Online Control Education Using 3D Holographic Visualisation

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Abstract:

 Interactive 3D visualization technology has brought many benefits into education. Since it is possible to visualize behavior of wide range of devices, it is much easier to imagine processes where these devices are included. The paper demonstrates the application for interactive teaching of control theory. It allows to simulate a holographic model of a selected mechatronic system that is a digital visualization of the real device. The behaviour of the device is controlled by Scilab/Xcos, which is open-source, cross-platform numerical computational environment. The main purpose of the application is to help students with better understanding of physical meaning of abstract mathematical models, that describes dynamical systems.

Keywords: *Control theory, Hologram, Furuta pendulum, Education, 3D model, Scilab*

1. Introduction

Last years, fast improvement of technology, many innovations and digitization of the world have changed the way how companies and institutions work. They also adapt and create new methods and processes for more effective and innovative educating. They try to make the process for students easier ([10], [7]) and more efficient. The progress in education also creates a contribution to science, technology and development. The ideal outcome is to bring education and research activities together, creating innovations that support the industry [1]. Better education can be ultimately benefit for everyone.

More effective education can be supported by digitizing the subject matter. Simplifying device designs, understanding technical specifications, facilitating device prototyping, or even making manufacturing process cheaper are just a few of the many different uses of 3D hardware digitization ([19], [3]). There are many three-dimensional environments around the world that try to incorporate, work, and simulate knowledge from different areas [12]. Study says that 58% students agreed that methodologies like simulations, demonstrations and virtual laboratories make them more comfortable in lab sessions [14].

Nowadays, we can observe the trend of digitizing in almost every working segment [4]. It allows us to face real situations before they happen, to learn from them, see issues from another perspective, respond to them much faster and, finally, to save costs.

There are many ways how to digitize 3D object.

Lately many institutions have specialized in virtual and augmented reality (AR), like in ([13], [11]) and brought attention to it. Study [8] says that more than 70% of the students thought that AR made the classes more interesting. However, the presented project wants to focus on an area that is not used so widespread. The aim is to show students another angle of innovative learning using holographic technology. Optical holography for recording three-dimensional scenes can be traced back to the early sixties. Since then, the art of holography has been applied in many areas, primarily as a tool for 3D imaging, processing, and display [17]. Study in [6] says that 45.5% of teachers believe that hologram technology would have affect in the field of teaching.

The holographic technology could be used in various areas of life. First example related to its use in cars was published in [18]. The authors attempt to present a holographic display, that should reduce the time when drivers were guided to the dashboard. Hologram should be projected onto the front glass, so time of inattention would be reduced. Another example is medicine area. The paper published in [16] presented a possibility of displaying real heart beating on a model of heart in four-sided hologram pyramid.

The aim of presented paper is to connect the holographic technology and control education. Created application should help students dealing with basics of automatic control. Our system can simply help to visualize the behavior of mechatronic system using a 3D digital model in holographic device.

2. State of Technology

The "Hologram" word refers to "a three-dimensional picture made by laser light reflected onto a photographic substance without the use of a camera [2]. Hologram device could be used to play video, represent some system behavior, show object models, etc. We know many varieties of holograms, and there are various ways for classifying them. For our purpose, we can divide them into three types: reflection holograms, transmission holograms and hybrid holograms.

Reflection holograms   The reflection hologram is the most common used type of the hologram. It can be seen in galleries and in presentation places. Such hologram is formed when the reference beam and the object beam are incident on opposite sides of the holographic surface. They interfere and record an image.

To reconstruct the image, a point source of white light illuminates the hologram from the proper angle, and the viewer looks at it from the same side as the light source emits. The setup of reflection holograms is very simple and holograms are visible without a laser light [5].
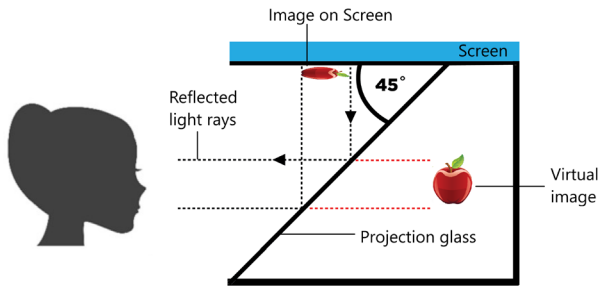

Fig. 1. Reflection hologram

Transmission holograms Transmission holograms are also known as Laser-Transmission Holograms. They are created when the reference beam and the object beam are incident on the same side of the holographic surface. They are viewed by shining a spread-out laser light through the emulsion side of the hologram at the same angle the hologram was recorded at with the viewer looking on from the opposite side. The light is transmitted from behind the hologram device to the side of the observer [5]. Image which is displayed can be very precise. For instance, through a small hologram, a full-size room with people in it can be seen as if the hologram were a window [9]. The materials, methods, and processes used to make transmission hologram are the same as at reflection holograms.
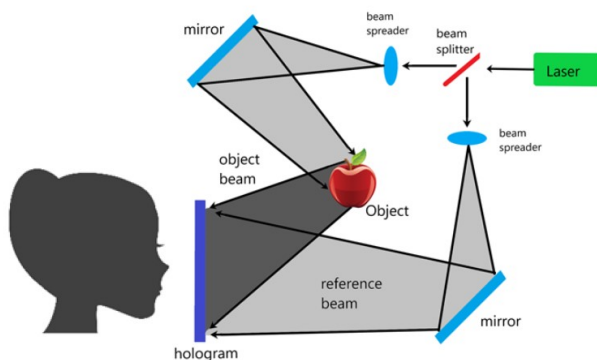

Fig. 2. Transmission hologram

Hybrid holograms Hybrid hologram could be considered as a combination of transmission and reflection hologram. Hybrid hologram can be specified as Multichannel holograms, Holographic interferometry, Integral holograms, Embossed holograms, and Computer-generated holograms. For example, embossed holograms are used for authenticity applications such as

security hologram stickers, in passports or on credit cards. Computer-generated holograms are used to make optical elements, for scanning, splitting, in general for controlling laser light (CD player can be an example) [9]. Thanks to its technology this type of holograms is not relevant for our work, so we will not pay more attention to it.

3. Holographic Hardware

Each hologram has to be generated by a holographic equipment. In our case we used product of Realfiction company. The company offers a wide range of devices that differ in sizes and in the number of display areas. The price of devices is between (2,000$ - 10,000$). Their main purpose is to present the good in markets.

In the paper we used the Realfiction Dreamoc HD3.2 (Fig. 3). The device has three-sided view, 23" screen and built-in loudspeakers. Its connectivity is realized via HDMI port and RJ45 port. More details about this equipment can be found in [15].

Fig. 3. Front side of Realfiction Dreamoc HD3.2

The Dreamoc HD3.2 device is big enough to help teacher with 3D model presentation in the lesson. On the other hand its biggest disadvantage is the already mentioned higher price.

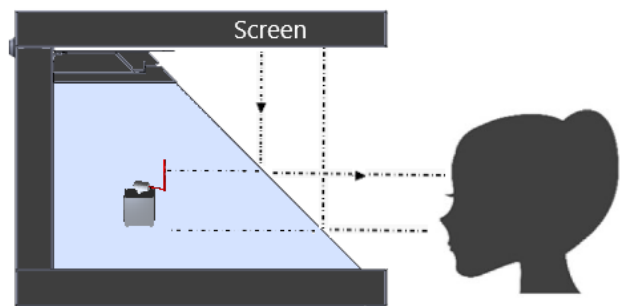Fig. 4 shows how the Dreamoc HD3.2 projection works.

Fig. 4. Projection in Realfiction Dreamoc HD3.2

The device consists of two main parts. The first part is the image-emitting screen, which is placed on top and emits the image. The Dreamoc HD3.2 uses Full HD screen. The quality of projected image is conditioned by used resolution. The second part is a projection

glass with a semi-permeable layer, which is placed at a 45-degree angle below the screen. The screen provides an image that is reflected on the glass. By placing the glass at the specific angle, the image is presented as if it is behind the glass. It acts as a delusion on the eyes, which creates virtual image of the presented object.

4. Application

Building the application we wanted to fulfil several goals:

- to make realistic view of 3D mechatronic experiment,
- to visualize the 3D experiment via holographic device,
- to control the behaviour of the experiment using parameters entered by the user.

Front-end side of application The application was developed with minimal requirements and possibility of future adoption. Using web technologies was probably the simplest solution. The main structure of web page is made by HTML, CSS and JavaScript with the use of its libraries. The front-end side is divided into control and view part. The view uses the Three.js library, which allows us to render the 3D model on the screen. It is necessary to realize that the display area is in the hologram, so it is not possible to change the control parameters from there. To do so, we needed to use two browser windows. The first one is opened in hologram as the view and the second one in computer screen as the control window. It is allowed via multiscreen model (Fig. 5).
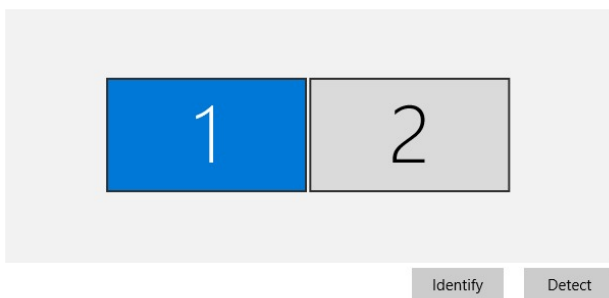

Fig. 5. Windows multi-screen mode

Back-end side of application The back-end of application is driven by Laravel PHP framework, which is mostly used because of its well-designed object relation mapping implementation. It is connected to a MySQL database, which contains information about the used control algorithm defined in the block schema and default input values for experiment controller.

Back-end is managed by Model-View-Controller architecture. When the control interface is opened, data for specific experiment are automatically downloaded from MySQL database and an HTML form with

parameters is generated. This form is generic to ensure the possibility of adding new experiments in the future.

The realistic movement in visualization is achieved by the use of numerical values computed in Scilab/Xcos simulation environment that is available as a web service. Each experiment is represented by one block schema and computed outputs correspond to changing position of dynamical parts of the simulated mechatronic system.
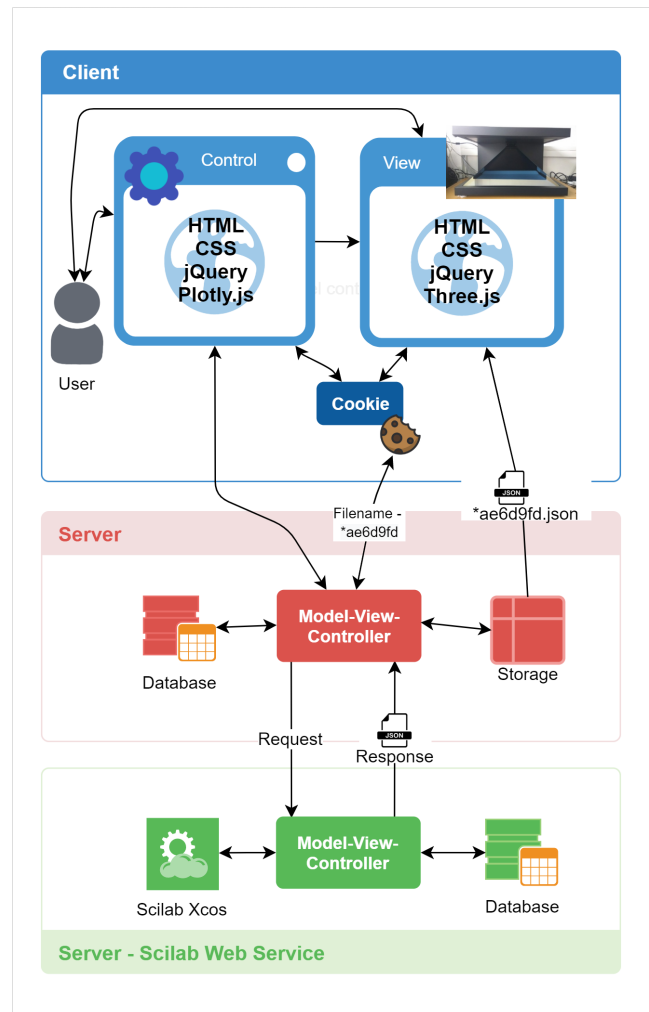
The system architecture is shown in Fig. 6.

Fig. 6. Architecture of the created system

Web service To facilitate calculation of numerical values needed for visualisation, the suitable simulation or computation environment such as Matlab, Scilab or Octave can be used. We decided for Scilab/Xcos. It is an open source distribution modeling and simulation software for numerical computation. There were several reasons why it was chosen.

Firstly, there is commercial and noncommercial software. Matlab is the most used and professional software, but the license is needed and not everyone can have access to it. Other programs can be included in open source category. However, Octave does not provide a a possibility to build block diagrams suitable for easier creation of controllers. The remaining Sci-

lab/Xcos environment fulfil this requirement and also has appropriate numerical methods to solve differential equations. In addition, it is the closest open source option to Matlab/Simulink.

Secondly, for the future development it is more suitable to create an application as a modular system. For these purposes it is very useful to have an Application Programming Interface (API) that allows us to use the simulation software as a web service. The advantage of the simulation environment that is located on the server is that everyone who requires to retrieve the data needs to know only the URL and how to access the software through the appropriate API. We had API for Scilab at the time of implementation, so therefore we decided to use it. Since the entire data processing module is running independently, it can be easily changed or replaced. Also, application can be expanded to a different simulation environment in the future.

Module with Scilab has its own interface, it works as standalone application. It requires uploading block schema to the server before the first simulation. Then, it can be accessed via URL by an authorized program.

3D visualization process   The main problem of showing results using the 3D model is to ensure how to communicate between the control and the view interface. During visualization the change of parameters should be possible. Since each client window works separately, it is necessary to inform the view interface about parameter changes in control interface.

The application uses simple solution. When the control view is opened, a random SHA code is generated and saved as cookie value. Then, the cookie is also used as a file name for data sent from simulation. The user view interface gets these data and starts to render the movement of experiment. The animation is generated in a loop, so experiment never stops.

5. Furuta Pendulum Experiment

The whole solution is demonstrated on Furuta Pendulum example. In similar way another 3D models can also be realised.

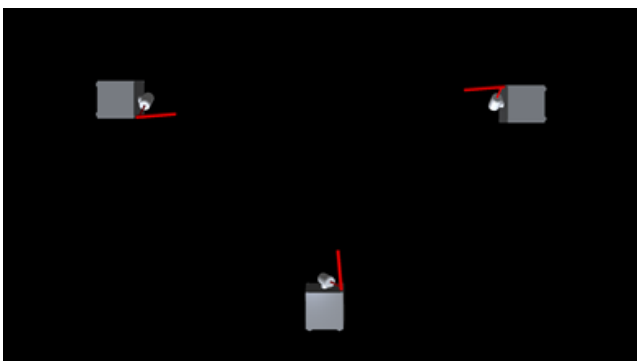Once the view for holographic device is created, it should look like in Fig. 7.

Fig. 7. Furuta pendulum 3D model visualization for Dreamoc HD3.2

The used device needs to have model displayed three times and rotated by ninety degrees, because of its three-side projection unit. Then, the 3D model on the bottom is shown on the front side of the device and the other two ones on its left and right side. The dark background behind the displayed objects enables to create more realistic movement of the hologram.

To start the experiment it is necessary to open the view interface (Fig. 7) in the holographic device. The computer during this process is connected to the screen via the HDMI port. To create a movement of the pendulum, data from simulation are required.

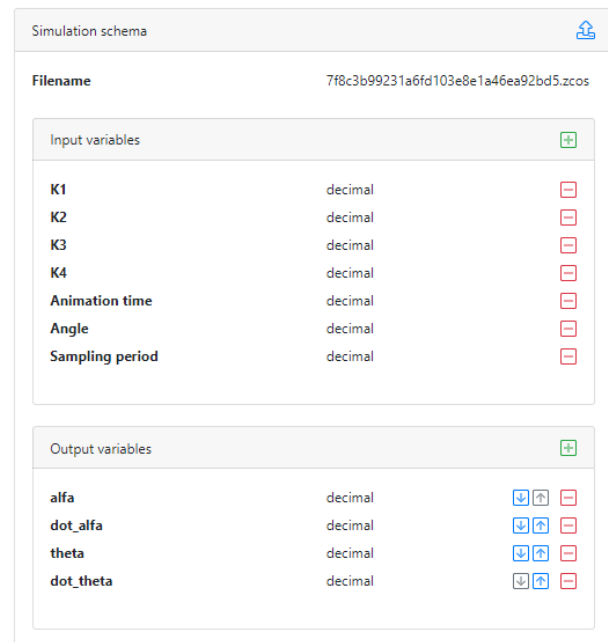In Fig. 8 GUI (Graphical User Interface) of created web service is shown.

Fig. 8. Graphical user interface of the Scilab module

One can see there the uploaded block schema containing a state space controller with predefined parameters:

- **Filename** is a file name used in Scilab/Xcos block schema. The name on the server after uploading is automatically encoded into random hash code. It uses zcos format, the newest standard used in Scilab 6.0.2.

- **Input variables** are names of variables used in uploaded zcos file. *K1, K2, K3, K4* are gains of the used controller. In addition, it is necessary to define the animation time (i.e. length of the simulation), sampling period and the required angle of pendulum.

- **Output variables** are time, height and speed. System uses these variables to map output from Scilab console to JSON format.

Fig. 9 shows the control interface that enables user to enter own parameters for simulation.

After sending the request to the server (by clicking on the button Start simulation), the data will arrive

Controllers

Controller	K1
State ▼	-3.5463
Animation time	K2
5	-2.1498
Angle	K3
60	-20.0816
Sampling period	K4
0.01	-4.6941

Start simulation

Fig. 9. Control view interface form for Furuta pendulum using state space controller

within seconds and the model simulation will automatically start. The initial parameters can be altered by sending a new request. The process is designed to change the movement automatically. Fig. 10 shows the holographic device Dreamoc HD3.2 connected to computer via HDMI.

Fig. 10. Dreamoc HD3.2 displaying Furuta pendulum controlled via control interface

6. Conclusions

Every educational institution should help students with understanding the subject matter. The presented paper deals with the use of holographic technology in control education.

The created application enables to simulate 3D objects presenting mechatronic devices that are control-

led by the predefined control algorithm. The application uses Scilab/Xcos as simulation environment for computing data needed for output animation of visualised model.

The presented 3D model was displayed as hologram. Unfortunately, the holographic device that was used to show the model and behaviour of Furuta pendulum cannot be considered as a solution that could be used massively due to its higher price. However, the tool can be used as a display device for teachers on lessons. On the other hand, the application can be simply modified to a device that is not subject of a high price and this version could be deployed for an everyday use.

As a future work authors would like to change the used device for the cheaper one. Also, they would like to extend the application to use it through augmented reality and deploying it on smartphones, using Google ARCore platform.

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