle of this method is based on the measuring of the distance from the scanner to the scanned points of the object using the method of triangulation. Emitter and detector (camera) are located at different levels and the beam is projected on a certain angle to the detector. Thus, a triangle appears, which bases on the emitter and the camera, and the top is a point on the surface of the object. After the reflection offsets from this point, which is formed on the sensor of the camera, we can calculate the angle between projected and reflected beams, knowing the angle and the length of the basis, the distance to the point of the object can be calculated.

The main software was DAVID Laserscanner, which allows to scan and to digitize background objects using manual laser module, calibration angle and camera. The program generates 3D data in the real time and displays them on a computer screen. There are different versions of the program, which are suitable for different scanning technologies. There is a ready package DAVID Laserscanner Starter Kit, which includes calibration sheets in four sizes, panel mount sheets, webcam Logitech C615 with a high-resolution, stand for the camera, a red laser (650 nm) with a variable focus and battery. Also, a necessary software is included [7]. Due to this set the high-quality scanned model can be created. However, the cost of this package is very high now. Separate acquisition of this program (current – DAVID-4-PRO) will cost less, but the free version also exists. It differs from the professional program by its restriction on resolution of model saving.

Stages of creating virtual model by means of 3D noncontact scanning and creating its prototype by means of 3D printing:

1. Preparing an object for scanning. The technologies of scanning have their limitations. These limitations usually refer to the scanning objects, since optical technologies do not support the processing of transparent, mirror and shiny objects. This is because the wave (in this case, the laser line) needs to bounce off the object, so that the camera could capture it, process the information about the distance and build an object on the computer. Therefore, the object should be analyzed before being scanned. If it contains unsuitable parts for scanning, they can be covered, for example, by matte paint. If the object is very dark or black, the same step should be taken.

2. Calibration of the camera. Calibration of the camera happen when the special calibration sheets are used, which are located at 90 degrees to each other. The type of sheets depends on the software used for scanning. I use DAVID Laserscanner 3.4.0.3008, and templates of the calibration surfaces in A3 and A4 in PDF file format and CDR are submitted together with program and are ready to print. The format of

sheets are selected depending on the size of a scanning object. The height of a scanning object should be by 1,5–2 times less than the height of the calibration angle.

The A4 format sheet had been chosen and, beforehand prepared wooden panels that are joined at the right angle, were placed on the sheet. The angle of 90 degrees is required to correct refractive of the laser line projected on the object which is placed before the angle. In addition to this, you should observe the printed sheets to remain smooth and straight, so that the surface should be gloss and unnecessary obstacles to scan should not be created.

The camera should capture the calibration markers and they should be clearly visible during the calibration process. If this process is not successful the camera settings window can be switched and then exposure, brightness, light, aperture settings, etc. can be changed.

The length of the Scale line is indicated on sheets which should be measured. Then this value should be entered into the program. If the calibration process runs successfully, the program will give a «Calibration successful» message and markers will be indicated with green cross (Fig. 1). It is important not to change the position of the camera after the calibration process.
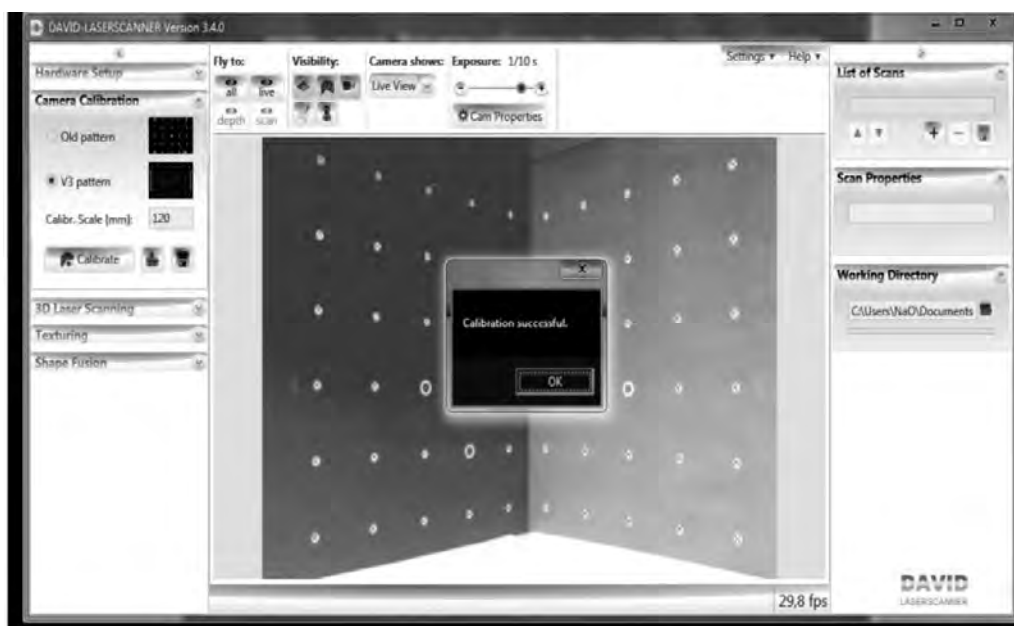

Fig. 1. Notification about the successful calibration proceeding

3. Scanning the object. To scan by chosen method is used laser module which contemplate not dot, but a line. Were used 2 red lasers: one is bought for 8$ and one is own created using a laser pointer and the power sweep. Power sweep – it is optical lense, which is glass cylinder on which gets beam of laser under angle 90 degrees and refract it, so creating a line. If necessary, angle of refract is able to count depending on diameter of lense.

As a detector of device , that is calibrated and records the reflection of the laser, used webcam Logitech C270 with autofocus. Resolution matrix – 3mP. Type of matrix – CMOS. Framerate video – 30 frames per second. Interface – USB 2.0.

When scanning camera image must be very dark. For this it is necessary to minimize light in the environment scan and change your camera settings so that one could see only a laser line.

Locate object , so that it was in the corner before calibration sheets. Around object must remain blocked calibration markers. If necessary, the object can be placed on a stand, preferably black ,to light is absorbed and not reflected, thereby transferring unnecessary data.

When the scanning process is started and the camera captures the data, we see objects in different colors (Fig. 2). This – the depth map. As you know, the wavelength of the visible spectrum is the biggest red and purple – the lowest. There object is painted on the same principle: the part that is closest to the camera – purple following – red. Other colors have intermediate values.

Fig. 2. The camera image while scanning mode maps depths

Scanning the object should be carried out in different areas of the review. That is, treating one side of an object should save the resulting image, rotate the object and start scanning again. The more scanned sides – the better to create a future model. Scanned parties should overlap each other parts. That is, each subsequent scan should seize a part of the previous scan. This is required for the next stage of sticking together of model.

The angle between the laser light plane and the camera must not be too small, otherwise the refractive line will be insufficient and the program will give a message: Intersection angle too low . There are other error messages in the program : Laser line not detected (too short / too weak?) – When the laser line is either too short or too thin or missing altogether. In this case it is necessary to check the serviceability of the laser, if possible, adjust its width and length or replace on laser which meets the requirements.

Laser line not detected on the left (right) side – if laser line is not different on the left (right) side of the angle calibration. That is, the laser line moved aside so that it can not be seen on both sides of the line or the line is contemplated not horizontal but with a turn. It can also mean that the object overlaps calibration markers left (right) and the camera can not capture laser. Therefore, it is necessary to pay attention to it and to control the scanning process.

4. Leveling and merge scanned parts for the full model. Alignment of scans – a process of substitution scanned parts to the appropriate place for them to then combine them into a single model. For this process used programs DAVID Laserscanner and Meshlab. Meshlab – a program for processing unstructured three-dimensional shapes. The system focuses on the processing of three-dimensional models obtained by 3D scanning and has tools for editing, cleaning, correction, validation, transformation and rendering processed model in the required format.

The program DAVID Laserscanner done cleaning + scans from large unnecessary elements and automatic leveling means and scans that program alone was not able to process, manually aligned in Meshlab. In DAVID Laserscanner also have the option of manual substitution, but it is designed for full manual control, and in the Meshlab you can align scans on the junction points (Fig. 3). Choosing already located in place part of the model and add to it another, noting the main points of the places that match. Thus increasing the probability of a correct substitution.

Fig. 3. Connection of scans on the junction points in Meshlab

Pasting of model implemented in the program DAVID Laserscanner with button "Fuse". The program merges aligned parts into a three-dimensional model ,interpolated places with discontinuities or abrupt transitions.

Then the model is exported in OBJ format and moves to the next stage – editing. Further editing model you could hold in Meshlab, but there is only a basic set of features that are not always suitable for the successful processing of model.

5. Processing, "cleansing" of model. In almost all cases, after scanning and pasting model requires the stage of processing. At this point you can fix holes, smooth the surface, simplifying the overall structure or eliminate unnecessary elements. All this is done in three-dimensional modeling programs. After analyzing information on existing popular 3D editors above, we can conclude that the choice of software for more functionality does not depend on further 3D printing, but from the individual needs and wishes. To implement the project selected editor Blender, as it is in the public domain. Another plus of Blender is that it is adapted for 3D printing. It has a plug-in model to test suitability for printing and import formats in STL and OBJ. In Blender there are many other plugins and extensions that allow you to configure it more flexibly. In addition, the unit of measurement equal to 1 mm in it, that is $1.00000 = 1$ mm. So 0.0010 – a 1 micron. In fact, the accuracy of the model is limited by printing capabilities of 3D printer.

First imported OBJ-file and set up work space of program. At this stage removes the sharp transitions between the glued parts of the model ,are corrected automatically interpolated holes and visually smoothed the entire surface.

6. Preparing the model for 3D printing. The object cannot be submitted immediately for printing after simulation. Each model, which is submitted to the 3D printer, must pass preliminary preparation [8].

Preparing the model was also done in Blender, using special plugin, the model was exported into the required format. Programs-slicers operate with a file format STL (stereolitography) [1]. So that, you need to save the model for printing only in that format.

7. 3D print. At this stage the model, at first, trained in the program-slicer, where it is divided on layers which form the material during the printing. The program Simplify3D was used for the printing this model.

The printer cannot print only the walls of the model; in this case, the object will be unstable. Therefore, any model must be filled inside. But to fill the entire object with a solid material it is expensive and time consuming. Therefore, for the purpose of saving, in the same slicer create the grid content of the model. Another condition is to support the overhanging parts. In the preparation to the Blender, you can check the available hanging locations and on one's own to arrange the support. But the slicer can calculate and create such designs itself. After printing, these elements are separated from the model itself.

The slicer also calculates the time of printing, the length of thread filling, the cost of the material, the weight of the object.

To print, you can view the division into the layers. The program displays parts of the model with different colors that indicate the print speed of these pieces.
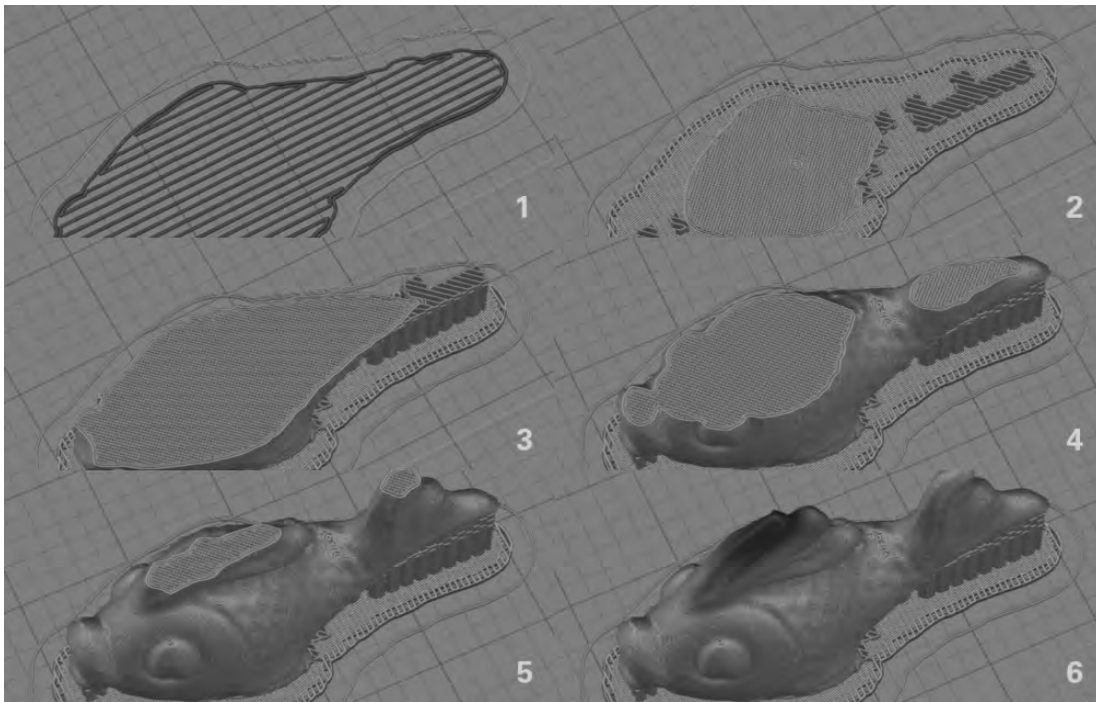
Fig. 4. The layer presentation of the model

The process of 3D printing was carried out by specialists who have experience with 3D printers and have this special hardware. Material – plastic PLA.

Conclusion

The result of the work is a self-developed hardware for three-dimensional scanning, which served as a basis to develop methods of fixing of physical objects with the expectation of further image processing in the software environment of 3D modeling and three-dimensional printing using a 3D printer.

To perform the project on develop a 3D scanner, chosen method of noncontact active laser scanning. This uses linear laser module, which is projected on the object. With the help of special calibration angle (view calibration angle is selected in accordance with the software to scan), calibrates the webcam, which then captures the reflected laser beams and using specialized software DAVID-Laserscanner, which calculates the 3D coordinates of the intersection of the laser plane and the visible rays from the camera, built a copy of a physical object in a virtual three-dimensional model.

On the basis of the conducted research concluded about the optimal technical characteristics of the scanner and the scanning environment. Namely:

– The minimum amount of light in the room during the scan. This is important, especially if you are using not too powerful and so not too bright laser. In order to camera-detector better recognize the projected laser line, it is necessary to give it contrasting conditions to the rest of the image was dark (even black), that is, to minimize the lighting environment.

– Webcam with 640x480 resolution and noise compensation. The required resolution is calculated depending on the size of the object. A 640x480 object is being set so that about covers 300x350 pixels. A pixel is a single 3D dot. In this manner, we get more than 100 thousand 3D dots, moreover only from one side of the object. Therefore, 640x480 is a sufficient resolution for scanning ordinary objects. Actually, the more important characteristic of cameras is the noise compensation.

– Manual focus and a high quality lenses camera. It is also important characteristics. You can use camera with autofocus, but much more convenient when the focus is manual. Then you can set the camera the way that's best for a particular environment. Regarding lenses, you should not use an expensive camera, it is enough to use a glass lenses instead of the plastic ones. This will improve the scan result.

– The laser with the power of 5mW and with the 30° or 60° module, that generates a line. The laser power, as already indicated above, depends on the scanning environment. If the room is not dark enough, the laser should be more powerful. This condition is also required when scanning dark objects (as you know, black does not reflect, and absorb light). Laser scanning, also can perform using laser pointer, that is, its' projection will be in the form of dots. However, to speed up the process, use a laser line instead of a laser dot. It is achieved thanks to the power sweep (cylindrical lens) or mechanical sweep system (the mirror, which turns). The angle of the module depends on the object that is being scanned. In most cases, the angle should not be less than 30 degrees, since the smaller value of the angle, projected line will not be enough to cover the object.

– The laser line should be as thin as possible, especially if the scanning object has small sizes. The thinner the line, the less it makes noises, which prevent a successful scan. Consequently, the surface of the model will be smoother and more detailed. You can also use a laser with the ability to manually increase/decrease the line thickness. However, such lasers are more expensive.

– Sheets for calibration are arranged at an angle of exactly 90° and with clearly printed calibration markers.

– Triangulation angle (the angle of the laser relative to the object) is about 30°. If you scan at a smaller angle, the fracture of the laser line will be too small for recognition of the surface of the scanned object.

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