

# Web Based E-learning Tool for Visualization and Analysis of 3D Motion Capture Data

Andraž Krašček  
eŠola d.o.o.  
Slovenia  
andraz@easistent.com

Kristina Stojmenova, Sašo Tomažič and Jaka Sodnik  
University of Ljubljana  
Faculty of Electrical Engineering  
Slovenia  
kristina.stojmenova@fe.uni-lj.si  
saso.tomazic@fe.uni-lj.si  
jaka.sodnik@fe.uni-lj.si

**Abstract**—In this paper, we propose an e-learning tool for visualization and manipulation of 3D data on a web platform. The data is streamed in real time from an optical motion capture system Qualisys consisting of eight infrared cameras and Qualisys Track Manager (QTM) software. A WebSocket protocol and WebGL application programming interface (API) are used to visualize and to interact with the data in a browser. The tool represents a web-based extension of QTM software providing also additional features and new possibilities to manipulate and analyze the data. We report also on a user study in which we evaluated the web based application and compared it with the original desktop-based application. The proposed application proved to be fast, effective and intuitive and can be used as an e-learning tool for demonstrating and teaching techniques for visualization and analysis of motion capture data.

**Keywords**—*motion capture; Qualisys; e-learning; 3D data; AIM model; WebGL; WebSocket.*

## I. INTRODUCTION

Optical tracking systems enable motion capture and recording of motion parameters of a selected object in space. They are commonly used to track motion in the field of biomechanics, industrial ergonomics, the moviemaking and entertainment industry, etc. Such systems consist of passive or active reflective markers that are placed on the points of interest of the monitored object, and infrared cameras that observe the motion of these markers in space. Active markers are light emitters, usually light-emitting diodes (LEDs), while passive markers are only light reflectors. Infrared cameras detect the light reflected from the markers and acquire their two-dimensional (2D) position in the recorded image. The system then combines 2D positions from all cameras and calculates the exact 3D position of markers in space. The tracking process begins with calibration, which provides information on exact positions and orientations of the infrared cameras. With higher number of cameras, a more accurate 3D position can be determined.

The goal of our research was to design and implement an e-learning tool for the visualization and analysis of motion capture data on multiple computers simultaneously. The analysis is of vital importance when dealing with motion and movements in sports. The tool we propose can for example be used for establishing the correlations between different

segments of data (i.e., observing the amplitude of head movements in relation to knee angle when performing squats). Consequently, it needs to include numerous measurements, such as the length of selected bones, the angles between the bones, the velocity or acceleration of selected segments, etc.

By e-learning, we refer to a web-based system that makes information or knowledge available to students and teachers disregarding their geographic proximity and time restrictions [1]. The users can analyse and manipulate complex data sets remotely and use the tool to demonstrate different methods and procedures in real time. E-learning web applications are also affordable and easy to distribute to a large number of users by simply using a compatible web browser [2].

## II. RELATED WORK

Visualization of 3D data in web applications has been addressed in numerous studies in different domains. In many cases, the rendering process was based on isosurface polygonization [3, 4, 5] enabled by various plug-ins in the browser. The most common issues related to this problem were specialized and dedicated programming languages, plug-in requirements, limited portability across browsers, devices and operating systems, and advanced rendering support [6]. Today, the rendering process has been significantly simplified by the technology called WebGL [7]. It is a JavaScript API based on OpenGL ES 2.0 for manipulation of 3D graphics in a web browser. It uses the OpenGL shading language, OpenGL for Embedded Systems (GLSL ES), and can be cleanly combined with other web content layered on top or underneath the 3D content. It is ideally suited for dynamic 3D web applications in the JavaScript programming language, and has been fully integrated in all leading web browsers.

Several researchers reported on using WebGL for monitoring and interaction of 3D graphics in a web browser. A lot of them exposed the benefits of using web-based applications in order to lose dependency of hardware.

Conote, Segura, Kabongo, Moreno, Posada, Ruiz discussed performance and scalability of the volume rendering by WebGL in different application domains [3]. In their work, they presented how implementation of a direct volume rendering system for the web articulates in efficient manner the capabilities of WebGL, making the formerly unusable accelerated graphic pipeline available.

WebGL with the ability to put hardware-accelerated 3D content in the browser represents a mean for creation of new web based applications that were previously exclusive for the desktop environment. C. Leung and A. Salga discussed how mid-level APIs can help develop web applications that do not only copy the desktop application but can contain unique 3D content as well [9].

3D monitoring of static objects has also been a subject of research. Museums and similar institutions show growing interest into showing their collections to a wider public through the web. Schwartz, Ruiters, Weinmann and Klein have proposed a WebGL-based presentation framework, which does not only provide a 3G geometry, but a powerful material representation, capable of reproducing the full visual appeal of an object as well [10].

In this paper, we propose a web based e-learning tool for visualization and manipulation of 3D motion capture data in real time and on high number of computers simultaneously. It also supports observation and analysis of various motion parameters of observed objects and models, as well as active collaboration between different web users. Our goal was not only to develop an application that will provide access to data for observed models but also to provide a positive user experience and good usability of the system [11]. Based on the positive experience with WebGL API reported in the Related Work section, we selected this technology to develop the user interface in a browser.

#### A. Our research contribution

To our knowledge, this is the first example of the visualization and manipulation of motion capture data on a web platform supporting a high number of simultaneous users. The research hypothesis of our work is that by enabling the instructors and students to work with motion capture models through web-based clients, the teaching/learning experience will be greatly enhanced. The main field of use of the application is academia and education where it can be used as collaborative tool for teaching motion tracking system techniques and data processing methods.

In the rest of the paper, we describe the proposed system and the corresponding user interface. We also report on a user study performed to evaluate the usability and user experience of our web application in comparison to the original desktop motion capture software. The results of the experiment are presented and statistically analysed. The Discussion section summarizes the most important findings and proposes some ideas for future work.

### III. SYSTEM ARCHITECTURE

#### A. Qualysis Track Manager

In our research, we use the professional motion capture system Qualisys [12]. The system consists of eight high-speed cameras, a set of passive markers and the proprietary tracking software called Qualisys Track Manager (QTM) [13].

This is a complex desktop application, which calculates the exact 3D position based on separate 2D images from all cameras. It also takes care of infrared (IR) cameras calibration, motion capture recording, creating and editing models, analyzing data on models, streaming captured motion, etc. It runs on a standard PC and exchanges data with the cameras through a standardized Ethernet protocol.

QTM shows the 3D position of each marker in a Cartesian coordinate system as a coloured dot. Individual markers or a group of markers can be labelled and connected to a structure called “model”. Each pair of markers with constant inter-distance can be connected with a line called bone (due to its rigid structure). When tracking the motion of humans the QTM bones correspond to the bones of human body.

The created model, which consists of a set of markers and bones, can be saved for future measurements as an Automatic Identification of Markers (AIM) model. However, the visualization and analysis of the stored AIM model can be done only on a single computer running the QTM software. Figure 1 shows a screenshot of QTM with an example of AIM model (the model represents an upper part of human body).

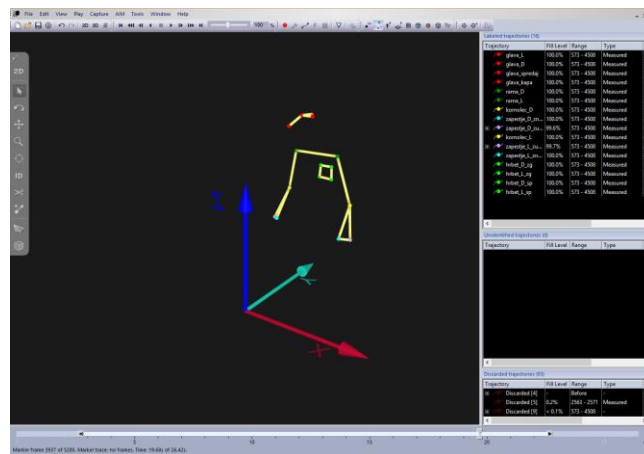


Figure 1. The visualization of an AIM model in QTM software.

QTM is a very complex tool, which supports a high variety of commands and features. The user interface is therefore rather complicated and not very intuitive. It is primarily intended for controlling the cameras and not for the analysis of the recorded data. The latter is rather limited and cannot be saved or exported in a way that it could be used in different application. Since it does not allow simultaneous work of a larger number of users it is inappropriate to use it as an academic tool.

#### B. Web Based E-learning Tool

The architecture of the web application is divided into three levels as shown in Figure 2 [14]. First, data on marker coordinates is streamed from QTM and stored to a special buffer on a Node.JS web server [15].

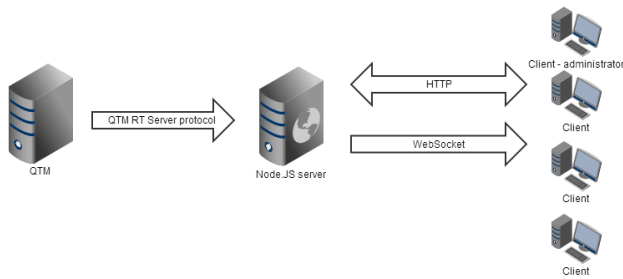


Figure 2. The web application system architecture [14].

Communication between the QTM and the web server is based on real-time (RT) protocol (Qualisys’ proprietary protocol for streaming data in real time). Server acts as a hub and translates raw data to JavaScript Object Notation (JSON) and broadcasts it to all connected clients through a WebSocket protocol [16]. The latter allows full-duplex communication between a server and a client and its packet headers are smaller than HTTP’s.

The client side application is divided into two main modules. WebSocket module is used for communication with the server while the WebGL module is responsible for rendering and interaction with 3D space through navigation panels. The WebSocket module reads the server data stream and updates the local storage when new marker data is received. It is built to be as lean as possible because both modules run in the same thread and the goal is not to block the WebGL module while it is rendering 3D data. WebGL module on the other hand is constantly rendering 3D space and exposing it in canvas HTML5 element. Constant rendering is needed for smooth user interaction with 3D space. When user moves, jaws, pitches or zooms in/out the 3D scene only the view matrix is recalculated and transformed. On each render loop, the markers’ coordinates are read from local storage and the bone data is loaded from the model. Finally, based on the view matrix the scene-space is transformed to view-space.

### 1) User interaction with 3D space

The main goal of web application is the visualization of 3D space with markers and corresponding AIM models. Markers are coloured in colours defined in QTM application to help the user to differentiate between groups of markers. User can interact with 3D space using the mouse. While holding a mouse button and dragging a cursor user can rotate 3D space. If user drags the cursor horizontally, 3D space rotates around Z axis. If user drags the cursor vertically, 3D space moves around X or Y axis depending of Z rotation. User can also zoom in or zoom out by turning a mouse wheel. This command can also be initiated by using keyboard keys “page up” and “page down” in case user’s mouse lacks the wheel. User can select a single marker by clicking it or an array of markers by holding “ctrl” key on keyboard while clicking several individual markers

consequently. The click on an already selected marker will deselect it.

### 2) Creation of a model

A model can be thought as an undirected graph where markers represent nodes and bones between markers represent edges. In the web application, we tried to design a process of creating models as seamless as possible. To create a bone a user must select two individual markers in 3D space. The bone is initialized by clicking the *BONE* button on the right bottom section of the dashboard. Only one bone can exist between the two individual markers. If multiple markers are selected in a consequential order multiple bones will be created between these markers. When all the bones in the model are created a user can save the model by selecting the corresponding command in the models navigation panel and defining its name. Models can be saved, loaded to a set of markers in 3D space or deleted.

The model navigation panel is positioned in the upper right corner of the screen and it is divided in two subpanels. It allows a quick overview of all saved models and interaction with models. It features all possible actions a user can execute on the currently loaded model. The screenshot of the application is shown in Figure 3.

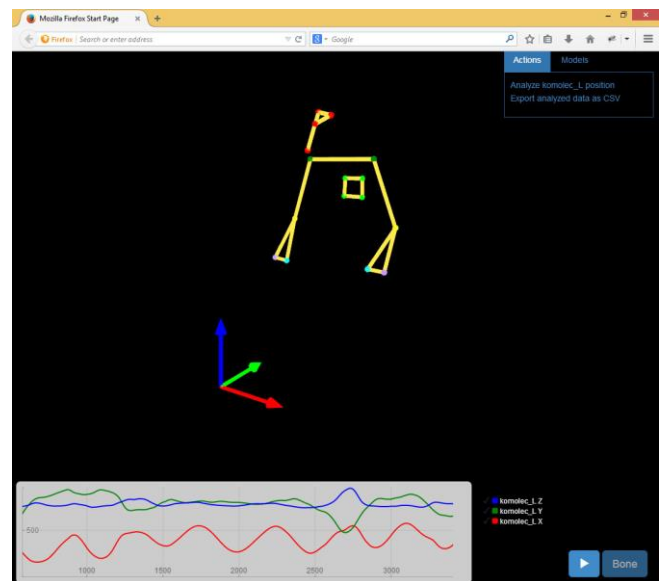


Figure 3. The web application with simple model and marker position analysis chart.

### 3) Manipulation with models and analysis

At each time, only currently available actions are visible in the panel depending on the current state of the model. The goal was to reduce the number of menus and settings in order to simplify the user interface and increase its intuitiveness. When, for example, only one marker is selected the only available action is the analysis of its position in space as a function of time. When two markers

are selected the length between these two markers can be analyzed as well their individual positions in space. If two bones connected by a shared common marker are clicked and selected, it is possible to analyze an angle between those two bones as a function of time.

Data from all types of analysis are presented in an interactive chart. The X-axis shows time frames and the Y-axis shows the corresponding distance or angle (the unit is therefore expressed in millimetres or angular degrees). The exact value of the individual time frame can be extracted by dragging the timeline bar across time frames and locating the desired frame. Figure 4 shows two examples of analysis charts for an angle (in degrees) between two bones and for a position (in millimetres) of a selected marker in space respectively.

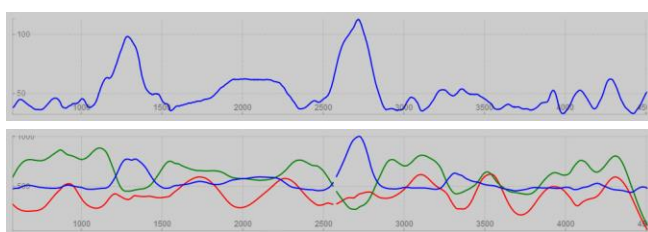


Figure 4. An example of two analysis charts showing the angle between two bones (upper figure) and position of a marker in space (lower figure) respectively.

All analysis' results can be exported by selecting the *EXPORT* action. The supported output formats are CSV (Comma separated Values) and JPG image. The CSV format can then be imported by majority of available third party software.

#### 4) User collaboration and data synchronization

The most important feature of the proposed e-learning tool is the possibility of simultaneous work and collaboration of high number of users. A typical scenario is when a lecturer demonstrates various motion capture techniques and scenarios by operating QTM software and IR cameras in real time. Students participate in the experiment at the same location or remotely through an internet connection. They can use any stationary or mobile device with a web browser supporting WebGL API. They all work on the same stream of data (same set of markers) but the interaction with the content such as creation of models and corresponding analyses are individualized.

Additional feature of the application is a collaboration tool, which provides methods for synchronization of users' data. All users connected to the same session can synchronize their local AIM models. Each user can propose and send his or her model to other session members or load the model proposed by other members. In this way, students have an option to participate actively in the manipulation of data or to be just passive observers. In the second case, a model, which is a subject of analysis, is built and sent to their application by other user (e.g., the lecturer). However,

they can still fully manipulate the view of the 3D scene and interact with the model.

## IV. USER STUDY

In order to test the proposed e-learning tool and to evaluate its effectiveness and intuitiveness, we conducted a user study in which we compared the tool with the original QTM application. The two applications represented two independent variables of the experiment. The three dependent variables were:

- Task completion time or the time required to solve given tasks;
- Subjective evaluation of the applications assessed with User Experience Questionnaire (UEQ) questionnaire;
- General subjective remarks given by the participants.

### A. Participants

A total of 15 students of multimedia, electrical engineering and computer science participated in the user study. The subjects ranged from 20 to 28 years of age ( $M=23.1$  years,  $SD=2.4$  years). All participants reported normal eye sight, except for one who was wearing glasses due to myopia. Eight participants had prior experience with the visualisation and manipulation of 3D data (applications such as Blender, Google SketchUp, SolidWorks, etc.). They were randomly distributed into two experiment conditions described bellow. None of them had any experience with motion capture systems whatsoever.

### B. Experiment design

The experimental design was a between-subject, dividing participants into two groups to avoid sequence effects and confounds (due to the similarity of commands and controls in both application). The first group (8 test subjects) performed the set of selected tasks with the proposed web application while the second group (7 test subjects) performed same tasks with the QTM application. Prior to the experiment the participants were given a short explanation on how motion capture system works and about the purpose of the application they were about to use. They were also given approx. five minutes to get familiar with the application and its interface. Each participant conducted the experiment individually following the instructions of the experiment leader.

In the first part of the experiment, each participant was asked to perform 3 different tasks:

- Build a model by connecting markers with bones (T1);
- Save and load the created model (T2);
- Perform an analysis on the built model (T3); This task was broken down to 5 subtasks:
  - Analyze position of the right elbow;
  - Analyze length of the right upper arm;

- Analyze the angle of the right elbow;
- Read the exact value of the previously analyzed angle for the specific time frame;
- Save the analyzed data to a file in raw format.

In the second part of the experiment, the participants from both groups had to fill in a standardized UEQ and evaluate the used application [11]. The UEQ questionnaire assesses the participants’ feelings, impressions and attitudes towards the tested application. The questionnaires were translated into Slovenian language – the native language of the participants.

In the third and the final part of the experiment, the participants were asked to give their opinion and general remarks about the tested application. Any comment or remark about the application at any stage of the experiment was also registered by the experiment leader.

All computers running QTM, NodeJS server and web browser were connected through a local network providing high bandwidth. As a consequence, the page response and loading times as well as latencies on the network were very low and did not affect evaluation procedure.

## V. RESULTS

The three variables evaluated in the user study were the following:

- Task completion times;
- UEQ;
- Subjective comments about the applications and user interfaces.

### A. Task completion times

The time required to complete the individual task was measured manually by the experiment leader. A timer was started just after the experiment leader would read the instructions for the selected task and stopped after when the participant was comfortable with the result achieved for that task. Figure 5 shows all task completion times for both applications. The between subject ANOVA and the post-hoc Bonferroni tests with a 0.05 limit on family wise error rate were used for the comparison of data (the normal distribution of data was confirmed with Shapiro-Wilk test).

The proposed web application seemed to be slower than the original QTM application for creating bones and building models (task T1). However, no statistically significant differences were found in this task ( $F(1,12) = 3.733, p = 0.077$ ). There was also no significant difference for T2 ( $F(1,12) = 2.037, p = 0.179$ ) and for T3.1 ( $F(1,12) = 4.505, p = 0,055$ ). For all the other tasks the proposed web application outperformed the QTM application:

- T3.2:  $F(1,12) = 20.618, p = 0.001$ ;
- T3.3:  $F(1,12) = 15.826, p = 0.002$ ;
- T3.4:  $F(1,12) = 43.153, p < 0.001$ ;
- T.3.5: ( $F(1,12) = 14.182, p = 0.003$ ;

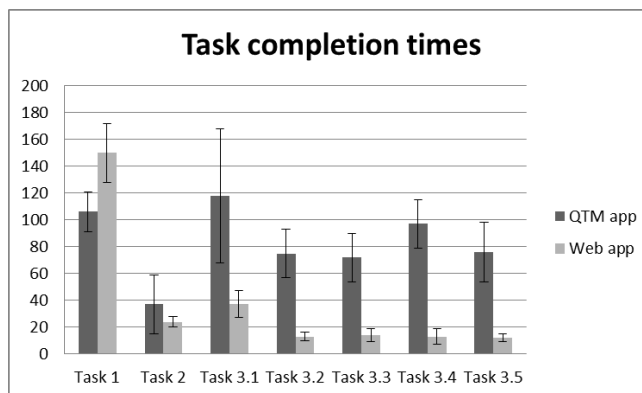


Figure 5. Average task completion times (in seconds) with confidence intervals.

The standard deviation is smaller and the corresponding confidence intervals are narrower for all tasks performed with the proposed web application. We believe this reflects intuitiveness, reliability and robustness of the proposed web interface.

### B. UEQ

After completing the set of tasks, the participants were asked to complete the UEQ questionnaire. The questionnaire consists of 26 individual statements, which are graded with a seven stage Likert scale to reduce the well-known central tendency bias for such types of items [18]. The results of these grades are grouped to 6 different categories (attractiveness, perspicuity, efficiency, dependability, stimulation and novelty). Figure 6 shows average UEQ scores for individual categories.

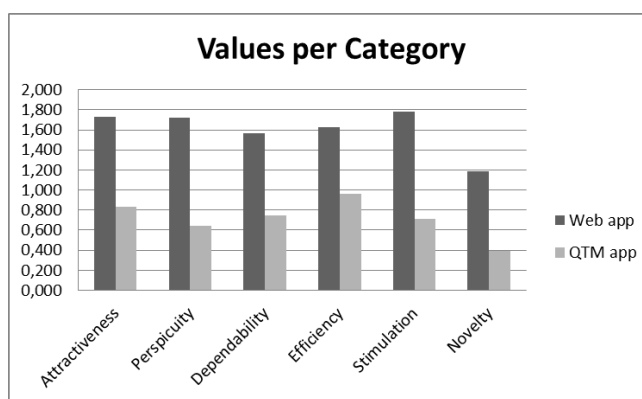


Figure 6. Average UEQ values for six categories.

The mean scores of the proposed web application were higher in all six categories. Again due to the normal distribution of data, the ANOVA and post-hoc Bonferroni tests with a 0.05 limit on family wise error rate were used for comparison. The statistically significant difference between the applications was found only in the categories attractiveness, perspicuity and dependability:

Attractiveness:  $F(1,12) = 11.703$ ,  $p = 0.005$ ;  
 Perspicuity:  $F(1,12) = 11.456$ ,  $p = 0.005$ ;  
 Dependability:  $F(1,12) = 12.928$ ,  $p = 0.004$ ;  
 Efficiency:  $F(1,12) = 2.001$ ,  $p = 0.183$ ;  
 Stimulation:  $F(1,12) = 3.123$ ,  $p = 0.103$ ;  
 Novelty:  $F(1,12) = 0.795$ ,  $p = 0.390$ ;

### C. General remarks

After each experiment, we interviewed the subjects about their experience. We were primarily interested in some general comments and remarks about the proposed web application. In this section, we list some comments and suggestions for improvement expressed by several test subjects:

- markers were too small and hard to select;
- there should be more keyboard shortcuts for some commonly used actions;
- some descriptions of results of analyses are unclear;
- double-click could be used to list available commands and actions at any time;
- etc.

Some participants who had experiences with 3D applications and 3D interfaces reported to have problems using the current interface due to new interaction methods and metaphors introduced in the software.

## VI. DISCUSSION AND CONCLUSION

The main goal of this user study was an evaluation of the proposed and developed web application to reveal its advantages and disadvantages in comparison with an existing QTM application. We aimed to prove that users' actions can be performed faster and more intuitively with such task-specific application compared to a general-use application. The final scope of functionalities and features for the analysis of the captured data is comparable in both applications as they both require similar complexity of analysis and manipulation of the recorded data. Since the proposed application runs on a web platform as an e-learning tool, it supports simultaneous use of high number of users as well as their collaboration and exchange of knowledge.

The user interface of a web application proved to be equally fast or faster for a majority of tasks. However, no significant difference was found in T1 in which users were asked to build bones and an AIM model for further analysis. This result was not expected since the new interface was improved with additional commands and tools enabling the creation of multiple bones at once. Since no specific instructions were given about these tools only a few users explored and effectively used these features.

For the T2 and T3 the web application was faster than the QTM application, which was an expected outcome. Our application was built primarily to enable various analyses on a model, such as, for example: detection of marker position,

identification of length of a bone, an angle between two bones, etc. The user interface was therefore optimized to support these actions and to make them intuitive. On the other hand, in the original QTM application the analyses and the corresponding actions are just a small set of available features and several users have difficulties finding them among all other actions and menu commands.

The second evaluated parameter in the study was the subjective perception of both applications measured through UEQ test. The web application was judged to be significantly more attractive (attractiveness category), understandable and clear (perspicuity category) and dependable (dependability category). We believe these high scores reflect simple, clear and intuitive user interface, which adapts to user actions and changes its state and a set of available controls depending on what the user is currently doing. The lower score on the other hand were given in the category novelty. There was no significant difference found between our web application and the original QTM application. We believe these scores reflect the facts that majority of test subjects had no or very few experiences with motion tracking techniques and visualizations of 3D data. The main part of the user interface was a simple 3D visualization of a Cartesian coordinate system with a set of coloured points (markers) at different positions, which the user did not find very novel or exciting. We also believe a more significant difference could be found if a within subject test was performed enabling the users a direct comparison of both systems and user interfaces.

The collected set of subjective comments revealed some problems and ambiguities of the proposed interface as well as missing commands and potential extensions. Several comments referred also to visualization problems, which are related to the WebGL API and their improvement is out of our power. These comments will be used primarily to improve the proposed interface in terms of its efficiency and clearness and its upgrade with new features and commands.

Our future goal is to extend the set of available features for the analysis of motion data in the applications as well as the features related to remote collaboration and exchange of data. Another important module which is currently not available and should be implemented in the future is a common platform supporting predefined learning processes and tasks, the authentication of users, the creation and storage of the users' profiles, the monitoring of learning progress, etc.

We believe our application demonstrates the high usability of modern web technologies for the development of new powerful and rich services in the e-learning domain. Real time streaming of complex 3D data and their visualization in an interactive scene in a browser are an excellent use case for many other similar services. In the future, the impact of the proposed e-learning software on the learning performance and methodology should also be evaluated.

REFERENCES

- [1] P. Sun, R. J. Tsai, G. Finger, Y. Chen, and D. Yeh, "What drives a successful e-Learning? An empirical investigation of the critical factors influencing learner satisfaction," *Computers & Education*, vol. 50, issue 4, May 2008, pp. 1183-1202.
- [2] A. Anyuru, *Professional WebGL Programming: Developing 3D Graphics for the Web*, John Wiley & Sons, Apr 23, 2012.
- [3] P.-A. Fayolle, B. Schmitt, Y. Goto, and A. Pasko, "Web-based constructive shape modeling using real distance functions," *IEICE - Trans. Inf. Syst.*, vol. E88-D, no. 5, May 2005, pp. 828-835.
- [4] R. Cartwright, V. Adzhiev, A. A. Pasko, Y. Goto, and T. L. Kunii, "Web-based shape modeling with hyperfun," *IEEE Computer Graphics and Applications*, vol. 25, no. 2, 2005, pp. 60-69.
- [5] Q. Liu and A. Sourin, "Function-defined shape metamorphoses in visual cyberworlds," *Vis. Comput.*, vol. 22, no. 12, Nov. 2006, pp. 977-990.
- [6] J. Behr, P. Eschler, Y. Jung, and M. Zollner, "X3dom: a dom-based html5/x3d integration model" in *Proceedings of the 14th International Conference on 3D Web Technology*, 2009, pp. 127-135.
- [7] *WebGL - OpenGL ES 2.0 for the Web*. Available from: <http://www.khronos.org/webgl/>, 2014.10.03
- [8] J. Conote, A. Segura, L. Kabongo, A. Moreno, J. Posada, and O. Ruiz, "Interactive visualization of volumetric data with WebGL in real-time" in *3D Web Technology*, 2011 pp. 137-146.
- [9] C. Leung and A. Salga, "Enabling WebGL", *World wide web*, 2010, pp.1369-1370.
- [10] C. Schwartz, R. Ruiters, M. Weinmann, and R. Klein, "WebGL-based streaming and presentation framework for bidirectional texture functions", *Virtual Reality, Archaeology and Cultural Heritage*, 2011, pp. 113-120.
- [11] J. Nielsen, "Usability 101: Introduction to Usability". Available from: <http://www.nngroup.com/articles/usability-101-introduction-to-usability/>, 2014.10.10
- [12] *Qualysis Motion Capture Systems*. Available from: <http://www.qualisys.com/>, 2014.10.10
- [13] *QTM – Qualisys Track Manager, User Manual*, 2011.
- [14] A. Krašček and J. Sodnik, "Qualisys Web Tracker – A web-based visualization tool for real-time data of an optical tracking system", *ICIST 2014 Proceedings*, 2014, pp. 155-160.
- [15] S. Tilkov and S. Vinoski. "Node.js: Using JavaScript to build high-performance network programs." *IEEE Internet Computing*, vol. 14, issue 6, 2010, pp. 80-83.
- [16] *The WebSocket Protocol*. Available from: <https://tools.ietf.org/html/rfc6455>, 2014.10.06
- [17] *What is the UEQ?* Available from: <http://www.ueq-online.org/>, 2014.10.06
- [18] B. Laugwitz, T. Held, and M. Schrepp, "Construction and Evaluation of a User Experience Questionnaire". Available in: *Holzinger, A. (Ed.): USAB 2008, LNCS 5298*, pp. 63-76.