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Using Interactive 3D PDF for Exploring Complex Biomedical Data: Experiences and Solutions

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Abstract. The Portable Document Format (PDF) is the most commonly used file format for the exchange of electronic documents. A lesser-known feature of PDF is the possibility to embed three-dimensional models and to display these models interactively with a qualified reader. This technology is well suited to present, to explore and to communicate complex biomedical data. This applies in particular for data which would suffer from a loss of information if it was reduced to a static two-dimensional projection. In this article, we present applications of 3D PDF for selected scholarly and clinical use cases in the biomedical domain. Furthermore, we present a sophisticated tool for the generation of respective PDF documents.

Keywords. 3D PDF, interactive document, software tool, visualization, complex data

1. Introduction

In the biomedical domain, three-dimensional (3D) data is ubiquitous. A three-dimensional representation of this data, however, is rather rare – although the usual projection of 3D data onto a two-dimensional plane ("2.5D visualization") comes with an inherent loss of information and should thus be avoided [1]. The main reason for this is a technical issue: Almost all contemporary means for visualization (e.g., computer screens) only provide a two-dimensional (2D) interface. A solution that does not need a special hardware is interaction: If the optical axis of a 2.5D projection is changed, depth perception is improved [1], previously occluded objects can be moved into the line of sight and the object can be explored in its entirety.

The Portable Document Format (PDF) is the most commonly used file format for the exchange of electronic documents. A PDF file specifies the content and the layout of an electronic document and allows for embedding all necessary resources for its reproduction. As a standard feature, this can comprise 3D models, which finally enables the interactive visualization (e.g., zooming, panning, rotating, selection of components) of 3D objects in qualified PDF reading software [2].

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In this article, we briefly describe this technology and present its applications in the biomedical domain. We suggest a tool for the generation of respective PDF documents for scholarly use cases and report experiences from a clinical use case.

2. Interactive 3D PDF Technology

The Portable Document Format is an ISO standard (ISO 32000-1:2008) for the platform-independent description of electronic documents. The specification is available for free from the original developer Adobe [3]. The latest version (PDF 1.7) allows for embedding three types of 3D objects (meshes, polylines and point clouds) and supports textures, animations, different render modes, different lighting schemes and several other features. The only 3D file format that is supported by the ISO standard is Universal 3D (U3D) as standardized by Ecma International (ECMA-363, "Universal 3D File Format") [4]. The most important details of U3D are described in [5].

At the present day, the only PDF reading software that fully supports all features of the ISO standard (including 3D objects) is the original Adobe Reader. It offers many options for rendering embedded 3D models and for user interaction.

3. Scholarly Use Case: Visualization of 3D Objects in Journal Articles

3.1. Background

The first application of 3D PDF in the context of scholarly publishing was proposed in 2005, soon after this technology has been available [6]. However, it took three more years until the feasibility of embedding 3D models into scholarly articles was really demonstrated [7]. Since then, the number of publications that apply 3D PDF technology either in theory or in practice has increased almost every year – but it is still on the fringes (~30 publications in the biomedical field in 2015 [8]).

Almost all scholarly journals (including traditional print journals) allow for supplementing articles with additional files, and – to best knowledge – PDF is accepted in all cases. The academic publishing company Elsevier invites authors of selected journals to supplement their articles with 3D models in U3D format and provides an online U3D viewer, but the only publisher that makes it possible to embed 3D objects directly into the PDF versions of their articles is PeerJ. Therefore, supplementary PDFs are currently the means of choice to enrich scholarly publications with interactive 3D models.

However, the creation of the U3D models and of the final PDFs has been cumbersome so far and this might be a reason for the very limited acceptance. Several authors proposed appropriate procedures and tools, but they all required a toolchain of multiple software applications, or they were limited to certain operating-systems or relied on commercial software. Non-commercial libraries were available, but required programming skills to be used.

3.2. Methods and Results

In order to provide an easy-to-use and all-in-one tool which facilitates the production of ready-to-publish PDF documents with embedded 3D models for scholarly articles, an add-on for the image processing framework MeVisLab has been created [8,9]. It can be used as an out-of-the-box app or as a basis for sophisticatedly tailored solutions. It is available for free and for all major desktop operating-systems (MS Windows, Mac OS and Linux).

The app can produce U3D model files that are compatible with the ECMA-363 standard and PDF documents that are compliant with PDF version 1.7. The raw model data can be collected either by importing a complete model or by assembling it componentwise by means of a built-in assistant. The app can import 39 different 3D formats, including point clouds and line sets. The latter are usually not supported by other tools. In order to reduce the overall file size, the density of imported meshes can be adjusted interactively. Finally, multiple views can be pre-defined interactively as well. This enables an author of a 3D PDF to specify exactly which details of a 3D scene are displayed.

3.3. Conclusion

By means of this new software tool, the complete workflow for generating interactive 3D supplements for scholarly publications can be processed in a consolidated working environment, free of license costs and with all major operating-systems. PDF documents produced by this tool can be opened with every off-the-shelf Adobe Reader.

4. Clinical Use Case: Presentation of Planning Results for Liver Surgery

4.1. Background and Methods

Although interactive 3D PDF technology has predominantly been applied for scholarly use cases so far in the biomedical domain, its value for clinical use cases is apparent.

One example is liver surgery. Preoperative knowledge of the individual anatomy of a patient is a key factor for this kind of intervention. A major issue in this context is the entanglement of the four intrahepatic vessel systems and their complex spatial relations to other structures (e.g., tumors, cysts or segment boundaries). Precise models of the manifestation of the patient-individual anatomy can be determined by the analysis of image data. The creation of these models and subsequent proposals for interventions are the domain of computer assisted surgical planning (CASP).

The results of a CASP need to be communicated with their consumers and PDF is the best suited carrier for this: First, it can be used as a trusted means to exchange, to preserve and to protect healthcare information digitally. The “PDF-Healthcare” (PDF/H) standard [10] describes how to use PDF features to address security issues. The most important topics (especially as regards the application of 3D PDF in a hospital environment) are discussed in [11]. Second, PDF allows for embedding the 3D models that emerge from CASP and for exploring them interactively [11].

The telehealth service provider MeVis Distant Services (Bremen, Germany) uses 3D PDF to ship CASP planning results. After more than 1,000 cases had been processed and reported, an online survey was carried out among the clinical users in

order to evaluate the user experience as regards acceptance, perspicuity, efficiency, ease-to-use and the difference to the previously used format (non-3D PDF) [11].

4.2. Survey Result

Nearly two-thirds of the questionees used the 3D PDF always (i.e., for every reported case), and more than 90 percent used it often or always. Therefore, the 3D PDF was most frequently used, followed by the former non-3D PDF. Almost all respondents used the 3D PDF for their decision about the surgical strategy. About two-thirds used it as support during surgery, for discussions with colleagues or for educational/training purposes. At least half of the questionees applied the 3D PDF for deciding whether surgery is performed, for personal or mental preparation for surgery or for case presentations. About one-third of the respondents used the 3D PDF for patient information. The possibility to exchange the 3D PDF with others was used by three-quarters of the questionees.

All features of the 3D PDF (interactive zooming and viewing, interactive selection of different views, tables and informational text, summary of all information on one page, grouping of all information in one file, independence of dedicated software) were rated to be useful. Almost all of the respondents agreed or somewhat agreed that the 3D PDF is easy to use.

Finally, the users were asked to assess the 3D PDF by means of a shortened version of the User Experience Questionnaire (UEQ) [12]. The users rated the 3D PDF positive for all four scales. The best score was found for the “attractiveness” scale. Very good scores were reached for the scales “efficiency” and “perspicuity”. A good score was found for the “novelty” scale [11].

4.3. Conclusion

By using the Adobe Reader and PDF with embedded 3D models, almost any modern off-the-shelf desktop computer is capable of visualizing even complex results of CASP without the need to install dedicated software.

The user survey showed that the 3D PDF report was used by almost every questionee and for a wide range of applications that go beyond the primary purpose of shipping the CASP results to the customers. The 3D version was preferred over the non-3D version. The general impression of the 3D PDF was very good and it was easy to understand as well as to get familiar with it. Furthermore, the UEQ results show that the 3D PDF can be used efficiently and that users assessed it to be innovative.

5. Discussion

The embedding of 3D models into PDF documents has proven to be both feasible and valuable for the visualization of complex data in scientific context as well as in clinical context. The Adobe Reader enables the consumers of a PDF document to interact with such models. This interaction enhances the three-dimensional perception and allows for exploring a 3D object from an arbitrary angle. Even animations are possible [13].

Every field of research that produces more or less complex 3D data can and should harness this technology in order to get the best out of that data. The areas of application are manifold: Meshes can be used to visualize volumetric objects, polylines can be

used to visualize vectorcardiograms or neural fibers, and points can be used to set fiducial markers.

Especially persons with little knowledge of a specific topic or of the respective background may profit from an interactive visualization by means of 3D PDF. This particularly applies for patients: It is an ethical obligation that most treatments and all invasive interventions require the patient's informed consent. On the other hand, it can be very difficult for a treating physician to convey the understanding of a procedure, its risks and future consequences without a minimum of medical knowledge. Several studies (e.g., [14]) have shown that patient education supported by multimedia and 3D visualization leads to better knowledge, higher satisfaction and reduced anxiety without taking more time for the patient-physician interaction. Interactive 3D-PDF is a suitable means for this purpose: An image is worth a thousand words – and this is even more applicable for an interactive image.

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