Design and Evaluation of 3D Models for Electronic Dental Records

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ABSTRACT
We present the results of a field study of some of the work practices and software used by dentists. We also present the design, implementation, and evaluation of a user interface that streamlines some of these practices, as well as providing a novel 3D visualization of a patient's mouth that also displays relevant radiographs depending on what teeth are visible in the visualization. Dentists found the 3D synchronized navigation intuitive, even with little to no 3D navigation experience, but further research is needed to see the effect on real clinical outcomes.

Keywords
Dentist, 3D Visualization, field study

ACM Classification Keywords
H5.2. Information interfaces and presentation: User Interfaces (D.2.2, H.1.2, I.3.7).

INTRODUCTION
Over the past few years there has been a rapid emergence of a variety of clinical software applications that incorporate 3D imaging. Currently, such applications are most predominantly found in dental specialties, and not in general dentistry. However, given the well-established trend of ever more powerful

technologies at declining prices, it is reasonable to assume that 3D imaging, in its various forms, will also find its way into general dentistry. The primary opportunity here for 3D in general dentistry would appear to be how we review and document clinical findings and diagnoses, make treatment decisions and record care.

This project attempts to address changes occurring in dental medicine, both in imaging techniques and the role that computers play in preserving and rendering patient records. Many dental offices already have such patient information as x-rays, scheduling, and billing in digital formats, but still rely on paper dental records for certain integration of such information. Even in offices that do use digital dental records, most dentists rarely interact directly with such a system; rather, they require photo printouts of x-rays or charts, thus leading to inefficiency and frustration (as described by our field study below). As advances in 3D imaging continue to evolve, the ability of the dentist to use computer-based views of data to assist in dental diagnosis will become increasingly important. Traditional 2D paper records will not be able to convey such rich data.

In this paper, we present the design and evaluation of a general dental record that incorporates an accurate 3D model of the patient's dentition and surrounding structures. Our aim was to create a new interface and method of interaction that will be ideal for dentists to view and navigate dental records without becoming a burden on the dentist's time or reducing efficiency. We also iterated on several user interfaces for 3D dental imagery, to assess the best ways of having dentists interact with such models, and to determine what functions of clinical relevance should be associated with such models.

EXPLORATORY PHASE

Our research phase consisted of an overview of background research, competitive software evaluation, and contextual inquiry with practicing dentists. A recent study has shown that approximately 25% of all general dentists use a computer in the dental operatory [1]. However, clinical computer use varies considerably among dentists, dental hygienists and dental assistants. Most practices use a hybrid system, in which paper-based documentation duplicates or complements information on the computer. Respondents listed insufficient operational reliability (such as crashes), program limitations and the learning curve as barriers to chair side computer use. Features of practice management systems that respondents disliked included usability, functionality, and charting.

Our competitive software evaluation involved a review of the four major dental software packages: Dentrix, Eaglesoft, Softdent, and PracticeSoft. The main purpose of this exercise was to familiarize ourselves with the software packages being used today. Our heuristic evaluation gave us insights into what sorts of standards are currently in place. We were also able to see clear violations of basic human-usability heuristics such as inappropriate coloring and presenting the user with too much information. Because we hope to generate an easy-to-use 3D interface capable of supporting features of current dental records, we also evaluated current 3D applications on the market: Google Earth (a mapping application) and Solidworks (a 3D engineering and modeling tool). We studied the 3D interaction techniques in these packages and looked for patterns in both good and bad presentation of 3D data.

To gain insights about actual use of these programs we conducted a contextual inquiry with four dental offices, some using digital records and others mostly relying on paper. No office we visited used an entirely digital process, and likewise no office used entirely paper, yet the degrees to which computers were used varied greatly. Although the dental record system is used throughout the office by hygienists and assistants, our primary focus was on how dentists use these systems. As such, we focused our inquiries on the way information about a patient was conveyed to the dentists. Information is conveyed primarily from hygienists, dental records (both digital and paper), radiographs, and from looking inside the patient's mouth.

Before, during, and after patient examinations we questioned dentists and hygienists about how they recorded data and used current dental record systems. Questions about computer use were asked and observations about tools used were noted. Observations were not video-recorded in accordance with the HIPAA privacy act, nor was identifiable patient information recorded. We also obtained blank paper records to be analyzed.

Two of the offices had dentists who were technology enthusiasts and made use of current software in their offices. The remaining two had computers but used them primarily for scheduling and billing, while keeping patient records on paper. All offices used digital imaging systems.

Findings from Contextual Inquiry

We uncovered three salient findings from our contextual inquiry. First, efficiency was the most important attribute in deciding whether or not to use an electronic record system. For many dentists, an electronic system will only be considered if it allows them to see patients at a higher rate than possible with paper records. For this reason, it was important that our system be as fast or faster than paper records in all tasks performed in routine checkups. Speed took priority over new advanced features and solutions, although we will see that they are still important features for the adoption of these electronic systems.

Second, dentists were not seeing any benefit in diagnosis and treatment planning in the current 2D electronic medical records. Often, a dentist can get a quicker and more thorough assessment of a patient's mouth by opening their mouth and peering in. The development of a new medical record system must at some level do better, providing a stronger incentive to use the system. Use of 3D data and imaging would allow for important information, such as the width of an infection instead of just the location, to be ascertained, giving the dentist a more informative view of the task he is about to perform.

Third, in addition to these interface concerns, it is also important to consider the physical constraints of the environment in which a dentist works. These include methods for examining patients and taking notes and concerns for maintenance of a sterile environment. One of the largest efficiency breakdowns we found was the hygienist having to remove her gloves numerous times to enter data on a paper record and then copy into a computer later. In this respect, it is important not to

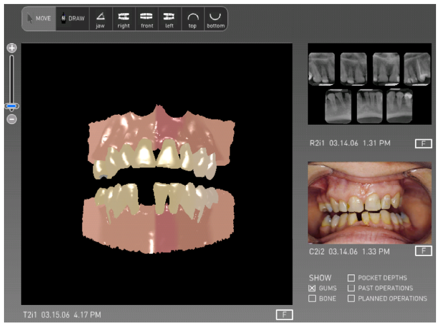

Figure 1. Enhanced retrieval of relevant images by synchronizing views between 3D (left) and 2D radiographs and photographs (right).

Figure 2. Preset views in toolbar

Figure 3. Patient timeline allows dentist to slide through historical data and snaps back to prevent user error.

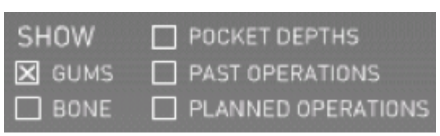

Figure 4. Layers allow user to show or hide image data and onscreen notes.

change the physical environment in which the dentist works, but rather to design a system that supports such an environment and works within the existing dental infrastructure.

OUR DESIGN

We iterated on our system multiple times to come up with a feature set that allowed fast navigation of extremely rich 2D and 3D data. This section describes our latest prototype.

Enhancements for Dental Information Retrieval

Manipulating the 3D mouth model through click-and-drag rotation proved to be an intuitive task for all users and provides a fairly high level of dental data by itself. However, in our records system, we leveraged this 3D manipulation by turning it into a navigational device that synchronizes 3D and 2D imaging data on one screen. We've done this by tracking the coordinates of the 3D model's rotation and used those to call up relevant 2D images that correspond to the 3D model's position. A dentist using this system always has a matching photograph, radiograph, and 3D image displayed for him/her for richer analysis of a patient's dental information.

The interaction with the 3D dental model was made more efficient with preset views. The preset views we chose are standard views used by most dentists.

We added a time navigation component to our system by creating a patient history slider to assist in viewing a patient's historical data. This once complex task of digging through a stack of paper records and images is now as simple as dragging a slider. Dentists can watch the progression of the state of a patient's mouth at whatever speed they desire with this slider. In addition, a snap-back mechanism has also been implemented in order to allow for ad-hoc exploration while preventing user errors in the case that they forget to return to the most up-to-date images.

We used a sliding panel design to navigate between patient information, dental record data, and treatment application. The dentist always has one of two views: 1) Full patient information with image thumbnails on a minimized pane and 2) Full dental record view with only the most critical patient information on a minimized pane. The user can switch back and forth through a simple tap on either of the panes but always has an overview of what is minimized.

The 3D data we will be able to collect with new 3D imaging techniques will allow parsing of different types of tissue data. Additionally, dentists need to mark up the data with planned and completed procedures. Our solution for this was to use layers that could be toggled on and off for all these types of data. This allows the dentist to display the exact types of data that he needs.

Hardware

The electronic patient record system we designed works well with standard computer data entry devices. However, the hardware solution we chose is a tablet PC with stylus data entry. We chose this for a number of reasons: 1) The screen and stylus can be made sanitizable for dental office use 2) Direct stylus to screen interaction makes rotating the 3D model more intuitive 3) Allows for handwritten notes and marks on the dental record 4) Can be attached to a swivel arm

Figure 5. Hi fidelity prototype running on tablet PC.

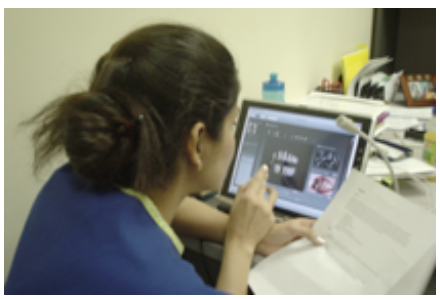

Figure 6. Hi-fidelity think aloud testing with University of Pittsburgh Dental School students and faculty.

common to most dental chairs and 5) Is portable so dentists can take it between examination rooms.

Prototyping tools

For our high fidelity prototypes, we used a combination of Java3D for a powerful 3D rendering and manipulation framework, and Flash for the user interface. Blender3D was used to create the first 3D model and to manipulate the final model. We used JFlashPlayer to integrate Java and Flash, which provided a fast and efficient combination supporting simultaneous front-end and back-end development.

EVALUATION

We recruited four participants to evaluate our high-fidelity prototype. All four participants were female, and all had experience in dental examination. Two were faculty at a dental school, and two were students at that dental school.

The evaluation was conducted on a 1.6GHZ Toshiba Portege M200 Tablet PC Notebook. Participants started with a 3 minute warmup task, and then were asked to complete three tasks while thinking aloud. There was one easy task, one medium difficulty, and one hard. The easy task was to review a person's dental history and find specific pieces of information in the dental record. The medium task was to go through the patient's records and make some observations about their status. This involved navigating the 3D model to a desired location and gathering information about a single tooth. The hard task was to make observations about the dental health of a patient using primarily the 3D model and make a treatment plan.

RESULTS

Although all users retrieved at least one selected patient information item in Task 1, their success in doing so varied greatly. No test participant was successful in retrieving all information items. Task 2, obtaining additional clinical findings, was completed successfully by all test participants. No participant was able to complete Task 3.

For the more complex navigation tasks we had less rigid quantitative data collection and opted instead on gathering qualitative information through recording think aloud comments. Key features that users commented on as having great value were: the automatic display of corresponding clinical photographs and radiographs when manipulating the 3D model, the ability to view the patient's dentition from any angle, and the easy access to historical clinical data, and switching layers of data on and off. Users also appreciated the exclusively clinical focus of our application.

A notable result of user testing was the ease at which all users became accustomed to navigating the 3D synchronized display. Most the dentists we tested had little to no 3D navigation experience, especially on a tablet, but all were comfortably navigating to selected locations in the mouth within minutes showing that these interaction techniques can be adopted by general practitioners with relative ease.

FUTURE RESEARCH

The research presented here has many implications for future exploration. We primarily focused on data manipulation and visualization in our system but there seems to be some very clear deficits in the data input experience in current electronic dental record systems. Our system remedied some of the navigational inefficiencies found in current systems and suggested that tablet stylus input might be the direction to move in for adding data to digital records. This is due to its intuitive nature and similarities to data entry on paper records. Other data entry devices like foot pedals and voice recognition can be explored as ways to further augment the stylus data entry scheme.

We also need to evaluate the effects of these new interaction techniques on real clinical outcomes. There needs to be more quantitative research to determine error rates in diagnoses and time to reach an appropriate diagnosis when using our system versus a paper records system. Showing that the system increases both quality and quantity of care would lead to greater adoption of electronic medical records by dentists. Finally, many current dental software suites also integrate billing and scheduling which introduces a whole new realm of possible process improvements.

CONCLUSION

In this paper, we presented the results of a field study of dentists, as well as the design, implementation, and evaluation of a system for dentists that manages patient records and provides a 3D model of patients' dentition.

From the research we arrived at a number of important conclusions. First, 3D data can be used effectively in fields which experts are not trained specifically to use 3D tools. After a basic three minute training task dentists were able to effectively navigate a 3D environment despite no previous experience in doing so. The use of tablets for navigation was also effective and welcomed by dentists despite an initial discomfort.

One of the primary advantages presenting the data in 3D afforded was the ability to better synthesize multiple information sources. By only presenting information that was relevant based on the context obtained by the current view of the 3D data we minimized switching back and forth throughout different information sources which was welcomed by dentists. Dentists also welcomed the ability to switch layers of tissue on and of as well allowing them to obtain information that a regular oral exam might not yield. In evaluating the usefulness of digital systems for dental offices it is of primary importance to consider efficiency.

Despite the advantages computers provide, digital medical record systems are not as popular as they could be because they often increase the time it takes to see and evaluate a patient. Any proposal to redesign a dentist’s use of chair side computing must take this into account and provide solutions that enable the dentist to navigate richer information with no loss in efficiency.

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