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Organisation, Transmission, Manipulation of Pathological Human Organs on the WWW*

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Abstract

The paper describes an integrated methodology for the development of a WWW computer system which addresses issues of the organisation, retrieval and manipulation of 3D volumetric models of pathological human organs. The library of organs is distributed on the WWW since medical expertise and needs are typically expensive resources and also because many pathological conditions are often restricted to local diffusion. Users are provided with a WWW viewer for interactive manipulation of the models of the organs. The system supports low-cost MS-Windows 32 platforms and requires no specialised hardware. Early results demonstrate that the compression techniques employed provide near real-time response for retrieval/manipulation, not only over high-speed expensive network lines, but also over low/medium network connections.

1. Introduction

One of the major contributions of computer graphics to the biomedical sciences has been to provide tools for reconstructing 3D volumetric models of anatomical structures, typically from 2D cross-sections captured by Computed Tomography (CT), Magnetic Resonance Imaging (MRI) or Single-Photon Emission Computed Tomography (SPECT) scanners. Computer applications are required to offer increasingly-advanced visualisation and manipulation techniques for realistic, intuitive and interactive displays of the reconstructed 3D volumetric models in order to decrease patient care cost and facilitate medical training. With the use of computer graphics spreading rapidly in medical environments, the emerging need is to organise systematically both 2D information and 3D models and to make them globally available on-line to the largest possible community of medical professionals and students.

Currently, the majority of medical visualisation computer systems are either localised and/or stand-alone, for example in the environment of a particular hospital. Frequently,

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they are based on static CD-ROMs containing 2D cross-sectional images of 3D volumetric models and are expensive and difficult to expand (often only possible by purchasing additional CD-ROMs). Many medical visualisation systems have the additional disadvantage of running only on high-cost computer platforms.

On the other hand, WWW servers are easily expandable and merely require low-cost connection hardware and software. However, medical visualisation systems currently found on the WWW often contain rather unorganised 2D radiological images and offer extremely impractical response times for downloading, thus making interaction difficult, or even impossible.

The aim of the project is to construct an intuitively-organised WWW reference library of 3D volumetric models of pathological human organs and to provide efficient mechanisms for their retrieval and interactive manipulation. The paper describes the integrated methodology employed for these purposes. An extensive survey was undertaken regarding the needs of prospective users to identify relevant preferences and trends; this is outlined in Section 2. Using the survey results and the currently-available technologies as a basis, the individual components of the computer system were designed and implemented, as described in Section 3. Section 4 discusses the operating scenario of the system from the user's point of view. Finally, Section 5 identifies possible extensions and future directions.

2. User Requirement Survey

This section will describe the preferences identified by the collection of requirements from the prospective users of our system - medical students and medical professionals (including general practitioners). The questionnaires concentrated particularly on the database (the nature and structure of the data to be included, search procedures, etc), the image synthesis (3D reconstruction techniques) and the expected functionality of the system (interface, interactivity specifications). Because no comparable WWW system is currently available (except for a limited number of high-cost and highly-localised ones), the medical community has little knowledge of the performance, function choices and trade-offs applicable, so in most interviews, only qualitative and/or partial answers were obtained.

Analysis of the questionnaires identified great interest in a computer visualisation system that serves as an educational tool, for training/practice of medical students and for continuous updating of medical professionals. Interviewees expected to be able to compare 3D volumetric models of human organs in normal and pathological states. Orthopaedists expressed strong interest in "virtual tours" of human organs to support the planning of surgical intervention. Generally, students requested a simplified system incorporating some auto-guiding mechanisms, while professionals required flexibility, involving sophisticated search mechanisms. The majority of interviewees expected low-cost equipment, e.g. standard Windows95 PCs equipped with popular Internet browsers. Rapid response times for downloading the 3D models was identified as essential, especially since many people had already experienced slow downloading times when using the Internet. Finally, emphasis was expected to be given to the understanding of diseases through 3D computer-graphics models - annotations were expected to be brief and have supporting functionality.

3. System Components

Based on the general requirements outlined in Sections 1 and 2, a WWW computer-based system for organisation, transmission and manipulation of pathological human organs was developed. This consists of three main components (Fig. 1):

- a database containing 3D volumetric models of pathological human organs, and related textual information; a Solid Model Producer (*SMP*) to generate 3D volumetric models from CT, MRI or anatomical 2D cross-sectional images; a Resource Manager for the input of 3D volumetric models into the database;
- a Database Connectivity Module (*DCM*) to enable a WWW server to communicate with the database engine;
- a Solid Object Viewer (*SOV*) to visualise and manipulate (rotate, zoom in/out, dissect, etc.) the 3D volumetric models in the database.

The design principles of the system were :
- the system architecture is open (i.e. non-proprietary components);
- any existing standards in the fields of computer graphics and database technologies are followed scrupulously;
- the system software should allow room for expansion (object-oriented technology is mostly employed) and not be built around any particular Relational Database Management System (RDBMS).

The database is relational and distributed on the WWW, that is it resides on multiple WWW servers which are not, necessarily, physically located at the same Internet site.

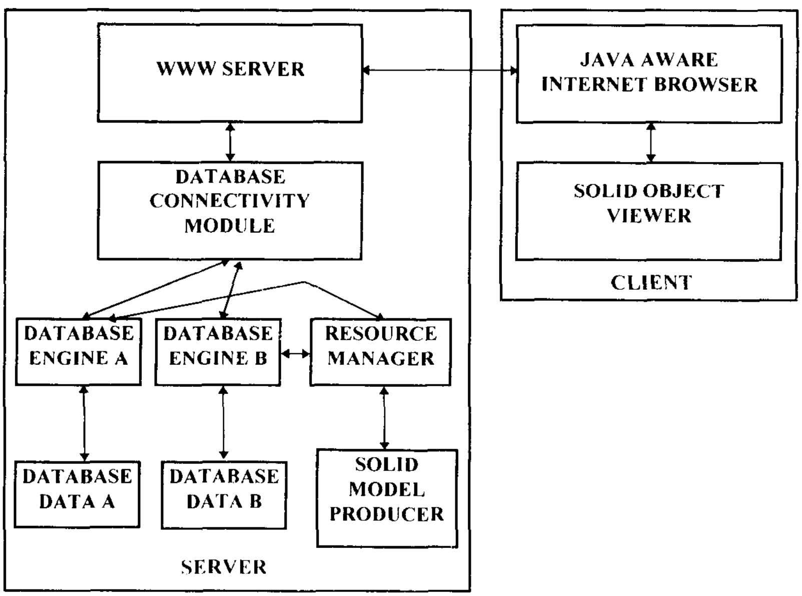

Figure 1. *Component configuration of the system for the organisation, transmission and manipulation of 3D volumetric models of pathological human organs on the WWW.*

Previous work on international standards was carefully examined (ICD-IX or ICD-X for pathological classification, SNOMED for topological classification, MESH for medical concepts, UMLS) to decide upon the retrieval procedure within the system. It was considered that the requirements of our system do not justify as wide an approach as that implemented by UMLS, and that SNOMED currently meets most of our needs as it includes a classification of topography, as well as disease and diagnosis. The inclusion of veterinary terms may be considered as a future addition to the system (it may be of interest, in the future, also to have 3D reconstructions of animal organs in our database).

The Solid Model Producer (SMP) generates 3D volumetric models of human organs from 2D cross-sectional images; it is implemented as C++ classes on top of the freeware libraries of the Visualisation Toolkit (VTK) [1], and employs OpenGL [2]. Early test data demonstrate encouraging results, and the main effort has been concentrated on speeding up rendering operations. Once the raw data collected, the 3D models produced by the SMP, and associated structure data are entered into the database using the Resource Manager.

The main functions of the Database Connectivity Module (DCM) are as follows : to receive data entry requests from the user; to translate these into SQL format; to pass them to the RDBMS; and, finally, to move the results back and present them to the user.

The Solid Object Viewer (SOV) is an independent component which can read a 3D volumetric model (from a file) of a human organ and render it. The SOV can co-operate with Mosaic/Netscape to enable prospective users, not only to view, but also interactively to manipulate, 3D volumetric models of human organs. The SOV provides a two-fold functionality that VRML viewers, in general, cannot offer : firstly, it provides special support for 3D models of human organs; secondly, it supports the interactivity which is necessary for our system. The SOV is also based on the VTK, and the main effort has again fallen on accelerating rendering operations and shrinking file sizes using some recent mathematical techniques based on wavelets [3] and polygon reduction [4].

4. Operating Scenario

The operating scenario for our system is described in this section. Once users connect to one of the WWW servers of our database, they are provided with two alternatives : for inexperienced users, the system provides automatic presentation of the WWW server contents, while more experienced users can use a free-text searching tool. Users may search directly into the database by employing search forms on various attributes of the organ and pathology; typing a word, or a set of words, connected with AND/OR operators, results in a database search to find all the codes containing these words. The resulting code list is then matched to the image database to retrieve all of the descriptors which appear in the database; users are able to choose which descriptors they wish to visualise. A navigation tool for moving in the topological tree of SNOMED is also provided.

Now, the user can elect to view a particular 3D volumetric model. The WWW server interrogates the database and retrieves the URL of the filename of the 3D volumetric model; this action initialises the operation of the SOV.

The SOV reads the file, processes the data, prepares it, and renders the image to the computer screen. Early results demonstrate that response times are between 30 seconds and 1 minute. The SOV performs incremental rendering, that is, the user is rapidly provided with a relatively crude image, and thus given a feeling that something is happening, and the image is continuously refined as the server transmits more detail and the user remains connected. This approach also enables the user to determine, at an early stage, whether the correct model has been retrieved and whether the viewing parameters are as desired.

The user can send requests for interactive manipulation (rotation, zooming in/out, extraction of orthogonal planes corresponding to axial, sagittal and coronal cross-sections, etc.) at any stage, and the viewing process is then repeated.

5. Further Development

The service is at a very early stage of development, and there are many possibilities for improvement in terms both of the available data and of the technological infrastructure.

Existing sites will continue to add more data (both 2D slices and 3D models), and the partners are interested in finding new sites to support the database.

In terms of software development, it is intended to support the reconstruction of 3D volumetric models from multi-modal imaging sources (bone structures are described better by CT, while soft tissues properties are better represented by MRI), the introduction of stereo viewing and the regular enhancement of the viewing system by the inclusion of state-of-the-art graphical procedures.

There is also much work to be done in the file design and modelling procedures for storing 3D models of human organs to produce further data compression and thus improve data transmission speeds.

Finally, the partners are interested in broadening the applicability of the system : firstly, as an advanced teaching tool by encompassing medical techniques, in addition to the physical and functional structures of the various organs, for example colonoscopy, arthroscopy etc.; secondly, as an intelligent tutoring system to give prospective users of the system educational support, structured tuition, etc.

6. Conclusions

The paper has described an integrated methodology for development of a computer-based system for the organisation, retrieval and manipulation of pathological human organs, based on the WWW. The primary purpose of the system is educational, but it can also be used as a virtual reference library to provide cost-effective solutions for medical care, with a focus on updating of particular pathological cases. The associated database is dynamic and can be easily updated with, for example, data from newly-discovered pathologies.

Prospective users are provided with a WWW viewer (a plug-in for popular WWW browsers) for manipulation (rotation, zooming, dissection) of 3D volumetric models of human pathologies. The system supports low-cost MS-Windows 32 platforms and requires no specialised hardware, thereby allowing accessibility to the widest possible audience. Early results suggest that response times for retrieval and manipulation are near real-time, not only over high speed expensive network lines, but also over low/medium network connections. This capability is provided by the incremental transmission of compressed data from a WWW server to the user's WWW viewer, involving a newly-developed flexible/incremental and low-volume file format for 3D models.

As far as we are in a position to know, no comparable computer systems for PC-based 3D synthetic-image illustration currently exist. To illustrate the benefits of such a system, in Histology the physiological histological structure of the organs has normally been taught to students in medical schools by the use of photonic microscopes, requiring the continuous presence of a specialised doctor who is able to use the microscope and provide all necessary explanations. Translation of the histological pictures from the microscope into 3D structures on the computer screen will mark a new era in medical education.

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