3D PDF Technology Combined with JavaScript Functions Enables the Creation and Visualization of Interactive 3D Presentations

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ABSTRACT

We present innovative tools for the visualization and creation of interactive 3D PDF presentations containing anatomical models. In this study we used a 3D embryonic craniofacial model reconstructed from 2D microscopic section images and imported it into an interactive PDF document, where it is managed by a set of JavaScript-based functions. Our documents serve two purposes: firstly, they enable a user to explore a 3D model, in a user-friendly and intuitive way examining anatomical structures, and secondly, they offer the possibility of creating a custom collection of slides containing model views and explanatory anatomical descriptions, later used in the form of a teaching presentation.

Categories and Subject Descriptors

J.3 [**Life and Medical Sciences**]: Health, medical information systems.

General Terms

Design, Standardization, Theory.

Keywords

JavaScript, 3D PDF, Embryology, Anatomical Models, Neuroanatomy, Education.

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1. INTRODUCTION

Significant technological advances have been made in recent years, introducing innovative teaching and learning techniques into health sciences, in particular to medicine. Reconstruction of three dimensional (3D) anatomical models from conventional two dimensional (2D) images has lately become a crucial tool in medicine, optimizing spatial perception of the underlying anatomy. Studies have shown that these 3D models offer better visualization quality, improve anatomy understanding and facilitate learning process [1][2].

Consequently, there has been an increasing need for a technology that would simplify sharing of these data. One convenient way to distribute such models is embedding them in a popular, broadly used portable document format (PDF), enabling the user to effortlessly manipulate them only by using freely available Adobe Reader, thus avoiding the need for expensive and complex 3D viewers. This technique has already been shown successful in anatomy of the whole human body [3] reconstructed from sectioned images provided by the Visible Korean project [4], embryonic development of a human heart [5] and a whole human embryo [6], providing us with interactive educational materials easy to share and use offline.

The object of our study is to upgrade and enhance such documents, expanding their functionality from simple visualization of a 3D model to several ways of interaction with a model and its representation in 3D space, accessing information about anatomical structures, and ultimately generating a set of slides explaining main highlights of the model, thereby creating a free-of-charge, highly compatible, innovative and easy to use learning and above all, teaching tool.

2. METHODOLOGY

2.1 Data

For this study, we used a 3D anatomic model of a human embryonic head. The images used to reconstruct the model were provided by The Virtual Human Embryo Project (VHE)[9]. The embryo in question was in the last stage of embryonic period of human prenatal development, Carnegie Stage [7], corresponding to the eighth week after fertilization. The embryo, 31 mm long, was sectioned to the long axis at 12 microns and 2090 microscopic section images were obtained. Approximately every 10th section was digitally restored and labeled. Superior hundred images which correspond to the embryo's head were downloaded from the DREM (Digitally Reproduced Embryonic Morphology) database[10] and used to reconstruct the 3D embryonic craniofacial model. The images have a spatial resolution of 35 x 35 µm.

2.2 Methods Overview

The process of 3D PDF creation consists of several phases and relies on different software packages (Table 2). All these steps are necessary to create the final document, but once it is finished the user only needs Adobe Reader (version 10 or higher) to open and manipulate it.

Table 2. Processes and corresponding software packages used for 3D PDF creation

Process	Software Package	Exported file format
3D surfaces reconstruction	Amira	VMRL
2D images position in space and extraction	Amira	VMRL
Combining surfaces models and sections	3D Reviewer	U3D
Embedding the model in PDF	3D PDF Converter	PDF
Creating interface for interaction with a model	Adobe Acrobat Pro Extended (JavaScript engine)	PDF
Viewing the final document	Adobe Reader	PDF

2.2.1 3D model reconstruction

The reconstruction of the model was performed in 3D analysis software Amira 5.4.0 ©. The 2D images are firstly post-processed: the informative volume of the images is reduced, they are overlapped and then aligned using the landmarks of coincidence to achieve better correlation between the slices. The surfaces are modeled by labeling anatomical structures in every slice and performing interpolation to obtain regions of interest. The models are finally smoothened in order to correct small errors in interpolation [8].

2.2.2 Organization of 3D Surfaces and 2D Sections

After the reconstruction, volumes of interest are exported to Virtual Reality Modeling Language (VRML) file format by Amira© and imported to 3D Reviewer© to receive final modifications. In addition to the reconstructed anatomical structures several axial 2D microscopic section images of the embryo are included in the model to serve as anatomical references. They are also converted to VRML format containing textured 2D slides, and together with the reconstructed 3D surfaces exported to Universal 3D (u3d) format which is then embedded in the PDF document by Adobe Acrobat XI Pro Extended © containing 3D PDF Converter plug-in.

2.2.3 3D PDF Document Generation

Once the model is imported in a PDF, it is managed by a set of JavaScript functions that enable the user to interact with the model and thereby modify its visualization in 3D space. These functions use different objects, properties and methods of the JavaScript™ extensions for Adobe® Acrobat® Professional, Acrobat Standard and Adobe Reader®, documented in Adobe API References [9][10].
The 3D model is accessed as an object inside the 3D JavaScript engine, where we can then access every triangular mesh representing particular anatomical structure:

```
// Get a reference to the Annot3D script context.
c3d =
this.getAnnots3D(pageIndex)[annotIndex].context3D
;
//access the triangular mesh representing
occipital bone
occBone =
c3d.scene.meshes.getByName("occipital");
```

The developed functions provide different tools that enhance the use of a document and make it more user-friendly. They are explained more closely in the next chapter.

3. Results

The 3D PDF file is included in the Auxiliary Material of this article, and can also be downloaded freely from University of Barcelona public repository[11]. The file is distributed under CC BY-NC-SA 2.0 license[12], which requires attribution to the authors, but allows derivate works without commercial use, provided that it is shared like the present document. JavaScript source code and original surface model geometry are not public and cannot be accessed or modified.

We developed a general interface of the document that serves for handling the 3D model. It can be applied to different branches of medicine, depending on the embedded anatomical model, so new PDF files can be created easily and in relatively short time.
Main functions of the document can be divided into two groups: the first group enables the user to interact with the model and review the predefined slides (Figure 1-A), and the second provides the functionality of creating their own presentation: a set of custom slides explaining the model in question (Figure 1-B).

[9] http://www.ehd.org/virtual-human-embryo/about.php

[10] http://www.ehd.org/virtual-human-embryo/slide.php?stage=23

[11] http://diposit.ub.edu/dspace/handle/2445/45143

[12] http://creativecommons.org/licenses/by-nc-sa/2.0/

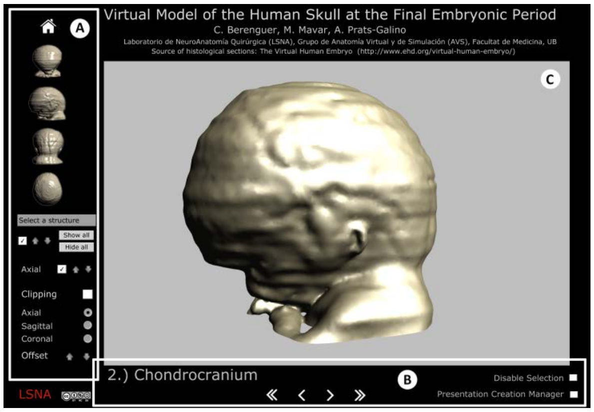

Figure 1. 3D PDF document interface: interaction with a model (A); presentation creation (B), screen working area (C)

3.1 Interaction with a 3D Anatomical Model

Simply by embedding a model into Adobe 3D engine, basic interactions like zoom, shift or rotation in 360º are available by using the keyboard and the mouse, and clicking inside the 3D area (Figure 1-C). More options are accessible from the Adobe interface (selecting elements from a model tree, creating views, cutting the model etc.), but are non-customizable. On the other hand, the JavaScript API (Application programming interface) permits much more freedom in manipulating document elements (3D annotations, buttons, menus etc.), so we used it to create and preprogram a number of buttons which facilitate and enhance the user's interaction with a model, making it more user-friendly and intuitive. These include:

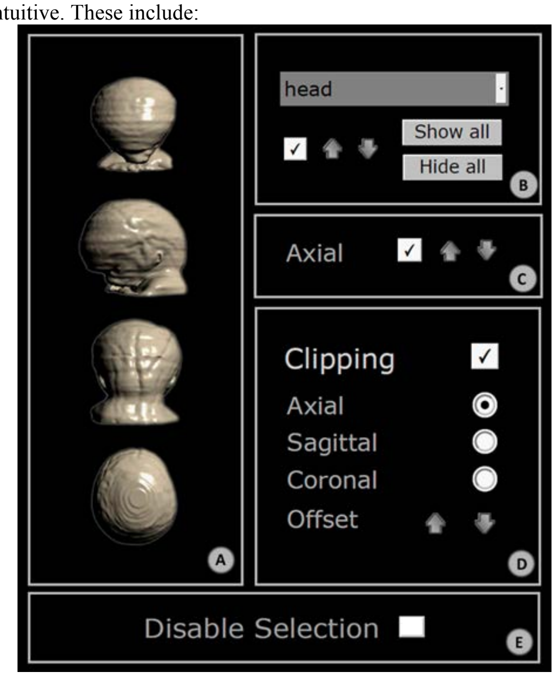

Figure 2. Buttons for interaction with the 3D anatomical model; default views (A); structure selection and transparency graduation (B); axial microscopic sections (C); clipping (D); disabling model selection (E)

- Switching through preset views (Figure 2-A): anterior, lateral, posterior, superior and default view are available. This option eliminates the need for manual rotation and speeds up model handling. Figure 3-A shows anterior, lateral and posterior view of all the structures except the head and brain with the spinal cord.
- Visualizing/hiding/adjusting the transparency of a particular structure (Figure 2-B). Each anatomical structure can be highlighted in two ways: by selecting its name from a dropdown menu or clicking on it with a mouse, in which case the corresponding name of the selected structure appears in a dropdown menu (which is also a useful anatomical names learning tool). Once the structure is selected, it can be made partially transparent, or hidden completely (Figure 3-B), to achieve better visualization of other structures.
- Handling 2D section planes (Figure 2-C): two dimensional sectioned images can be shown alongside the model in order to compare the reconstructed structures to real microscopic images. At the same time only one section is shown, and by arrows user can move to superior or anterior sections superimposing them to the reconstructed surfaces (Figure 3-C)
- Cutting the model by clipping plane and moving along successive cuts of the model (Figure 2-D). It allows cutting in axial, sagittal and coronal planes (Figure 3-D), and may include all the structures and 2D sections. The cutting plane and cutting edges were changed from default colors and set transparent in order to achieve better visualization of the cut surfaces

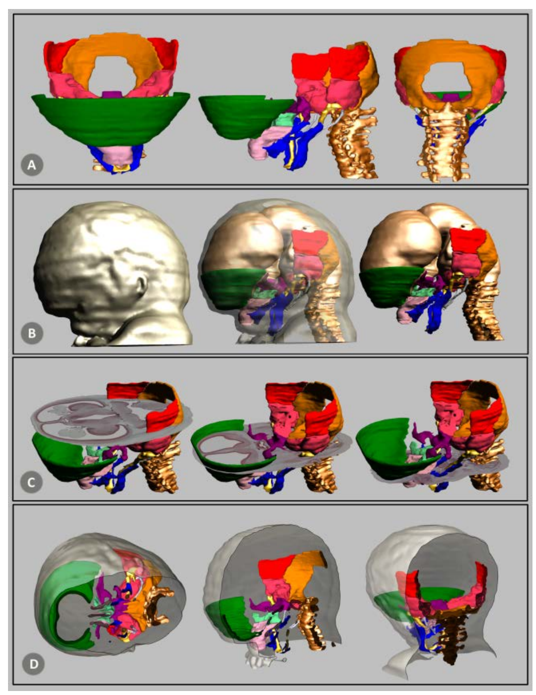

Figure 3. Anatomical 3D model views managed by buttons; default views (A); transparency graduation (B); axial microscopic sections (C); clipping in axial, sagittal and coronal direction (D)

- Enabling and disabling the structure selection tool (Figure 2-E): this option can be useful during the presentation, while rotating the model to show the anatomy without the need of highlighting particular structure. This way the accidental structure highlighting in color red is avoided. We also set all the 2D images to be unselectable, as they mainly serve as a reference and don't carry additional information that can be accessed by clicking on them (e.g. anatomical name).

Other developed functions not visible to a user are:

- Initializing and visualizing the model: the functions are set to wait for the model activation during 60 seconds. In case of a problem with a model after this time period the console reports an error and stops looking for the model, which in such case avoids crashing of Adobe Reader
- Handling external XML files (for descriptive structure names): functions were developed to handle anatomical terminology behind the model. Instead of using a VRML file name of each triangular mesh (the default way), we attach a small XML file to the 3D PFD, which contains corresponding descriptive names which the user will see in a structures dropdown menu. This makes the document robust and adaptive to change in structure names, e.g. if we want to change the language in which anatomical structures are displayed or the language of the entire document.

3.2 Presentation Creation

The documents that we created until recently had a defined number of slides which served as a presentation but couldn't be modified or amplified by a user in any way. This is why we decided to develop a way for the user to make the most of the anatomical model, by being able to create a set of their own views and descriptions explaining it.

Main developed tools are the following:

- Presentation Creation Manager: In order to access functions for creating a presentation, the user must activate Presentation Creation Manager (Figure 4-A). Concurrently, several fields appear: a drop-down list of current views (Figure 4-C), and four buttons allowing view modifications: Update List, Rename View, Modify Comment and Reset List (Figure 4, D-G). Their purpose is to serve as an addition to the default Adobe interface for view creation, providing a user with an Adobe API-based GUI (graphical user interface) allowing him to generate and modify a sequence of 3D views and corresponding descriptions. This sequence can be reset, updated or modified at any time. This is particularly useful for modifying the short text describing each view (Figure 4-B), e.g. in case of document language change, or any text change.

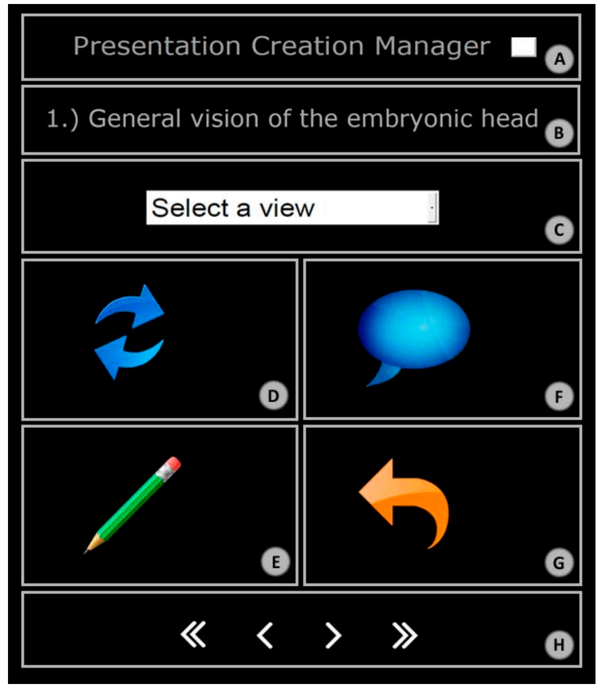

Figure 4. Buttons for presentation creation; starting Presentation Creation Manager (A); view description at it will appear in the document(B); views dropdown menu (C); update view list (D); rename view (E); modify description (F); reset views and descriptions(G)

- Handling external XML files (storing view names and descriptions): similarly to descriptive structure names, we store all the presentation details in a separate XML file attached to a PDF. Every time a new slide is added or an old one modified, the XML file is updated, and every time the PDF document is opened, all the views are loaded from a XML file.
- Presentation Mode: after the presentation is finished, Presentation Creation Manager option is unchecked and a user can use the document as a presentation, switching between slides by arrows (Figure 4-H). Figure 5 illustrates a short presentation, starting with general vision of embryonic craniofacial model (A), explaining ossified and non-ossified structures (B), and classifying structures in three main developmental skull divisions: cranial base (Chondrocranium), cranial vault (Desmocranium) and embryonic face (Splanchnocranium) (C).

It is possible to toggle between Presentation Mode and Presentation Creation Mode at any time, allowing view modifications and preventing repetition of view creation.

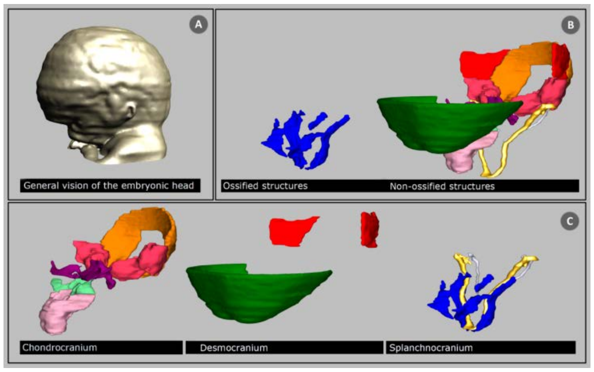

Figure 5. An example of a created presentation: General view of the embryonic head (A); Ossified and non-ossified structures (B); main developmental skull divisions (C)

4. DISCUSSION

The final product of this study is a PDF file containing a 3D interactive embryonic craniofacial model, opened on Adobe Reader. The presented work introduces several technological novelties to the field of teaching and knowledge sharing in health sciences.

Firstly, we expanded the functionality of 3D PDF technology used in health sciences up to now. Similar documents [3][5][6] had three-dimensional anatomical models embedded into PDF file, but were lacking a more intuitive interface allowing user to interact with the models (e.g. accessing and managing surfaces directly from the buttons inside the document, not from Adobe navigation pane). These tools make the document much easier to use for the users that are not familiar with Adobe's 3D tools, and visually more attractive and perceptive.

Secondly, a completely new feature was added to 3D interactive documents: tools were developed to enable creating and visualization of a custom presentation explaining main points of interest of the anatomical model. Visualization of presentation means that the document contains a number of predefined model views and by navigating through them a description of each view appears, making it easy to understand what that specific model view represents, a characteristic that would contribute to 3D PDF document clarity in (Sizarov A, 2011) and (deBakker, de Jong, Hagoort, Oostra, & Moorman, 2012). However, the main novelty here is not so much in visualization, but rather in customizability: each user can easily change an existing presentation or build a completely new one, using the same anatomical model. This way, beyond being a great tool for learning and intuitive understanding of anatomy and embryology, our document becomes a convenient teaching tool as well. Planned future work includes further development of a presentation creation tool, making it completely independent from the Adobe interface.

Thirdly, all the developed functions are robust to document modifications: a model can be deleted and a new one added, or some buttons removed, and the functionality will be preserved. This makes it easy and relatively fast to adapt the document to a completely new topic (e.g. to analyze another anatomical region). These options are not available to the end-user though, as the document is protected to prevent JavaScript code or model copying and Adobe's privacy configuration in such cases doesn't allow model modifications. The importance of this point is that we can apply the product of this study to any 3D model we have developed over time [11][12] in order to present our work in a clear, intuitive and well-organized way.

Finally, in this work we presented a 3D anatomical embryonic model which was reconstructed from histological section images. These images are not obtainable from patients, unlike the ones acquired by the rest of the imaging techniques (magnetic resonance, computerized tomography, etc.) and have higher spatial resolution. Therefore, reconstructed surface meshes are high-resolution as well, so even after triangle number reduction (in order to reduce size of the files) the average triangle surface in our model is of 0.007 mm2, around 15 times smaller than in [3]. The accuracy and resolution of the models would improve even more with an access to non-digitalized section images (as only every tenth section was digitalized, resolution in long axis could improve up to ten times), which we are currently attempting to gain. Even with the high quality models the PDF file size stays under reasonable limits, which is important for file sharing and downloading.

All these characteristics are highly compatible with the PDF standard and confirm that it is indeed a convenient tool for embedding our anatomical models. Additionally, given the PDF's popularity, it is reasonable to expect Adobe's 3D tools to become cross-platform and multi-device soon, making 3D PDF documents even more accessible and convenient for medical teaching and learning.

To summarize, the contribution of this work to health science education is generating an interface for interactive 3D documents, effortlessly applicable to any branch of medicine simply by embedding different anatomical models, and making them easily distributable, allowing each user to modify and expand the original document in order to create a customized teaching tool. The documents are free of charge, easy to grasp, have a simple and intuitive use, and don't require previous specialized knowledge, which makes them convenient for a broad audience to use.

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