

# Technologies of 3D-prototyping of Objects

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**Abstract.** The innovative trends of development of 3D modelling and printing technologies have been analysed. The available methods of manufacturing computer 3D models of real objects have been studied. Using the results of the conducted research, the optimal technical characteristics of the component devices and environments have been summed up, provided that the process of creating 3D models is of high quality.

**Keywords:** 3D-technologies, 3D model, photogrammetry.

## 1 Introduction

The modern world is on the verge of scientific progress. Science and technology are developing very fast and every day researchers are demonstrating new discoveries. One of the scientific breakthroughs is the field of 3D technology, the level of progress of which has increased significantly lately.

3D printing technology is already being used in a large number of areas of human activity [1]. For example, medicine has developed the first 3D printers to print orthopedics and surgery items, and new areas of application of these technologies emerge every year, including the organ printing [2]. More often, this technology is being used in industry. For example, the company Boeing already uses 3D printing technology to make and design their engines. Researchers at the University of Southampton were able to produce a drone on a 3D printer. With the emergence of new 3D printer capabilities and the use of a variety of materials, the prospect of using 3D technology is emerging in printing industry as well. For example, today there are attempts to produce stamps for embossing and other technologies. By using 3D printing technology, one can create an alternative to congreve stamping. Another

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interesting way is to use this printing technology in the design of printing products, namely to create voluminous decor details for both covers and book blocks, such as children's books. In addition, due to the fact that this technology now allows printing of a layer of 0.1 mm thickness, it is possible to create voluminous illustrations in books for people with visual problems [3].

Ukrainian and foreign scientists study the use of 3D technologies in various areas of human activity. The publications of foreign scientists are devoted to the study of the impact of 3D printing technology on innovative development. In particular, such issues were studied by S. Bekhtold, A. Gurko, K. Jewell, B. Deporter, D. Mendis, D. Kolesnikov, V. Smirnov, S. Tolkachev, B. Tokarev. There are works of domestic scientists: H. Androschuk, A. Hrechko, D. Dubov, O. Kronda, S. Chernyshov, O. Stefan and others [4]. However, the versatility and complexity of the problem requires further scientific, technical and economic research, because 3D printing technology is promising [5]. The main advantages are the creation of complex internal structures of the object, the non-waste production, the ability to combine different materials, etc. It allows one to reduce the time and cost of creating bulky products that is not always possible or profitable to produce with other technologies [6, 7].

A model is required for printing, and there are many ways of obtaining it today. However, the two most popular ones are: manual modelling of objects in editing programs and scanning of required objects using a 3D scanner with further processing in the same editors. One way or another prevailed at different time. It depended on the emergence of new digitalization technologies, visualization algorithms, and new software that made it easier and more efficient to process 3D objects [7, 8].

Nowadays it is possible to say that scanning and modelling are equally popular, but this equality is gradually diminishing, due to the constant improvement of 3D scanning technology [8]. In addition, the average user does not have the skills of 3D modelling; it requires a theoretical and practical knowledge base and experience. Therefore, you can use the three-dimensional object scanning method to simplify the task and save the time. The only problem is that creating a high-quality 3D model requires the use of professional 3D scanners, the costs of which are quite high [8, 9]. However, it is possible to create a simple, budget analogue of a 3D scanner independently. Using this kind of 3D modelling one cannot expect very high quality and accuracy, but if the details are not critical, then budget 3D scanning can be a solution. In order to maximize the quality of a scanned model and successful prototyping, it is important to pay attention to the specifications and compliance of the scanner components, to control all the important factors.

Another breakthrough in computer modelling is the development of 3D models with the help of still photographs using a digital camera or any phone camera to capture real-world objects as fully textured 3D models. This method is ideally suited for objects of complex shapes, when you need photographic similarity to the object, as well as for creating 3D models of people with minimal material and time costs.

The main objective of this work was to research 3D printing technologies and available methods of making computer 3D models of real objects. Based on the research, various prototyping methods have been implemented and physical objects have been subsequently obtained using 3D printing technology.

## 2 Technologies of 3D-prototyping of objects

### 2.1 Creating a virtual model by 3D contactless scanning method and its physical prototype by 3D printing technology

The contactless scanning method has been selected for the implementation of the work. Contactless scanners have two types of scanning: passive and active. An active 3D scanner has been selected that has the ability to generate its wave signal: directional light, laser, sound, infrared. The principle behind this method is based on measuring the distance from the scanner to the points of the scanning object using the triangulation method. The emitter and the detector (camera) are at different levels, and the beam is projected at a certain angle relatively to the detector. Thus, a triangle is formed, the basis of which is the emitter and the camera, and the vertex is the point on the object surface. One can calculate the angle between the projected and reflected beams by shifting the reflection from this point, which is formed on the camera sensor, and one can calculate the distance to the point of the object, knowing the angle and the length of the base.

The main software is DAVID Laserscanner application [10], which allows one to scan and digitize objects using a manual laser module, a calibration angle, and a camera. The application generates 3D data in real time and displays it on a computer screen. There are different versions of the application that are suitable for different scanning technologies. There is DAVID Laserscanner Starter Kit available, which includes: four-dimensional calibration sheets, panels for sheet fastening, a high-resolution Logitech C615 webcam, a camera stand, a red laser (650 nm) with variable focus and battery, and necessary software.

Stages of creating a virtual model by 3D scanning method and its physical prototype by 3D printing technology:

**1. Preparing the object for scanning.** Scanning technologies have their restrictions. Usually, these restrictions apply to scanning objects, because optical technologies do not support the processing of transparent, mirror and shiny objects. This is because the wave (in this case, a laser line) must be reflected from the object so that the camera can capture it, process the information about the distance and construct the object on a computer.

**2. Camera calibration.** The camera is calibrated using special calibration sheets at 90 degrees to each other. The type of such sheets depends on the software used for scanning. DAVID Laserscanner 3.4.0.3008 is used, and templates of calibration surfaces in PDF and CDR ready-to-print file formats are available. The sheet size is selected based on the size of the scanned object. The height of the scanned object should be 1.5-2 times smaller than the height of the calibration angle.

A4 format has been selected and the sheets have been placed on pre-prepared wooden panels connected at right angles. The angle of 90 degrees is required to refract the laser line correctly, which will be projected onto the object that is located in front of the angle. One also need to make sure that there is nothing glossy on the surface to prevent unnecessary interference with scanning.

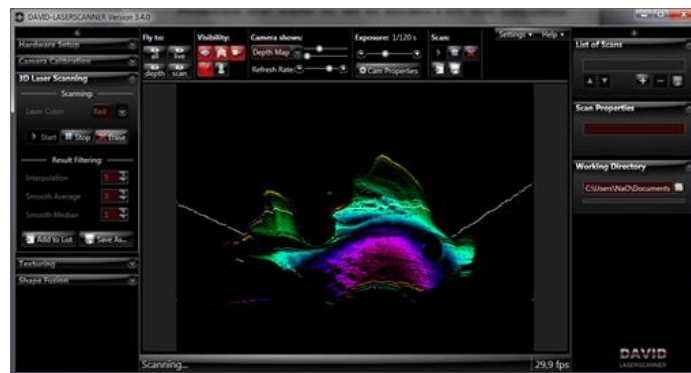
The camera should capture the calibration markers and the markers should be clearly visible during the calibration process. The sheets indicate the length of the Scale line to be measured and input into the application. If the calibration process is successful, the application gives the corresponding message "Calibration successful" and marks the markers with green crosses. After the calibration, it is important that the camera does not change its position.

**3. Object scanning.** A laser module is used for scanning by the selected method that projects not a point, but a line. Two red lasers have been used: one purchased and one created independently using a laser pointer and a scanner unit. The scanner unit is an optical lens, which is a glass cylinder that captures a 90-degree laser beam and refracts it to form a line. If necessary, the refraction angle can be calculated depending on the lens diameter.

Logitech C270 webcam with autofocus has been used as the detector, a device that calibrates and captures the laser reflection. The matrix resolution is 3MP. The matrix type is CMOS. Video frame rate is 30 frames per second. The interface is USB 2.0.

The camera image should be very dark when scanning. To do this, it is necessary to minimize the light in the scanning environment and change the corresponding camera settings so that only the laser line is visible.

One must position the object so that it is in the corner, in front of the calibration sheets. Calibration markers should remain unobstructed around the object. When the scanning process is started and the camera captures the data, one sees the object in different colours. This is a depth map (see Fig. 1). As it is known, the wavelength of the red visible spectrum is the largest and the purple visible spectrum is the smallest. Here, the object is coloured on the same principle: the parts closest to the camera are purple, the farthest ones are red. Other colours have intermediate values.



**Fig. 1.** A camera image when scanning in a depth map mode

The object scanning should be carried out from different view directions. That is, having processed one side of an object, it is necessary to store the received image, turn an object and start scanning again. The more scanned sides you get, the better is for creation of a further model. Scanned sides must overlap each other by parts. That

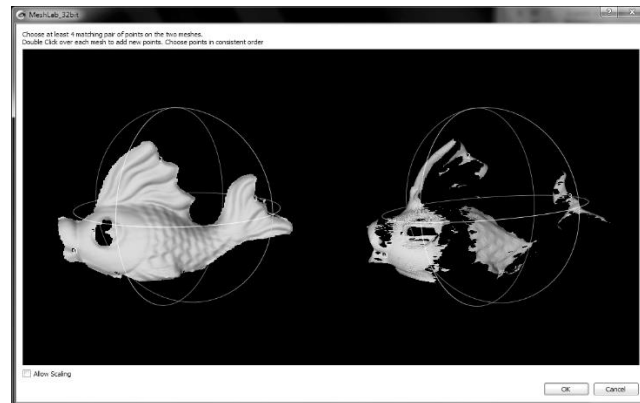
is, each next scan must contain a part of the previous one. It is needed for the next stage of gluing a model together.

An angle between the area of laser light and the camera must not be too low, otherwise the refraction of the line will be insufficient and the application will report the following: Intersection of angle too low. There are also other messages concerning errors: Laser line not detected (too short/too weak?) – when a laser line is too short, or too weak, or it is absent at all. Laser line not detected on the left (right) side – if a laser line is not detected on the left (right) side of calibrated angle. That is, a laser line shifted aside, so it is not detected on both sides, or a line is not projected horizontally but with a curve. It can also mean that an object overlap calibrated markers on the left (on the right) and the camera cannot detect a laser. Therefore, it is necessary to pay attention to this and to control the process of scanning.

#### **4. Adjustment and merging of scanned parts to get a complete model.**

Adjustment of scans is a process of setting scanned parts into corresponding places, so to join them into an integral model. For this purpose, the applications DAVID Laserscanner and Meshlab are used. Meshlab is an application to process unstructured three-dimensional forms. The system is aimed at processing three-dimensional models, obtained by 3D scanning, and has tools for editing, cleaning, correction, verification, rendering, and converting of a processed model into a necessary format.

DAVID Laserscanner application performs scans cleaning from large unnecessary elements and adjustment by automatic facilities, and scans, which the application is not able to process itself, are adjusted manually in Meshlab. There is also possibility of manual substitution in DAVID Laserscanner, but it is designed on the total manual control, but Meshlab allows adjusting scans on intersection points (see Fig. 2). Choose a part of the model already located on its place and add another one to it, marking with points basic areas that coincide. Thus, accuracy of correct substitution increases.



**Fig. 2.** Joining of scans on intersection points in Meshlab

Gluing of the model itself has been carried out using DAVID Laserscanner application. The program merges the adjusted parts in one three-dimensional model, interpolating places with breaks or sharp transitions. After that the model is transformed in OBJ format and passes to the next stage – editing.

**5. Processing, "cleaning" of a model.** Almost in all cases, after scanning and gluing, a model needs a processing stage. It is possible, at this stage, to remove holes, smooth out a surface, simplify general structure or remove unnecessary elements. All this is performed with 3D design software. For project fulfilment, the editor Blender has been chosen, as it is on free access. Another advantage of Blender is that it is adapted for 3D printing. There is a plugin to test a model for fitness to printing, as well as possibility to import into STL and OBJ formats.

**6. Preparation of a model to 3D printing.** An object cannot be printed at once after simulation. Every model that is sent to a 3D printer must pass over the preparation stage. Preparation of a model was also performed with the application Blender, using a special plugin, and transformed a model into a necessary format. Program-slicers operate with the STL file format (stereolithography). Therefore, a model for printing [11] must be stored just in this format.

**7. 3D printing.** On this stage, a model first passes over preparation with a program-slicer, where it is split into layers that are formed during printing by a material. Simplify3D application was used for printing of this model.

On the basis of the conducted researches, the following conclusions as to optimal technical specifications of the scanner parts and scanning environment have been made:

- The minimum illumination in a room during scanning. This is essential, especially, if not too powerful, and thus, not too bright laser is used. For a camera-detector to recognize a projected laser line better, contrast conditions are required, so that another part of an image remains dark (even black), that is to minimize illumination in the room.

- Webcam with resolution capability of 640x480 and noises compensation. A required resolution capability is calculated depending on the size of an object. At 640x480 resolution capability, an object is set in such a way that covers approximately 300x350 pixels. A pixel is one 3D dot. Thus, we obtain more than 100 thousand 3D dots, but just only on one side of an object. Therefore, 640x480 is a sufficient resolution capability for ordinary objects scanning. Compensation of noises, in fact, is more important feature for cameras.

- Manual focus and quality lenses of a camera are also important characteristics. It is possible to use cameras with autofocus, but it is more convenient to have a manual focus. In this case, it is possible to adjust the camera to various environments. As to lenses, it is sufficient to use glass instead of plastic lenses. It will improve the outcome of scanning.

- Laser with power of 5mW, and 30° or 60° module that generates a line. Power of a laser, as it was already mentioned above, depends on the environment of scanning. If a room is not dark enough, then a laser must be more powerful. This condition is also required at dark objects scanning (black, is known, does not reflect, but absorbs light). Laser scanning is also possible to perform using a laser pointer, i.e. its projection will be in a form of a dot. However, a laser line instead of a laser dot is used to speed up the process. It is achieved due to the scanner unit (cylindrical lens) or the system of mechanical scanner unit (a mirror that turns around). The angle of the module depends on an object that is scanned. In most cases, an angle must be not less than 30 degrees, if the angle value is lower, then the line that is projected will be undersized to cover an object.

- A laser line must be as thin as possible, especially, if an object of scanning is of small size. The thinner the line is, the less noises it produces that prevent successful scanning. Thus, a model surface will be smoother and more detailed.
- Sheets for calibration, must be located at an angle of exactly  $90^\circ$  and with distinctly printed calibration markers.
- Triangular angle (angular inclination of a laser in relation to an object) should be about  $30^\circ$ . If to scan at a lower angle, then refraction of a laser line will be too little to recognize the surface of a scanned object.

## 2.2 Research and creation of 3D model using photogrammetric method

For implementing the experimental part, a method of the camera rotation around the object and the object rotation around its axis has been used, since this method is suitable and does not require special expensive equipment. Sony Cyber-Shot DSC-W290 camera was used for the study.

For the research part, 3 objects, different in shape, texture, color and size had been chosen beforehand. Based on the research, and considering all the mistakes, a complete 3D model was created. The creation process can be divided into the following stages:

### 1. Object preparation for the photography process.

Not all the objects can be displayed when creating a 3D model by overlaying photos. It can be difficult to work with transparent, translucent, shiny, or mirror objects, because the camera cannot catch their points clearly enough. In this case, it is necessary to mask the surface with matt paint applied to the object. If the object is of monochrome, little textured or plain, it will be difficult for the application to identify which side the object was taken from. For this purpose it is necessary to apply special signs (markers) for the subject of shooting (see Fig. 3), which will be further marked in the application and numbered.



**Fig. 3.** Applying of the markers on the object

## **2. Preparation of the photographic zone.**

To keep the photo sharp, you need to fix the digital camera with a tripod. Lighting is one of the key factors for quality photography, so the next step is to create a light-box. It has a white monochrome background and also mixes and scatters directional light, which is formed by light fixtures, creating a drawing of the subject without any shadow.

## **3. Camera calibration.**

The camera should be positioned in such a way when the subject occupies the largest possible area in the shot. When shooting small objects, it will be better to make photos by the camera equipped with a macro lens that provides high image clarity and detailing. In the absence of a macro lens, it is possible to use a lens with the fixed focal length. The automatic white balance mode must be disabled before shooting to ensure that it is the same in all shots.

It is also necessary to choose the mode – the aperture priority (A). Close the aperture closer to the minimum value from f5.6 to f11 (depending on the subject) to avoid loss of photo sharpness. The smaller is the aperture, the greater the depth of area will be. Accordingly, the exposure will last more. ISO sensitivity is set to a minimum value (50-100 ISO) to get the best possible picture quality.

## **4. Photo shooting.**

The process of photo shooting can be performed in two modes:

- It is performed by rotating the model (manually or using a special rotary table)
  - such shooting is most convenient to perform in a light-box, where diffuse light is required.
- It is performed in such a way, when the photographer with the camera moves around the model.

In both modes, photos are taken, approximately, after every 10 degrees, so at one height nearly 30-36 shots are taken. In the case of complex models, photo shooting should be repeated from a higher or lower position to fully cover the entire model.

## **5. Photo processing.**

It is not recommended to cut photos, change their size [12] any resolution by any editing program. At this point, extra points that are not relevant to the object are masked. You can do this in Adobe Photoshop or in applications, in which a 3D model can be created (such as PhotoScan).

## **6. Modeling a 3D object.**

6.1. In PhotoScan application we load photos, select "Align Photos" from the menu. The application finds common points of photos and determines such camera parameters as status, orientation, focal length, distortion settings and more. At this point, we obtain a sparse cloud of common points in the 3D space of the model and data on the status and orientation of the cameras.

This result is used for visual evaluation of the photo alignment quality and further creation of a 3D model based on a sparse point cloud. When you receive a point cloud, you need to remove the extra points with the removal tool.

6.2. Now one needs to create a dense point cloud. To do this, we choose the menu item "Create a dense point cloud". When this stage is complete, the contours of the model are clearly visible and the extra points can be removed again.



6.3. Then we go to the model creation and select the menu item "Create Model". As a result, we obtain a three-dimensional polygonal model describing the shape of the object, based on a dense points cloud.

After making a model, sometimes it is necessary to edit it. In Photoscan application it is possible to make such changes as removing of the isolated model components, filling the holes, and so on.

The 3D model obtained by the scanning method usually has an excessive polygonality. Polygonality reduction can be done with the help of Autodesk 3Ds Max.

When one switches to frame mode, in the application one can see an increase in the number of vertices in the 3D model for several times. To do this, we call the ProOptimizer modifier in the modifier stack.

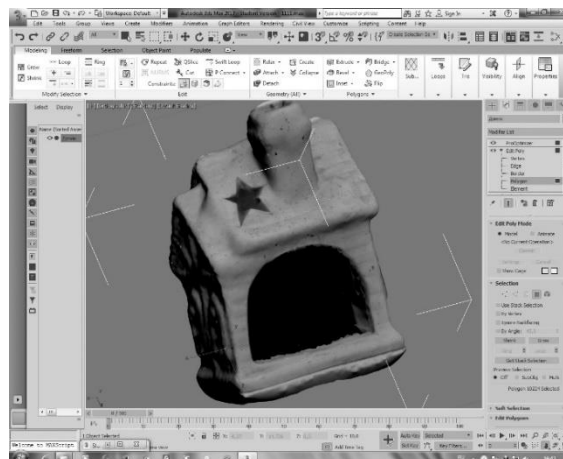
Click on the Calculate button, and then the number of vertices in the model will be calculated. Decrease them by a percentage where 100% is the current number of vertices in the model. You must reduce the number of polygons until the shape of the object is affected.

In this case, it was reduced to 20% of the total number of vertices. A smaller percentage showed the deformation of the object. For further work, it is recommended to transfer the 3D model into Editable Poly.

6.4. The next menu item is Texture Creation. After processing, we get a finished model that can be exported for viewing with Adobe Acrobat or Adobe Reader. It can also be exported for further processing of the model in 3D .obj editors, in particular in 3Ds Max.

Another type of object texturing is working with Autodesk 3Ds Max application. For this type, we pre-export the 3D model from PhotoScan in .obj format and a texture by a separate .jpeg file. Next, we choose the type of Bitmap material into which we upload a file with our previously stored texture and transfer it to the object.

7. Model correction. If necessary, clean the model in Autodesk 3Ds Max (see Fig.4). In this case, due to the complex shape of the object, unnecessary polygons were modeled. In EditPoly - Polygon mode, the selection tool picked unnecessary polygons and removed them.



**Fig.4.** Correction of the 3D model

The result is the creation of a 3D model using a digital machine, which can be used both electronically and to prepare the file for 3D printing. The photogrammetric method was chosen for this. This method allows determining the spatial coordinates of an object on its image, made from different angles. As a result of overlapping photos in PhotoScan a three-dimensional model with the most realistic effect has been created.

Based on the conducted researches, it has been concluded about the optimal technical characteristics of the device and the conditions of photography:

- No usage of transparent, translucent, shiny or mirror objects, or cover these objects with matte paint and subsequently apply a texture to the software. In the case of small textured objects, special marks must be affixed to them.
- The object should be on a solid background.
- It is necessary to provide a uniform diffusion illumination, with the help of a photographic zone – lightbox, creating a shadowless image of the object. If the subject is photoshoot in the natural conditions, it should be done in cloudy weather.
- To increase the sharpness of the photo, you need to lock the camera with the help of a tripod. The object should occupy the largest possible area in the frame.
- A camera with a macro lens or fixed focus lens.
- Enable manual white balance mode. Set aperture priority (A). Close the aperture closer to the minimum value, from f5.6 to f11 (depending on the subject). Accordingly, the shutter speed will be longer. The ISO sensitivity is set to a minimum value (50-108.0 ISO).
- The object is photographed rotating every 10 degrees (30-36 shots). In the case of complex models, repeat shooting from a higher or lower position to fully cover the entire model.
- It is not recommended to crop photos and resize them by any editor.
- Reduce the polygonality of the object to about 20% of the total number of vertices, depending on the model. Decrease the number of polygons until the appearance of the object is affected.

### **3 Conclusion**

3D printing technologies and available methods of making computer 3D models of real objects have been researched. Different prototyping methods have been implemented, and physical objects have been subsequently acquired by 3D printing.

The result is the development of 3D scanning hardware, which was the basis for the development of a method of fixation of physical objects to further processing the image in the 3D modeling software environment and 3D printing with a 3D printer.

For the project of 3D scanner development, the method of contactless active laser scanning has been chosen. A linear laser module that is projected onto the object has been used. Using a special calibration angle (the type of calibration angle is selected in accordance with the scanning software), the webcam, which further captures the reflected laser beams, is calibrated and the specialized DAVID-Laserscanner

application that calculates 3D coordinates from the intersection of the laser plane and visible rays from the camera, a copy of the physical object in the form of a virtual three-dimensional model is built.

Based on the conducted researches, the conclusions about the optimal technical characteristics of the components of the scanner and the scanning environment are made. A methodology for creating a 3D model using a digital device has been developed, which can then be used both electronically and to prepare the file for 3D printing. This method allows determining the spatial coordinates of an object by its images taken from different angles. PhotoScan creates a three-dimensional model with the most realistic effect.

Using the data of the conducted researches, it is concluded that the optimal technical characteristics of the component devices and environments provide the process of creating 3D models of the highest quality.

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