Development of Web-available Models of Human Spinal Vertebrae for Biomedical Engineering Research and Education

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***Abstract* - Sharing different types of models over a long distance using Internet has great potential as a resource for research and education. This paper presents the development of different 3D model types of human spine and web-based application for user access and interactive exploration. The remote visualization of models is powered by O3D plug-in/WebGL, GLview 3D Plugin, and STLDroid. End-user is able to review online in real time, and download high-definition 3D models of spinal vertebrae. The presented solution could improve education in the field of biomedical engineering and become useful tool in spinal research.**

I. Introduction

The Internet is strongly influencing all aspects of present-day life including learning [1-4]. Many examples of web-based applications in engineering education are described in the literature [5-8]. Web-based training offer an elegant solution to the need for better training, since realistic and configurable training environments can be created [6, 7]. This can bridge the gap between basic training and performing the actual intervention on patients, without any restriction for repetitive training [7].

Today's Internet knows many web-based solutions in this area. The Body Browser [9] from Google, ZygoteBody [10] from Zygote, and BioDigital Human [11] from BioDigital Systems offer Internet users a new, hi-tech way to explore the human body. These online resources obviously can help students at every level. These new tools promote knowledge and learning while having fun. However, models of organs on these applications are not publicly available.

Many sharing platforms are being currently developed thanks to users' contribution. The ability to share their work and ideas with a large audience of users is an incentive to create and add new content. The VAKHUM project [12] has developed an interactive database of human organs for educational, research and industrial purposes. Users can access the database through a virtual interface and download high-quality data for their own applications, or take an online class on functional anatomy. The 3DVIA [13] empowers anyone, at any skill level, to create and publish professional quality, lifelike 3D applications and experiences, by providing an integrated suite of 3D software and authoring tools, a large marketplace of 3D models and 3D content and a growing community of 3D professionals. GrabCAD [14] also provides different types of free CAD models. All models are created by GrabCAD members and shared for free. These models are general purpose and were obtained without CAD modeling information on how they are faithful to realistic models.

Over the years, finite element method (FEM) has established as appropriate for the predicting of the biomechanical behavior [15-17]. The results of the finite element models may be trusted if they take into account the actual geometry of the domain and realistic boundary conditions [18, 19].

Recent improvements in 3D scanning technology allow a reliably and accurately digitizing of the external shape of many physical objects with high definition and accuracy [20-23]. However, many researchers do not have access to scanning facilities, dense polygonal or quality finite elements models.

In this paper we present the development of a web-based application for user access and interactive exploration of three-dimensional biomedical models through an intuitive interface. It is presented the whole pipeline from the creation of a high resolution 3D and FEM models of each human spine vertebra to its remote rendering on user's computer without any loss of details or accuracy, ensuring enjoyable learning with good academic quality and flexibility, as well as quality resource for R&D.

II. Methods

A. Development of Human Spine 3D Models

In human anatomy, the vertebral column (backbone or spine) is a column usually consisting of 24 articulating vertebrae, and 9 fused vertebrae in the sacrum and the coccyx. It houses and protects the spinal cord in its spinal canal and allows complex motions while providing stability and protection for the spinal cord during a variety of loading conditions. The observed spine was found to be free from spinal disease and trauma (Fig. 1).

We have adopted a direct digitizing approach that provides an alternative method to common method (by stacking coronal and sagittal computed tomography (CT) images) in capturing the highly irregular bony structure of spine. Accordingly, this approach has allowed a better mesh representation of the geometry, which is of the essence in the study of stress distribution patterns in the spine. For each vertebra of spine, overall process consists of the following phases: (a) geometric model development, (b) volumetric model development, (c) surface reconstruction, (d) FEM model development, and (e) upload to web server. After all processing steps, high definition and high density surface models are obtained.

Figure 1. Spine to be digitized

B. Digitizing

3D scanners accurately scan and capture the surface of objects and provide real 3D data [24-26]. Scanning of 3D shape of each spinal vertebra was performed by using optical measuring system GOM ATOS IIe [27-29]. Overall scanning process with the ATOS IIe system covers following phases: (a) calibration, (b) preparation and setting of device, (c) preparation and setting of measurement object, (d) measurement/scanning, (e) processing of measured/scanned data, and (f) post-processing (processing of results).

Figure 2 depicts some phases in the scanning procedure. Figure 2a shows the vertebra being digitized in the vice while the ATOS IIe was used to extract the geometrical data by moving its sensor across the vertebra. Figures 2b and 2c show the scanning vertebra process. Complex geometry is scanned in two measuring project: first project deals with the top half of the model (Fig. 2b), and second project deals with the bottom half of the model (Fig. 2c). Measurement projects are connected through common uncoded reference points that are available (visible) in both projects. Structured-light 3D scanners projects white light fringe patterns on an object surface. The deformations of the pattern are captured by two measurement cameras (Fig. 2d).

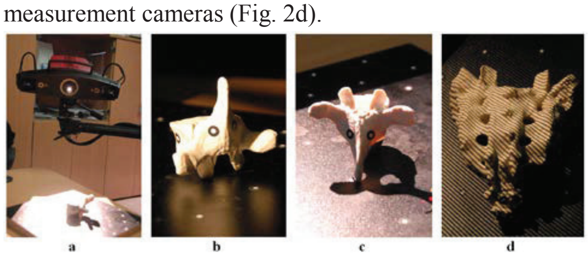

Figure 2. Digitization of specific vertebrae

Complex geometries of the measuring object are digitized through sufficient number of individual measurements. In order to digitize specific part of free-form 3D surface, at least one measurement is required. For each spinal vertebra, more than sixty individual measurements were acquired due to the topological complexity of the physical model, moving the scanner in different position around the object. Figure 3 shows the different stages in generating points on surface of volumetric models. Configurations shown in figure 3 correspond to point cloud generated after 2nd (a), 11th (b), 18th (c), 32th (d), 48th (e), and 62th (f) individual measurement. A dense point cloud is then produced through software. The point cloud represents the digital model of the scanned object. After the poligonization process, the result is a detailed triangulated mesh. The obtained models are registered into the appropriate coordinate system.

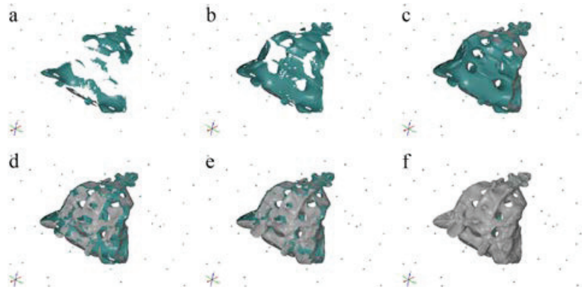

Figure 3. Acquisition of sacrum's 3D shape of scanned object using ATOS IIe system

C. Models' development

Further processing (erasing, reparation, relaxation, decimation, detection of contour lines…) of triangulated mesh is conducted by using Polygon Phase in Geomagic Studio. The key step in development of high quality surface is decomposition of polygonal models in patches or the number of patches covered by grid (the union of Bezier curves). Creating of the model's surface is carried out with introduction of certain assumptions and approximations. Surface reconstruction is performed using generative shape design (CATIA V5) module. Process of reconstruction is ended by export of surface model. Furthermore, the surface created was compared with the actual (digitized) vertebra to ensure its geometric integrity. Following this procedure, volume modeling was thus developed for the entire spine structure. Figure 4 shows the volume rendering for randomly selected spinal vertebrae: C1 (Atlas), L2, T9, and S1-S5+Sacrum.

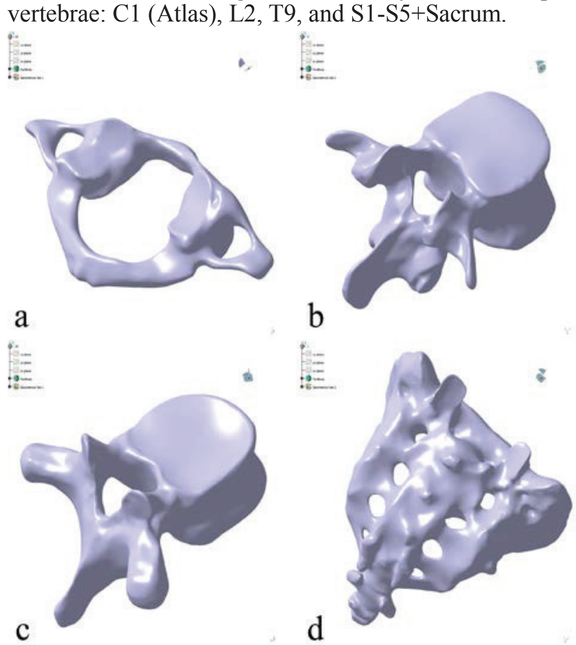

Figure 4. CAD models of random vertebrae: (a) C1 (Atlas), (b) L2, (c) T9, and (d) S1-S5+Sacrum

D. *Interactive Web Resource Development*

The project uses the open source code JOOMLA to implement a repository of 3D models. In terms of system architecture, the portal is created with Apache as a server and PHP as scripting language for dynamic pages. The data and metadata related to the models, as well as a hierarchical organization of the model parts and the link between model parts and relative information is stored in a full open-source object-relational MySQL. Operations delegated to the client are limited to decompression of the records and keyboard and mouse input management.

Raw COLLADA files [30] exported from Meshlab are converted by the COLLADA Converter for use by the O3D JavaScript API. The volumetric models are stored in *.o3dtgz file, which supports binary compression, useful for sending lighter data over the Internet, and hypertext mark-up language. The remote visualization of models, stored in *.o3dtgz file, is powered by O3D plug-in [31], as the most appropriate solution for developed viewer. The O3D JavaScript application code is completely contained in an HTML document that is loaded into a web browser. O3D software communicates with system's graphics hardware through either the OpenGL or Direct3D library. The framework supports known HTML interaction standards and event models on 3D objects. Nowadays, JavaScript implementation of the O3D API using WebGL replaces the original O3D plug-in. To be able to enjoy the power and the knowledge of this new Google asset, users must have a WebGL capable Web browser.

GLview 3D Plug-in [32-34] is a free 3D viewing component enabling presentation of finite element analysis data generated by GLview Inova or the GLview Express Writer. GLview Inova support standard simulation codes (PAK, ABAQUS, ANSYS, FEMAP, I-DEAS, LS-DYNA, MSC. Marc, MSC. Nastran, PAMCRASH, RADIOSS, CGNS, Fluent). The analysis results can subsequently be distributed in a compressed file by utilizing the free tools GLview Express and GLview 3D Plug-in. The plug-in is embedded into web environment and enables full 3D interactivity and high performance graphics. GLview 3D Plugin reads encrypted VTF and VTFx files, that can be created using GLview Inova or wrote as a solution calculated by software PAK [16, 17] using the GLview Express Writer. The files can contain the 3D model, selected scalar and/or vector results, display and animation settings, feature extractions (iso-surfaces, cut planes, particle traces) and annotations.

Due to the rapid development of mobile platforms and operating systems, next step was to enable the developed models are displayed on these devices. With this kind of technology the user can utilize hardware tools (netbook, PDA or smartphone), even despite the limited bandwidth connection, to access the platform. For the Android platform, there is a number of open source software that can display generated models. Within this part of project the open source STLdroid viewer was implemented. Using dedicated links, models stored on the dedicated server can be interactively displayed on users' devices. These models are smaller and have a smaller number of details due to still limited performances of these devices.

III. Results and Discussion

Application can be accessed through the Internet. It requires that the users register once to the system database. The platform allows efficient and effective sharing of high quality 3D models without the need for the end user to download it to the local PC.

The Figure 5 shows a block diagram of the developed application. The user, through the dedicated web page, has to run O3D and/or GLview plug-in which installs and automatically configures the client to access the graphics application. It is not required to the user to know any configuration features or install other kind of applications. Once the plug-in is activated, navigation in the view is done using the mouse.

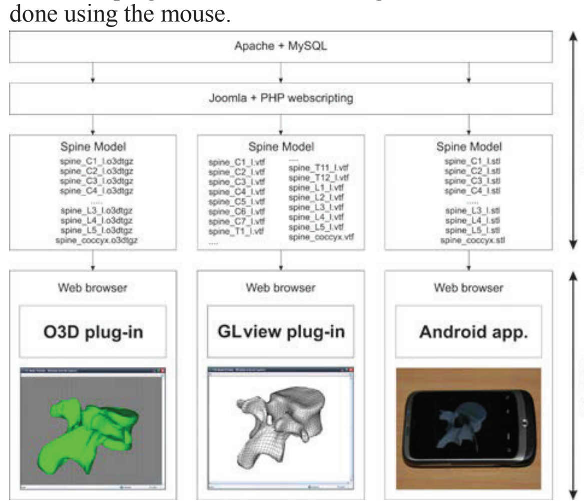

Figure 5. Model implementations in web-based application

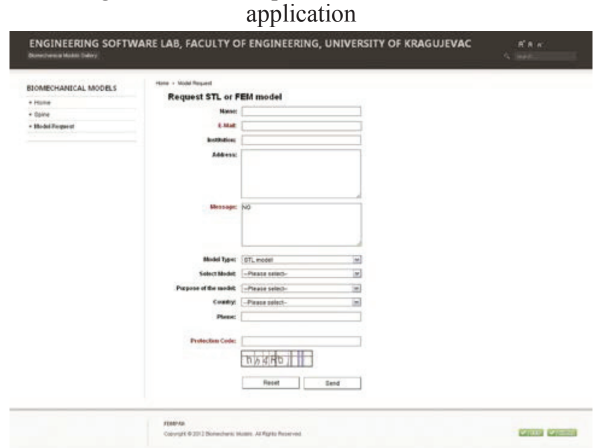

Figure 6. Model Request form in web browsers

At this stage, models are uploaded exclusively by paper authors, due to registration and verification of the content. All the models created so far completely free accessible to registered visitors of the web portal [35], figure 6. Users are quested to send basic personal information, model type (STL or FEM model), select one of vertebras, and define purpose of downloaded model. Improvements and FEM models tests are made continuously.

IV. Conclusion

This paper describes the technique and results in development of web-based application providing end-user with intuitive navigation interface for exploring models developed using CAD/CAM/CAE, as well as section for download of developed models.

The goals of developed web-based application is to: (a) bridge (mostly technical) gaps between biologists, doctors, student and engineers by providing knowledge and training in finite element modeling and analysis of complex biological and biomechanical structures, (b) provide resources to the community in the form of geometry, polygonal and finite element models, (c) promote the integration of biology and engineering by facilitating research and education.

The following types of models are available: solid model, volumetric watertight model, and finite element mesh. Acquisited point clouds and models present virtual shape of each vertebra identical to real one. Improvements and FEM models tests are made continuously. The software characterizes efficient knowledge transfer for spinal vertebrae using 3D-realtime display and animation, bringing good visibility and students' satisfaction. Presented objects become personal; they can individually be zoomed, rotated and animated. The user has the specific artifact virtual in his hand and can explore the product interactive and personalized.

ACKNOWLEDGMENT

This work is a part of ongoing research on "Software Development for Coupled Multiphysics Problems" at Laboratory for Engineering Software (University of Kragujevac, Faculty of Engineering, Kragujevac, Serbia). The research is supported by the Serbian Ministry of Education and Science under the grant TR-32036.

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