

VIRTUAL REALITY AND MOBILE DEVICES IN 3D OBJECTS DESIGNING AND PROTOTYPING

Paweł BUCHWALD, Maciej ROSTAŃSKI, Krystian MAĆZKA

Abstract: This article presents chosen modern information technology solutions in virtual reality. The additional goal of this research is to provide a concept for the possibility of realization of the computer system for special imaging, helpful at 3D objects prototyping. The chosen 3D visualization devices are presented, as well as modern control interfaces with examples. Finally, the concept of connecting presented devices and applications with Unity 3D for construction of a prototyping application is described.

Keywords: Virtual Reality, User interfaces, STL, Android, Myo, Mobile devices, Prototyping, 3D, Unity 3D.

1. Introduction

Prototyping is the initial phase of the product manufacturing, and its purpose is to create the designed item according to the documentation. In the outcome of this process the prototype emerges, that can serve as the model mapping the product properties for testing and verification of the engineering blueprints made in the design phase. The construction of a prototype is often expensive, considering its unique character and the single item as an outcome, and the costs of the prototype construction are often quite large part of the investment in the new product manufacturing cycle [1].

This article presents chosen modern information technology solutions in virtual reality. That allow for the construction of the system utilizing modern technologies for designing and creating digital and physical models of the same product. The additional goal of this research is to provide a concept for the possibility of realization of the computer system for special imaging, helpful at 3D objects prototyping, and in some cases, eliminating the need of a material, physical prototype. We want to show the possibility of creating such system using relatively cheap, commodity hardware and software equipment. The particular task of this article is also the presentation of the modern input-output interfaces, that can bring benefit to the experience of described applications of the virtual and augmented reality. The chosen 3D visualization devices are presented, as well as modern control interfaces with examples of Myo controller or IGS Glove. Finally, the concept of connecting presented devices and applications with Unity 3D for construction of a prototyping application is described. Thus, authors' application is capable of supporting 3D prototype validation even before it's printed or constructed using other measures.

2. Virtual reality application in design phase

Minimizing prototype construction costs is in many cases realized using information technology and modern techniques of computer graphics. At the prototyping phase of the three-dimensional models, the techniques that allow for observing properties and physical

behavior of the prototype, can harness the possibilities provided by augmented and virtual reality.

Virtual reality, as according to Byrson and Larnier [2], is understood as the interactive effect achieved by computer technology by creating the three-dimensional model with objects, giving the impression of the physical presence. The precursor of the virtual reality is Myron W. Krueger, a creator of many installations in education and psychological therapy fields, being prototypes of virtual reality systems.

The development of today's applications for 3D graphic modeling, modern visualization solutions and the evolution of sophisticated devices for user-computer interaction [3] made the implementation of simulation and visualization environments possible. The intention behind such environments is to illustrate the designed models better and better in order to intensify detail and object properties recreation.

Of course the virtual reality has many applications, including entertainment (movies, games, presentations). Large field of application of virtual reality involves the simulation of ground or aerial vehicles. It is possible to equip the system with sound devices, delivering sound incentives for realism enhancement. The introduction of modern virtual reality systems and devices, such as mentioned 3D helmets, can be very cost-effective compared to simulation environments without such equipment.

The another example of interesting virtual reality application is Bloomberg's project of virtual workspace for stock-brokers. It allows for presenting many financial data screens at the same time on virtual reality. This solution provides good mobility because it is based on 3D Oculus Rift helmet, and the interaction with user relies on Leap Motion technology. User's body, hand and fingers movement is detected – it provides more intuitive and effective work with much larger quantities of financial data compared to conventional applications [4]. Another unique case of virtual reality application is created by National Center for Supercomputing Applications platform for car prototyping. It allowed for cooperation between Belgium and US engineers, including interactive group work using real-time video transmissions between remote locations [5].

3. Modern rapid prototyping methods

Rapid prototyping can be defined as a group of technologies allowing for physical model creation, based on a three-dimensional model. The rapid prototyping techniques most often rely on 3D CAD systems, that improve not only the realization of design, but the physical image of designed 3D object before production phase.

The rapid prototyping methods use so-called additive techniques, that, unlike 'machining', realize the process of creating an object by adding more layers. The model is built layer by layer, using techniques of combining different materials, such as plastic, paper, ceramics, metal, or specially selected composites. The first rapid prototyping technique (which was used already in the 80's) is stereolithography. This technique ensured high precision and the possibility of a direct mapping of complex structures inside the prototyped item. Its disadvantage are quite high costs compared with methods employing 'machining'. Stereolithography is a slow process, and the size of the prototyped object is quite limited. Also, the disadvantage of this method is the lack of choice of the material from which the prototype will be realized. Stereolithography techniques use a special type of polymer that has a low mechanical strength. For this reason, it was necessary to develop other rapid prototyping techniques. Most popular of them are shown in Table 1.

Each method of rapid prototyping requires the implementation of a 3D model using a computer application, that allows for the conversion to digital format supported by the prototyping device. The CAD tools supporting the 3D model are run on conventional computers, which of course forces to reflect three-dimensional space on a flat screen.

Table 1. Popular rapid prototyping techniques. Source: [10]

Rapid prototyping technique	Principle of operation
Stereolithography (SLA)	Utilising layers of photo-reactive material with a laser (or similar) source.
Laminated object Manufacturing (LOM)	This technique uses cutting layers of traced prototype on sheets of adhesive material and 'glueing' them together.
Selective Laser Sintering (SLS)	Utilizes laser to selectively sinter powdered composite materials (or metals).
Multi Jet Modeling	Additive applying of a molten acrylic photopolymer by a multi-nozzle head.
3D printing	Similar to ink printing, but in prototype 3D printing, the ink of each layer is replaced by a powder which is a material for the model.

Graphics library for 3D visualization use projections to reflect the three-dimensional image on a computer monitor. The most common are the following types of projections:

- parallel projection:
Good for exact measurements, however angles are not (in general) preserved. Can be oblique or orthographic. This type of projection is often used in architectural design and CAD applications.
- perspective projection:
Size of the objects varies inversely with distance – gives the effect of reducing the remote parts of the object being modeled. This type of projection is often used in 3D visualization, whose aim is to achieve greater realism mapped three-dimensional objects.

None of the techniques of projection gives an accurate representation of a 3D object and both have some imperfections. For this reason, it is necessary to apply modern techniques of a spatial visualization using dedicated 3D imaging devices. Only such an approach makes it possible to fully reflect the appearance of the modeled three-dimensional object.

4. 3D objects visualization devices for virtual reality

The principle of operation of the popular devices for 3D visualization is based on the properties of stereographic view. Through the acquisition of different images for the right and left eye, we achieve the illusion of spatial presence of the visualized 3D objects. Images for the left and right eye are generated by cameras pointed at the same item and shifted in three dimensional space relative to each other, by a distance equal to the distance between the one and the other eye of the recipient. Such generated images are sent to separate displays, or a common display ('side by side' 3D images display). If each of the images is seen by only one eye, then the user has the impression of a full three-dimensional effect. The illustration of the operation based on this principle is shown on Fig. 1.

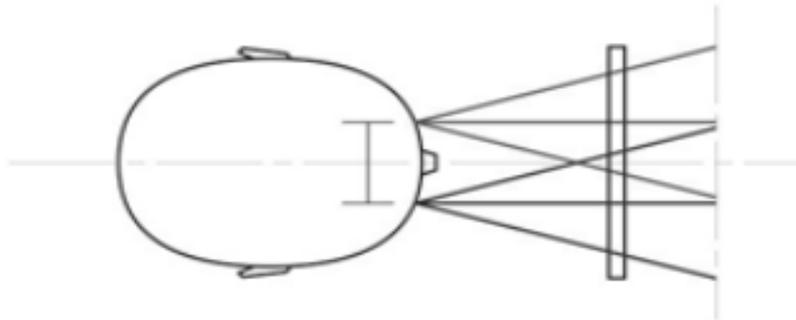


Fig. 1. Diagram of the apparatus for three-dimensional visualization
Source: Oculus Rift documentation

The first attempts to implement the 3D visualization were done using the anaglyphic techniques. They are based on an overlay of the two images for the right and left eye on one picture. To create an anaglyphic picture, one uses the red color component of the image for the left eye, and green and blue components of the image for the right eye. This method has a high coefficient of loss of the color information of the visualized object. Another algorithm capable of better color mapping is the Doubois algorithm [4]. To determine the color component values for the images delivered to the right and left eye it uses both images. This makes the colors in this method rendered most faithfully. The transformation of the original images for the left and right eye into anaglyphic image is lossy (causes a loss of image information). For this reason, anaglyphic method is not used for visualization of 3D prototypes in a wide range.

Display miniaturization has allowed for the design of 3D helmet displays, making the use of separate images transmitted to the right and left eye in an independent manner possible. An example of this is the device called Oculus Rift. The first version of the device was created with Kickstarter funding platform for social networking. It is compatible with most of the popular libraries for creating three-dimensional visualization, such as Unreal 4 or Unity 3D. One of the important elements distinguishing the device is its ability to track the movements of the head using the built-in gyroscope. In the latest version of the device manufacturers have achieved fair performance of visualization. The use of LCD displays with low inertia resulted in reduced delays and the elimination of the effects of blur. The first version of the device was made publicly available in September 2014, under the Creative Commons 4.0 Attribution license (which allows to adapt for commercial purposes), including plans for digital circuits, code, firmware and mechanical designs. This means that anyone can produce a similar product, modify the design to suit their needs, and to develop it commercially [11].

The dynamic development of smartphones, which have good quality high resolution displays, allowed for their use in the field of 3D visualization. It is a relatively simple idea of placing the device in special goggles, which leads to surprisingly good effect. An example of such implementation are Dourovis Dive glasses [12]. In addition to the smartphone display, the device also uses a gyroscope and accelerometer. This gives the opportunity to evaluate the user's head movement and adjust the projected image. An undoubted advantage is the low price that was achieved through the use of the smartphone as a component. The disadvantage of the solution is low visualization quality and performance, compared for example to Oculus Rift. Worth mentioning are also attempts to

use 3D goggles, a mobile phone with Android operating system, and a PC allowing for transmission of video stream directly to a cell phone to get a better 3D visualization effects [13].

To restate, minimizing the cost of imaging devices through the use of three-dimensional displays and computing power of today's mobile devices has led to a number of solutions of this type. Table 2 shows some of them.

Table 2. Glasses using smartphones for three-dimensional visualization.

Device	Properties	Address
Dourovis Dive	Has SDK components for creating iOS/Android native applications, as well as Unity3D. Compatible with many smartphones.	http://www.durovis.com
Samsung Gear	Developed for Samsung smartphones. Has relatively low delays.	http://www.samsung.com/global/microsite/gearvr/gearvr_specs.html
Google Cardboard	Low-cost DIY Google glasses. Utilizes NFC for configuration.	https://www.google.com/get/cardboard/

5. Application support for reflecting 3D objects in virtual reality

One of the tools that can be used to visualize the 3D object prototype is Unity environment [14] [20]. Unity 3D environment allows to implement business logic in JavaScript, C#, and Boo (which is based on the Python language syntax) languages. There is a Mono Develop environment installed with Unity, which is an integrated tool for RAD (ang. Rapid Application Development) and allows for the preparation of a software solutions and the tracking of errors in the program. [21]

Unity 3D is based on cross-platform implementation of the .NET environment called Mono. Common Type System allows the use of namespaces providing classes to handle the communication over the network [22]. It is possible to handle the HTTP protocol, and thus implemented application allows to communicate with a business logic layer implemented in accordance with the REST model. Thanks to the ability to use the typical to .NET solutions, applications implemented in the Unity environment can utilize communication with Web Services.

Designing a proper interaction with the user is also associated with a software event handling, and dynamic change of the properties of the components used in the visualization. Unity environment is capable of event handling and creating procedures that will run when visualization scene is refreshed, application starts, or as a response to pressing a specific key. For the realization of user interaction, Unity environment provides a specially designed set of event-procedures that allow the implementation of HUD objects. Using event-driven model one can read information about the position of the device (the orientation of the screen horizontally or vertically), or the value of the acceleration sensor. The events generated during operation of the application can be signaled to the mobile device user not only through the display but also using acoustic signals or vibrations. These elements must also be handled programmatically and taken into account in the design of business logic of the solution [23].

When using mobile device as a display image visualization glasses for virtual reality, the majority of standard event handler components simply can not be used. Specificity of

the solution requires the development of new methods and components that are used to interact with the user.

Most CAD software provides the option to save the output in STL format. This means using common files used in prototyping to visualize three-dimensional virtual world: STL format files are used for transformation for visualization in virtual reality. The concept of the system of the 3D objects validation during their design involves the use of equipment and systems used in the implementation of virtual reality to validate the model before its prototype 3D printing. For this purpose, an application is implemented using STL file that would allow visualization of a prototyped object in virtual reality. Application, created in Unity environment, can import the model file and allows to work with Douravis Dive glasses used for spatial imaging. An important advantage of the Douravis Dive is the possibility of cooperation with the programming libraries offered by the manufacturer, which can enable the detection of the user's direction of view and display a 3D image.

Manufacturers have released the SDK for the Android operating system and iOS, and a component for collaboration of applications created in the environment Unity with the device. Programming libraries provided by the manufacturers of today's 3D visualization solutions allow, with a relatively small amount of work, for the creation of the three-dimensional visualizations, which are characterized by a high degree of realism and allow user interaction. Thanks to this, the designs of items and prototyped 3D objects, which are prepared using CAD tools, can be used for visualization purposes. The import of STL file using Unity environment is realized in exemplary code on Listing 1.

Listing 1. STL file 3D object data read in the Unity 3D environment.

```
FileStream fs = new FileStream (filename, FileMode.Open);
BinaryReader rd = new BinaryReader (fs);
byte[] description = rd.ReadBytes (80);
string stlName = System.Text.Encoding.UTF8.GetString (description);
UInt32 facetsCount = rd.ReadUInt32 ();
for (int i=0; i<facetsCount; i++)
{
    float nx = rd.ReadSingle();
    float ny = rd.ReadSingle ();
    float nz = rd.ReadSingle ();
    Vector3 normal = new Vector3(nx,ny,nz);
    Vector3[] vert = new Vector3[3];
    for (int l=0;l<3; l++)
    { vert[l] = new Vector3(rd.ReadSingle(), rd.ReadSingle(),
rd.ReadSingle());
        newNormals.Add(normal);
        newVertices.Add (vert[l]);
        SetMinMax(vert[l]);
        VertexCount++;
    }
    rd.ReadUInt16();
}
mesh.Clear ();
mesh.vertices = newVertices.ToArray();
mesh.normals = newNormals.ToArray();
for (int i=0; i<mesh.vertices.Length; i++) newTriangles.Add (i);
mesh.triangles = newTriangles.ToArray ();
Vector2[] uvs = { new Vector2(0,0), new Vector2(0,1), new Vector2(1,1) };
for (int i=0;i<mesh.vertices.Length;i++) newUV.Add(uvs[i%3]);
mesh.uv = newUV.ToArray ();
mesh.Optimize();
mesh.RecalculateBounds ();
```

On the presented listing it is shown how to import STL files in binary format. Also, text versions of the STL file format are commonly used. Unity 3D tool, and a set of standard libraries for Mono environment provide programming support for parsing files in text format.

Representation of three-dimensional objects in the Unity environment is implemented using the Mesh class objects. It allows to store information about the mesh of triangles from which the 3D object is created. Dynamic three-dimensional objects meshing provides creating an object based on data from the STL file we want to print, and permits the use of components of the Unity 3D environment to create a three-dimensional environment in which the object is located. Using Unity environment enables appropriate selection of lighting parameters, determines the characteristics of light reflection for certain parts of the object being modeled, and placing it in the virtual reality generated environment.

Unity 3D environment provides a range of software components responsible for the visualization of generated 3D objects. One of these objects is a camera. It is possible to include two cameras in the created stage, positioned relative to each other in an appropriate manner to transmit the images appropriately to left and right eye using glasses for three-dimensional visualization.

Full use of virtual reality for prototyping needs to create an environment that allows not only for a preview of an interactive component, but also to ensure the possibility of manipulation of objects in the real world. This functionality requires the development and use of special devices for user interaction [19]. Standard devices such as a keyboard, computer mouse, or pad are insufficient for their convenient use in virtual reality.

6. The use of modern communication devices as user interface for visualization systems utilizing VR and AR techniques

Along with the introduction of innovative ways to display the image to the user of the system, it becomes necessary to enable intuitive control. In a situation, where the virtual reality is displayed before the user, or when user is moving around the extensive grounds, using AR techniques, it is difficult to expect that the communication will be realized using the keyboard.

Already introduced into the market Glass, the invention of Google, uses gentle movements of the wearer's head, also gestures like moving finger across the frame glasses. Innovative ideas go even further - to support virtual reality one can utilize special gloves like IGS Glove or Control VR (the second product is developed for the market right now). An example of solution – Vrealities - is shown on Fig. 2. The glove shown uses a highly accurate inertial sensors for data capture about movement of hands or fingers. The use of the glove has a very important advantage - it allows to track and retrieve movement data even when the hand is completely obscured from possible cameras (eg. during the repair of the camera device). This is a big difference compared to solutions used for similar purposes known as mocap systems (Motion capture). Gloves available on the market fully cooperate with the modeling systems like Unity 3D or industry, for example Siemens JACK.

Another interesting concept is the use of hand movements and changes in forearm muscle tension or electrical impulses while performing gestures by the user. Data needed to interpret a control gesture can be processed by the controller applied to the shoulder like a normal band (as shown in Fig. 3).



Fig. 2. Inertial glove made of lycra. A distinct lack of visible controls. Source: [15]

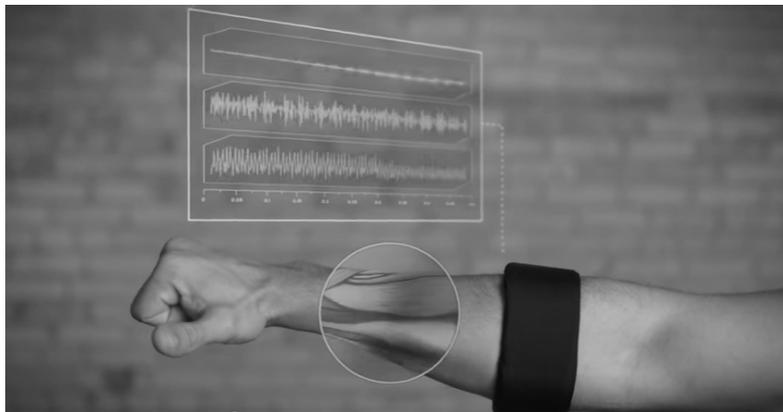


Fig 3. Myo Armband – an example of using electromyography for control. Source: [16]

The device constructed in accordance with this concept (for example – Thalmic Labs' Myo Armband) operates on the basis of analysis of the two data sets:

- IMU data (Inertial Measurement Unit), known particularly in the field of unmanned aircraft control related to the movement. Measures velocity, orientation, acceleration, using a combination of accelerometers, gyroscopes, and sometimes magnetometers [17].
- EMG data (Electromyography), obtained by the technique of assessing and recording the electrical activity produced by skeletal muscles [18]. Electromyograph is capable of detecting the electrical potential generated by the muscles activated neurologically, and therefore analyze the biomechanics of human movement.

Using the combination of the two sets of data, and communicating (via Bluetooth) to a remote receiver device, the system can control the user's behavior, receive commands in a much more intuitive way, and finally allow completely new control techniques.

5. Summary

Technologies presented in this paper indicate the direction of development for modern prototypes design of different types of products, intermediates, or their structural parts. 3D visualization seem to be the ideal solution is not absorbing the additional cost of the prototype, typically associated with the set-up of production equipment, creating forms, ordering custom components, etc.

However, application support is not without significance for the development of the techniques presented in the article. Modern environments for design and application programming offer extensive support in the creation of 3D visualization. A significant stimulus to the development of the use of virtual reality is a drop in the price of equipment for three-dimensional visualization. The application of virtual reality isn't completely new area, but it's progress is very dynamic, thanks to the development of devices and software with enormous 3D visualization capabilities. That's why there is a lack of enough current research within virtual reality solutions considering ergonomics and applications for prototyping, as well as designing support. The implementation of the concept system for prototype design and validation is a challenge on its own, taking into consideration the costs of IT system, which would have to be at some point compatible with typical CAD tools and allow to for representation of a prototyped objects in virtual reality.

Modern virtual and augmented reality visualization helmets, such as Oculus Rift or Microsoft HoloLens are actually nearly prototypes or developer versions. One can assume that the initial market phase introduction costs would be significant. In the article it is shown, that the virtual reality utilizing system can be realized with common mobile devices and popular 3D software, so it may lower costs of the application of such methods.

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Dr inż. Paweł BUCHWALD

Dr inż. Krystian MAĆZKA

Dr inż. Maciej ROSTAŃSKI

Katedra Informatyki

Wyższa Szkoła Biznesu w Dąbrowie Górniczej

41-300 Dąbrowa Górnicza ul. Cieplaka 1c

tel: +48 32 262-28-05

e-mail: pbuchwald@wsb.edu.pl

kmaczka@wsb.edu.pl

mrostanski@wsb.edu.pl