Evaluation Of A Head Tracked 3-D Document Visualization

Clarence Chan
University Of British Columbia
Department Of Computer Science
2366 Main Mall
Vancouver, B.C. V6T 1Z4
(604)-822-5108
clarence@cs.ubc.ca

Sherman Lai
University Of British Columbia
Department Of Computer Science
2366 Main Mall
Vancouver, B.C. V6T 1Z4
(604)-822-9182
s.lai@fisheries.ubc.ca

Ying Zhang
University Of British Columbia
Department Of Computer Science
2366 Main Mall
Vancouver, B.C. V6T 1Z4
(604)-822-5108
yingzhan@cs.ubc.ca

ABSTRACT

This paper describes a controlled experiment in which we outfitted a simple electronic document viewer with 3-D display capabilities and head tracking technologies, to provide a convincing 3-D representation of a document at different viewing angles. The head orientation and position of a user viewing a document is also tracked, to allow the user to browse the entirety of a page simply through head movements. This system was compared to conventional paper documents and simple electronic views of documents, by evaluating search and reading comprehension tasks involving academic research papers. We determined that the modified system showed no significant benefit with regard to these tasks, in comparison to the views provided by standard paper and electronic documents.

Categories and Subject Descriptors

H.5.2 [User Interfaces]: Interaction styles; H.1.2 [User/Machine Systems]: Human factors; I.3.8 [Computer Graphics]: Applications.

Keywords

Head tracking, information visualization, 3D interaction, document search and navigation.

1. INTRODUCTION

The overall aim of our study is to investigate the use of novel 3-D display techniques in document search and navigation problems. We choose to analyse the problem as it pertains to the reading and perusal of academic texts. The motivation for this study stems from two intertwining facts: firstly, that paper documents have long been regarded as superior to electronic documents for the purposes of reading and acquiring information [15]; secondly, that repositories of electronic documents and journals are becoming increasingly prevalent, and their usage amongst academic communities continues to be on the rise [5].

Reading of research papers and journals is an important part of graduate academic studies; publications are often read and distributed in both electronic and paper forms. However, from the observations discussed above it would appear that the ubiquity of electronic documents is not necessarily matched by satisfaction of their use.

Despite the proliferation of academic papers in electronic form, the issue of creating effective tools to support electronic reading remains an interesting problem, and a number of approaches to creating document manipulation systems have been developed.

The early approach to document visualizations focused mainly on reproducing the functionality directly afforded by paper documents, such as with the DigitalDesk [165]. Systems designed in this fashion would either attempt to recreate the paper document in the electronic world, with all its rich interaction possibilities, or work with the appropriate metaphors to simulate real-life document interaction.

However, direct reproduction of paper document functionalities, as in the DigitalDesk, required the use of prohibitively expensive technologies and hardware, such as image tracking and specialized visual displays. Furthermore, it was not clear that a good document visualization or interaction scheme necessarily needed to reproduce the benefits of paper documents in full. As such, many researchers have taken a second approach to document viewing and navigation.

The more popular approach thus far lies in the field of information visualization, where researchers have focused on supporting document views by manipulating the visual space of electronic documents and adding functionalities not otherwise afforded by a traditional paper document. Typically, these systems either rely on the usage of context-relevant visual distortions to supplement the user's reading habits [5], or support larger-scale visualizations of document information i.e. effective representation of document structure, keywords, user search queries and results [7][8]. The focus in this approach is to exploit the advantages of computerized data and their representations, in an attempt to replace the paper document rather than replicate it.

However, as human interface technologies, such as head tracking, become more widely available and less costly [12], it makes sense to once again explore elements of the former approach, so that they may even augment existing information visualizations derived in the latter approach. While 3-D visualizations of data have often been met with much criticism and caveats to their usage, we believed it worthwhile to explore the possibility of using 3-D visualizations of documents in conjunction with head tracking technology, something that has not been done previously to our knowledge.

Noting that paper documents provide an intuitive assessment of current position and document length, as well as an association of physical pages with specific sections and information [5], we chose to approach the problem by providing the electronic document with these same natural cues, by explicitly acknowledging the document as a 3-D object with depth and spatial location.

In doing so, we can literally give a new dimension of contextual information to the user with regards to the current text passage being read; it becomes possible to gauge one's overall position in the document by merely looking at the document from a different angle to ascertain the relative depth of a page, while gaining the ability to "look ahead" at partially occluded pages that follow.

2. RELATED WORK

2.1 Single-Document Visualization Techniques

We describe some of the more prevalent approaches to document viewing within the information visualization community, and particular implementations and applications of each approach.

The overview + detail method presents a summary of the document and a high level view of the regions and chapters in conjunction with the currently viewed portion of text. It is also incorporated in many commercial applications such as Adobe Acrobat. Despite its simplicity, it is acknowledged as superior to simple linear text [5], since one has the option to navigate across multiple regions non-linearly.

Another major class of viewing techniques makes use of the fact that fovea (mid-region) of the eye processes images at a higher resolution than the outer fringes of the eye. This class of techniques, known as focus + context, accentuates focal points of interest by presenting specific document regions at high resolution relative to their surroundings. However, contextual information is preserved by presenting regions on the fringe of the viewing area at low resolutions. One of the many particular applications of this technique can be found in Baudisch's work [1].

The fisheye principle (described first by Furnas[6]) illustrates a similar idea, by zooming in on particular document regions and distorting the surrounding text to preserve context, all while allocating maximum real estate to the current relevant area. Frokjaer [4], in fact, argued to the overall superiority of fisheye views compared to the overview + detail method, because fisheyes provided an optimal balance between the content of the "focus" and the distorted, but (still recognizable) content of the context. However, unlike overview + detail, commercial fisheye document viewers have yet to appear on the market.

Other miscellaneous works have focused on exploiting and creating other computer-exclusive properties of electronic documents. Intelligent, speed-dependent zooming navigations, demonstrated by Hinckley [9], zoom out automatically when the user desires to skim through a document, and zoom in when the user wishes to stop to read a particular section. Masoodian [11] artificially introduces a depth-based metaphor with the DeepDocument display, a layered transparency-enabled viewer that allows users to view multiple overlapped transparent pages. The user chooses to view a particular page by adjusting the focus of her eyes to a particular transparency layer.

2.2 Multi-Document Visualization Techniques

Yet another approach to document visualization is realized in the information systems realm, where approaches to visualizing documents involve directories or databases of texts, and the ability to spot document trends and display them in an efficient and fashionable manner. Most of these techniques actually pre-date the single-document visualization techniques, and are often concerned with effective semantic representations of a document.

One of the earliest works by Hearst, TileBars[8], accepts search queries and ranks the relevance of documents in the database with respect to the terms. For each document, a set of horizontal bars is displayed; each bar represents a single search term, and the darkness of an individual tile in a bar represents the frequency of the search term in that section of the document.

Related work by Byrd [2] describes and implements a search highlighting tool within an online document's scrollbar; the scrollbar is populated with small coloured tiles which denote search term occurrences throughout the document as a whole, with different colours representing different terms. These kinds of data representations arguably are the inspiration for the later overview + detail interfaces for single documents that provide large-scale views, often in conjunction with search data.

There has also been research into the use of 3-D depth cues to organize multi-document data. The concept of Piles [10], followed by Data Mountains [14], investigate the notion of arranging iconic representations of documents in a similar manner to the real world, making use of piles and layers. Documents can be stacked upon each other and in the case of Data Mountains, can be filed individually in the foreground or background, generating a sense of depth.

2.3 Head Tracking and 3-D Visualizations

The use of head tracking to generate perspective-correct 3-D displays was first popularized by Deering [3], who describes a method of manipulating the projection matrix within the graphics pipeline to provide a perspective-correct projection to a monocular subject outfitted with head tracking technology. This has served as a reasonable approximation to "true" 3-D displays thus far.

The canonical paper on head tracked virtual reality by Ware *et al.* [16], investigates the notion of "fish tank" virtual reality displays and the role of head tracking technologies in its implementation. They stress that head/eye tracking, and dynamic changing of the view in the fish tank, provides for a stronger sense of virtual immersion than other cues such as stereoscopy. In terms of task performance, when users were asked to manipulate three-dimensional objects, they found lag to be the determining factor in ease of performance, rather than the frame update rate of the display.

Later work, such as Rekimoto's vision-based fish tank system [13], suggest that heavyweight hardware is not strictly necessary to provide a convincing virtual reality display, and emphasize the fact that head-tracking technologies are becoming more transparent and less costly. More recent developments [12] have shown that head tracking can be done efficiently with the right algorithms and software, merely using low-cost cameras that simply triangulate distance.

3. USER STUDY

3.1 Rationale

The above research suggests that it is worthwhile to explore ways of dynamically adapting document displays to the user's direct area of reading interest, as in the aforementioned single document visualization techniques. Additionally, the treatment of documents as objects with dimensional depth in recent research gives promise to the notion of the document as a fully realized 3-D object. Inexpensive head tracking technologies can provide an accurate gauge of the user's current area of focus in the document, while making it possible to generate a depth and perspective-correct spatial representation of the document itself, for a more realistic and immersive feel to document navigation.

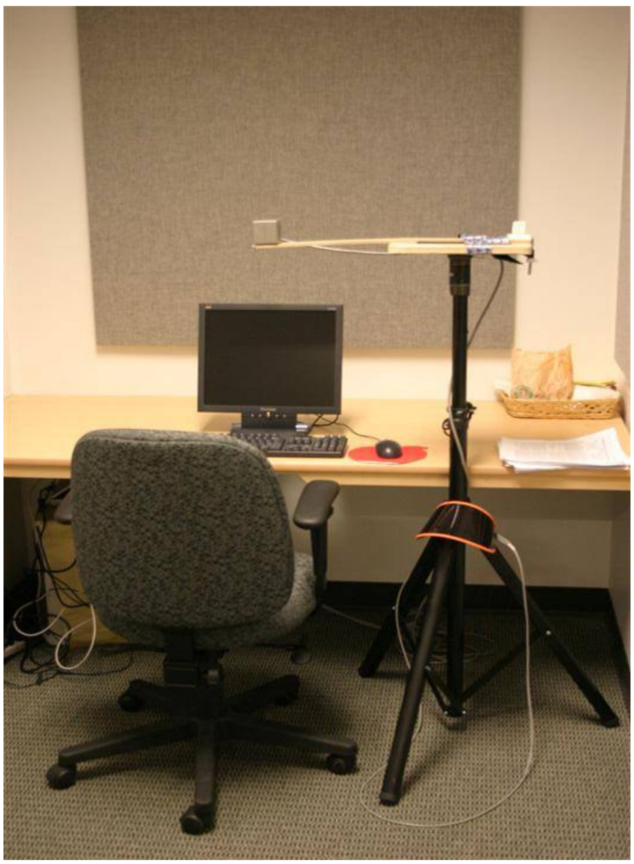

Figure 1. The head tracking system setup.

With this in mind, we sought to evaluate whether such a system would significantly improve users' reading comprehension and search times with regards to academic research papers. We conducted a study to determine the effect of a head track – controlled document viewer on these variables. These results were compared to those achieved with the use of a simple document viewer without head tracking controls, and printed paper documents.

3.2 Materials

For the purposes of our experiment, we designed and implemented a head tracked document viewing system called BookViewer. BookViewer was implemented in C++ in a Windows environment using the OpenGL framework. Head tracking was performed with the use of a Polhemus FASTRAK hardware system; the magnetic tracking tip of the FASTRAK must be affixed to a user's head to provide accurate orientation and position information.

3.2.1 BookViewer - motivation

Some of the key requirements for a better document viewing interface as indicated by Sellen [15] (touched upon briefly in the introduction) include the ability to derive contextual information of a passage quickly with a minimum consumption of screen real estate, and support for immediate responsive feedback with regards to document re-orientation and/or manipulation. This is reflected in BookViewer by having the user control relative zoom and spatial location of a document with her head alone.

Additionally, a major factor differentiating paper from electronic documents is the association of physical pages with relative location of sections and information. We sought to reclaim this capability in BookViewer by representing individual pages as separate parts of a virtual document 'stack' in a 3-D space. Relative position of a page could then be determined by comparing page content to later pages further 'behind' in the document, or by noting the depth of the document, viewed as a book.

We were then justified in producing this list of key requirements; the aspects of BookViewer which attempt to meet these requirements are in parentheses:

1. Relative location and contextual information should be easily determinable. (document depth, and parts of adjacent page content, are easily ascertained at all times by viewing the virtual book representation at an angle)
2. Users' interactions with the document should produce logically mapped, responsive feedback. (head tracking allows the user to simply move her head to a relative spatial location to view a different area on a page, at a continuously mapped zoom level)
3. A convincing metaphor should be applied, and its execution should be seamless and immersive (we employ the book metaphor, and give it a full 3-D representation to enhance its believability as a fully existent and functional object)

3.2.2 BookViewer - functionality

BookViewer is a document display system that employs a book metaphor. When a document is loaded into BookViewer, it is viewed as a double sided document spread apart in a book layout. Each page has a thin shadow border overlay to visually separate the pages and give the document viewer more depth. When the user hits the Page Up or Page Down key, the current page(s) will flip backward or forward, respectively.

The user is outfitted with a Polhemus FASTRAK attached to a cap for purposes of head tracking. When the user's head is moved to the left, right, upwards or downwards, the in-screen document moves in the opposite respective direction, to provide the semblance of the book as a object in real 3-D space. Co-ordinate averaging is applied to smooth out the jitter inherent in both the FASTRAK's data gathering and the user's head orientation.

When the user's head moves past the left or right ends of the page, the document will start to tilt as shown in Figure 2, enabling the user to gauge the depth of the document and view

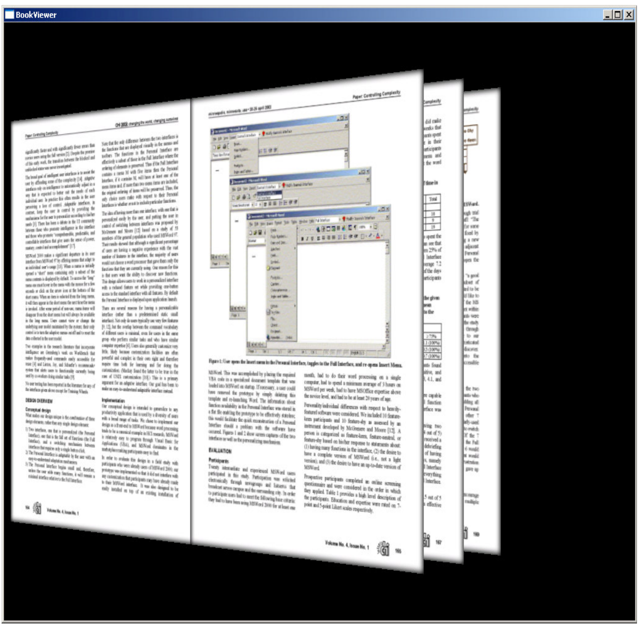

Figure 2. The tilting functionality of the BookViewer.

partial page content of adjacent pages. If the user's head is moved closer to the screen, the viewer will zoom into the document, and the exact opposite behaviour is induced by moving one's head outwards from the screen.

3.2.3 BookViewer – calibration/scaling issues

The head tracking system can be calibrated at the outset by positioning oneself appropriately with respect to the Polhemus base station and hitting the spacebar. The calibration places the document at the maximum available viewing depth into the screen, so users of the system are recommended to lean back an appropriate distance before calibrating.

Because the computer display itself naturally becomes larger to the user when she moves in to view the document, care had to be taken in implementing the in-program zoom function. In-program zooming was implemented as a low-order exponential function, so if calibration was done at a relatively normal distance from the screen (roughly 30 inches), users could see the full text of a document by advancing their head forward by about 5-7 inches. We informally checked that the distance ascribed to the zoomed-in view to be a reasonably comfortable one for users; even with an exponential zoom the action of moving one's head inward by such a distance does not result in an overly sensitive zoom function. The inverse effect was applied when zooming out.

With regards to the tilting rotation described earlier, we had originally intended to use the specialized projection matrix described in Deering's paper to display a perspective-correct representation of the book. However, we found that this required too far a tilt on the user's behalf to visualize the rotated edges of the document in any useful manner. Thus, we employed a simpler, non-linear rotation to present the document in a tilted fashion with less head displacement required of the user.

3.2.3 Simple Viewer - functionality

The Simple Viewer is a modification of the BookViewer, and does not use any head tracking hardware. The Simple Viewer was used as a comparative condition in our user study as indicated earlier.

The core functionalities are replaced by keystrokes; the arrow keys change one's relative position on the page spread, while the + and – keys zoom in and out of the document, respectively. The Page Up and Page Down keys still control the advancement and backtracking of pages.

3.3 Experimental Design

As mentioned earlier, our study compared the effectiveness of three different viewing conditions with regards to the reading of academic documents: a paper-based version, the Simple Viewer and the BookViewer. We evaluated the effectiveness of the system using short, medium and long computer science research papers (4, 10, and 34 pages respectively). Six graduate students in computer science, all proficient in the English language, were recruited so that varying levels of computer science-specific knowledge would not be a confounding factor.

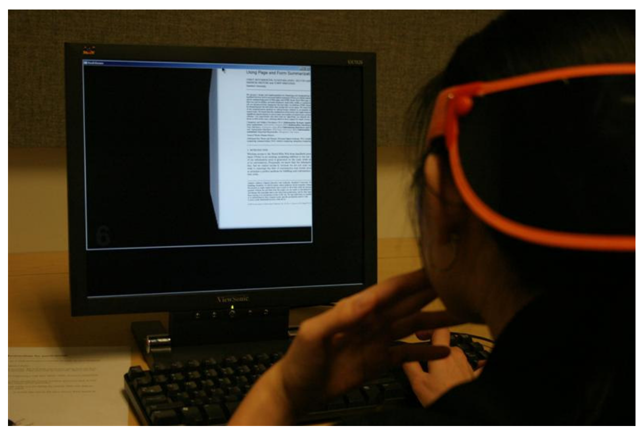

Figure 3. The BookViewer in action.

Our study was performed using a within-subjects design, so that each participant was tested on each system. Presentation of the systems was counterbalanced so that each subject would experience the three systems in a different order, to counteract possible learning effects, especially in the case of the Simple Viewer and BookViewer.

A document of different length was used with each system; we chose to counterbalance the document lengths to accommodate for different levels of participant fatigue (as the sessions could be very long), but the tradeoff was that not all systems could be tested with each document type. The only important combination missing would be the BookViewer + short paper combination; however, we felt it valid to let this case slip as the short paper presents a trivial condition anyhow in which all aspects of document length are already known and visible (4 logical pages means a two-page representation on screen).

We tested participants on four major tasks, performed in sequence by all participants in each condition:

a) Reading overview: acquire an overview of the document in a short period of time.

b) Reading comprehension: acquire a deeper understanding of the document over a longer period of time.

c) Search task: answer questions about the document by visually searching through the text.

d) Retrieval task by page number: answer questions about the document by flipping the document to a previously indicated page.

Table 1. Experiment ordering table.

Paper + short	**Simple Viewer** + medium	**BookViewer** + long
Paper + medium	**BookViewer** + long	**Simple Viewer** + short
Simple Viewer + long	**Paper** + short	**BookViewer** + medium
Simple Viewer + short	**BookViewer** + medium	**Paper** + long
BookViewer + medium	**Paper** + long	**Simple Viewer** + short
BookViewer + long	**Simple Viewer** + short	**Paper** + medium

[Note that task C) represents a search task whereas D) is an information retrieval task. The distinction is that partial knowledge of the page index is known in D) and so the information query is not a blind one].

In tasks A) and B), participants were given a fixed amount of time to read the document, and were instructed to answer questions about the text afterwards, to gauge their level of reading comprehension using the required viewer. These questions were of a general nature, and the same for all documents. They are as follows:

Task A):

- Describe the (paper's area of research) / (major theme of this subsection).
- Describe the software innovation / (specific concept or subtopiC) in brief.
- On a scale of 1 to 5, how would you describe the amount of time given to you to read the document? (1 = more than enough time to answer the questions above, 5 = not enough time to answer the questions above)

Task B):

- Describe the paper's experiment design in as much detail as possible.
- Describe the paper's main experimental results in as much detail as possible.
- On a scale of 1 to 5, how would you describe the amount of time given to you to read the document? (1 = more than enough time to answer the questions above, 5 = not enough time to answer the questions above)

In tasks C) and D), participants were given as much time as necessary to complete the task and answer the given questions to their appropriate level of satisfaction. The questions asked were directly specific to the given paper. Finishing times for tasks C) and D) were recorded.

We were satisfied that the ordering of tasks was consistent and provided no clear advantage to any condition or participant, especially in the case of tasks C) and D) where knowledge of facts could have been pre-acquired in tasks A) and B). We ensured that all subjects were given the same amount of time to do tasks A) and B) so that exposure to the document would remain consistent across all subjects. Furthermore, the reading questions for tasks A) and B) were given to participants before starting the timer and instructing them to read, to eliminate the possible advantage of knowing those general questions in advance for a subsequent condition.

Finally, participants were given a questionnaire to rank the document viewing systems in terms of ease of use, ease of reading and overall preference, and asked to justify their rankings.

3.4 Hypothesis

We hypothesized that the subjects would perform the search tasks C) and D) in BookViewer at least as quickly as in the paper-based version in all cases, and that both of these systems would yield quicker times for tasks C) and D) than the Simple Viewer. We also believed that answers would be more verbose and on the whole, more correct with the BookViewer and paper-based methods than the Simple Viewer. Finally, we also believed that participants would feel the most satisfied with the time constraints in tasks A) and B) in the BookViewer and paper-based conditions, as well as in terms of overall satisfaction from the questionnaires.

3.5 Results

On the whole, we discovered that the BookViewer performed poorly in comparison to the other two systems; however we shall first note the positive aspects of the BookViewer's performance before delving into the negative.

In the medium-length paper condition, all participants of the BookViewer were able to describe the general innovations and goals of the paper in task A) when given time to do a 60-second overview, while only one participant amongst the paper-based document and Simple Viewer was able to identify the major innovation presented by the medium length paper. Also, BookViewer participants in this condition reported that the time given to them to view the document was more satisfactory (3.5 average) than the either the Simple Viewer or the paper-based system (dissatisfied with the time, all scores were either 4 or 5). A similar trend was noted for the longest paper, as all participants of the longest paper in conjunction with the BookViewer were able to identify both the main research idea of the paper and its focal innovation.

However, for task B), in which participants were given a fixed period of time to read the document in greater detail, participants in the BookViewer + medium length paper condition fared very poorly. All participants of the paper-based version of the medium paper ranked their satisfaction with the time allotted at least a 3, and were able to answer both questions in task B) satisfactorily with multi-line answers, whereas the all the BookViewer participants indicated in at least one of sections that they could not answer satisfactorily, having not been able to read a sufficient amount of material in the paper, or gave incorrect guesses.

While for the most part, performance on questions about the longest paper was generally good for all viewing systems, the paper-based system posted the best satisfaction in terms of viewing time allotted (the best was a 2), compared to either the BookViewer or the Simple Viewer, which posted best scores of 4 and 5 respectively.

Where BookViewer really failed was in tasks C) and D), which were the information search and retrieval tasks respectively. All questions were answered satisfactorily for all conditions; however, the completion times varied largely.

The Simple Viewer posted the best times for task D) for the longest paper (31.0 seconds from one subject), while tasks C) and D) had the lowest average times from the paper-based view on the medium-length paper, as well as the lowest overall time (22.1 and 12.8 seconds, respectively). However, use of the BookViewer, in the worst case, took twice the amount of time to complete any given task in comparison to its paper counterpart. BookViewer posted the worst times for both the medium length and longest papers, and was the only condition to exceed 5 minutes to complete task C). A one-way non-parametrized ANOVA determined no significant effect between conditions on task completion times, which is to be expected from the small sample size and high variability of participants' abilities to perform visual search in a text.

3.6 Discussion

We suspect the reason that the BookViewer performed so well for the overview task is that it is very easy to home in on a specific section of a page to immediately grasp a quick view of its contents; in this case, the abstract was immediately available on the first page and so could be located easily.

However, prolonged use of the BookViewer became a strain on the participants as the concentration required to keep the same passage at a constant level made it difficult for participants to absorb the material at the same time. However, this suggests that BookViewer shows promise as an extensive reading system [7] rather than an intensive one, used to acquire overall knowledge and home in on specific key areas with a minimum of effort.

Table 2. Times for tasks C) and D), in seconds. Each entry describes the time for that specific condition.

	C	D		C	D		C	D
Paper + short paper	**94.2**	**120.3**	**Simple Viewer** + medium	**43.4509**	**87.1168**	**BookViewer +** Longest	**202.655**	**191.269**
Paper + medium	**22.1469**	**12.886**	**BookViewer +** Longest	**100.296**	**125.19**	**Simple Viewer** + short paper	**102.00**	**125.00**
Simple Viewer + Longest	**190.093**	**31.55**	**Paper** + short paper	**55.0**	**107.00**	**BookViewer +** medium	**149.476**	**166.265**
Simple Viewer + short paper	**186.323**	**113.911**	**BookViewer +** medium	**557.502**	**581.869**	**Paper +** Longest	**111.3**	**180.5**
BookViewer + medium	**424.379**	**203.584**	**Paper +** Longest	**237.6**	**346.6**	**Simple Viewer** + short paper	**145.396**	**115.845**
BookViewer + Longest	**329.242**	**368.287**	**Simple Viewer** + short paper	**78.9082**	**70.6572**	**Paper +** medium	**319.11**	**354.41**

However, the same homing and retrieval abilities supposedly supported by BookViewer in the overview task did not apply in the page information retrieval task; we suspect that because such a task requires searching through a passage intensively in addition (hard) to locating that passage in the first place (easier), BookViewer failed in this regard. It is worth noting that no participant ranked the BookViewer as the #1 choice for ease of use, reading, or overall preference by any of the participants. It was consistently ranked the lowest, and in fact, and 5 of the 6 participants chose the paper-based document as their best overall choice. Only two participants overall preferred the BookViewer over the Simple Viewer (i.e. BookViewer was ranked #2 and Simple Viewer ranked #3).

Common complaints about the BookViewer included comments on its dizzying factor, that it was hard to navigate around and zoom into a page using the head-controlled mechanisms of the BookViewer (even with our anti-jitter correction in place), and that it was easier to control the Simple Viewer due to the discrete actions available to the participant. When informally questioned about the BookViewer's presentation of depth and the ability to see adjacent pages at a tilted orientation, participants either stated that these features were not strictly necessary to effective use of the BookViewer, or that they believed the head tracked navigation and zooming to be the main novelty of the system rather than the tilting and depth features.

By contrast, people noted their appreciation for the traditional paper document, stating that it was the most familiar and easy to handle in one's hands. This suggests that our approach of putting the emphasis of interaction all on the head and eyes is a poor delegation of responsibility.

4. CONCLUSION

In comparison to simple document viewers and paper implements, the head tracked 3-D BookViewer offers no clear benefits, save the ability to identify passages of interest quickly by means of head orientation. As such, the above criticisms suggest several points of action:

1) Despite the novelty of head tracking for navigation, the disorienting nature of such a navigation style should be either discretized to negate superfluous motion, or the motion factor should be desensitized further in a continuous environment.

2) The ability to offer depth and / or perspective-correct views is not the essential factor in supporting an effective 3-D representation of a document; zoom perception should not be controlled by head movements, but rather by alternative methods such as gestures and haptics.

3) Thus, document manipulation and interaction should be handled as an active process rather than a passive process in which the document is "observed" using head motions, rather than "read" as an object in one's hands. Good interaction techniques should supplement the demonstrated capability of users to select and identify large text passages by use of head tracking.

In light of the criticisms put forth and the unpromising data provided by this user study, we assert that 3-D depth cues and head tracking alone do not provide any significant benefit to the viewing and navigation of a document; we suggest that such a system must be combined with a suitable interaction metaphor that makes the document reading experience a co-operative effort between one's viewing system (the head / eyes) and some form of active control.

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