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Usability in mobile interface browsing

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Abstract. The advent of mobile devices imposes great challenges for user-friendly displays for effective browsing for Web contents. This paper reports some initial findings in an empirical study that explores the problem of finding a highly-efficient, user-friendly interface design method on small display devices. We compare three models using our PDA interface simulator: presentation optimization method, semantic conversion method, and zooming method. A controlled experiment has been carried out to identify the pros and cons of each method. The results show that of the three interface methods, the zooming method is slightly better than the semantic conversion method, while they both outperform the optimizing presentation method. The results provide a useful guidance for future design of small display devices.

Keywords: Mobile devices, web browsing, user interface, empirical study, usability, PDA

1. Introduction

With the rapid advance of the Internet and mobile technology, an increasing number of people use wireless devices such as Web-enabled cell phones and PDAs (Personal Digital Assistants) to go online. The emergence of mobile devices and wireless networks has opened up new business opportunities known as *mobile commerce* (m-commerce). The design of mobile devices needs to address the requirements of mobility, limited input and output capabilities, multitasking and adaptive to a dispersed and widespread population. On the other hand, the technologies of mobile computing and Web intelligence have provided more opportunities to develop effective and efficient applications, such as Web browsers for clients. These technologies include ad hoc connectivity, location-aware services, and the capability to adaptively receive information and conduct transactions anywhere, at any time and in real time environments.

There are significant differences between a desktop computer screen and a small display. First, a small display device has a limited number of input facilities, processor power, memory and bandwidth [1]. The display form also introduces several new constraints for human computer interaction design. Second, there are various kinds of viewing conditions when surfing the Internet, such as varying screen sizes, style preferences, and different device capabilities [2]. For example, consider the case of a user viewing a diagram representing an organizational structure on the Web, the fully expanded diagram is of considerable complexity and may be unsuitable for small displays. Thus, if the diagram is to be viewed on the screen of a mobile device such as PDA, the original layout may not be appropriate. Furthermore, the interface of a small display device is less sophisticated. The standard components of traditional graphical user interfaces, such as scrollbars, buttons and menus, which on a desktop only take a small percentage of the available screen estate, take up a considerable percentage of screen estate on a PDA.

Designing a user interface that is effective within the constraints of mobile devices is a tough challenge and becoming a hot research topic. It requires more than just squeezing information into a tight little GUI. Good usability is the primary requirement for such an interface design and is critical to attract and retain users. Usability can be viewed as having three broad dimensions: efficiency, effectiveness, and user satisfaction.

In order to adapt to different clients, we need an efficient mechanism to browse the content of the Web.

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There are increasing demands for the ability of efficient browsing to meet the client side requirements. To meet these demands and fully exploit the technical potential of advanced user interface design and mobile computing technologies, we have made a preliminary investigation into the usability of various browser technologies. Present browser technologies for mobile devices can be characterized into three categories [3]: presentation optimization, semantic conversion, and scalable (zooming) methods. We designed a simulator to implement these three methods and compare their pros and cons by a controlled experiment. This paper reports our findings and experience.

Section 2 introduces the aforementioned three interface design models. Section 3 briefly describes the goal and procedure of our experiment. Section 4 reports the results of the experiment, and Section 5 compares these three methods. Section 6 discusses related work, followed by the conclusion and future work in Section 7. Appendix A provides the original questionnaire used in our study and Appendix B is the user guide providing further details of the simulator.

2. Three interface design methods

This section will first set the background and then introduce three different interface design methods for small displays in order for us to compare their usability, i.e. presentation optimization, semantic conversion, and zooming.

2.1. Background

Chen and Mohapatra proposed the method of scalable browser [3] and argued that their method is a new way to design PDA interfaces. There is however no data or experimental evidence to support the claim that their method is better over other prevailing methods, such as presentation optimization and semantic conversion.

Chen and Mohapatra compared their method with another method called *Format Conversion* which converts Web contents in a format that suits wireless devices. Referring to Format Conversation, they admitted that "the limitation of this approach is that format conversion usually cannot retain the layout and presentation style of the original document, which may confuse the clients when they hop between desktops and handsets. Usually our familiarity with most of the web sites that we frequently access helps us in quick and easy access to the information that we are looking for. For example, if we browse cnn.com often, then we are well aware of the location of stock quotes, weather, sport news, etc. If we use multiple handheld devices in addition to our desktops, the format conversion may be an inconvenience for quick access of information. It would be desirable to exploit our familiarity with the web site design even when we are accessing the site using the handheld devices. Furthermore, similar to the semantic conversion method, this approach also requires the maintenance of multiple versions of the web pages (HTML and WML)." Also, according the comparison of different browser technologies [3], after applying the Format Conversion method, the new style and layout is "usually not" consistent with the original one. For these reasons, we decided to compare the three methods of presentation optimization, semantic conversion, and zooming, excluding Format Conversion which is obviously the weakest method.

There are commercial products such as NetFront v3.1 for Pocket PCs, which is the latest version of the NetFront family of Web browsers and have been installed in approximately 254 models of PDAs, game consoles, mobile phones. It mainly uses the zooming method, which reflects the importance for the need to conduct an empirical study in comparing these browsing interface methods.

2.2. Presentation optimization

Presentation optimization represents a broad range of technologies whose objective is to optimize the rendering process so that the contents to be displayed on the screen are maximized and users' navigation complexity is minimized. For instance, the embedded version of Microsoft Internet Explorer has the functionality of fitting the contents into the screen size. This technology can properly adjust the width of the displayed area such that users are relieved from scrolling horizontally to locate the desired contents [3]. Using this method, we fit the contents of a document to the limited size on a small screen. The disadvantage is that the semantics cannot usually fit the style well and users cannot easily locate their desired content parts within the document.

2.3. Semantic conversion

Since the presentation capability of mobile devices is limited by their screen sizes, converting the original contents into what will facilitate the reading process is another viable solution. In the semantic conversion approach, Web contents within a given page are parsed,

analyzed, and reordered based on certain psychological and statistical rules that determine the rank of importance within the page [3]. We can use text summarization [4] and tree structure to provide an overview of contents to users. Users can jump from any page directly to the page containing the desired material.

2.4. Zooming

The zooming approach is based on a progressive rendering process that retains both the structural and semantic information. In the progressive process, the structural data are delivered first and the semantic data are delivered on demand. More specifically, upon requests, the server first replies to the client with the structural data plus a small set of semantic data that assists the client's understanding of the whole information. The client's mobile device can render the structural data within the screen size. When the user at the client side navigates to a certain area and clicks to see the complete semantic information, the browser fetches the corresponding data and renders it using as much screen space as necessary [3].

In order to compare these three methods objectively, we have simulated the methods and implemented a controlled experiment to compare them, as described in the next three sections.

3. Simulator and experiment

3.1. Experimental assumptions

The purpose of this experiment is to survey the efficiency and effectiveness of the three design methods using our PDA interface simulator. Participated by twenty-seven graduate students as subjects, this experiment has made the following assumptions.

- Experience of using the simulated PDA interface by the subjects is similar to using a real PDA screen. Mouse clicks make little difference from PDA button clicks. Our simulated PDA screens are of approximately the same size as on a real PDA.
- The level of familiarity of the subjects to the e-business model of the case study makes little impact on the ability in answering the questions in a questionnaire we designed (see Appendix A). In fact, our questionnaire was designed to be neutral to the subjects' background knowledge.
- The text selected from the case study is general enough rather than too specific, and contains popular materials that are easily understandable. We prepared two groups of materials with similar generality (or specialty) to avoid any discrepancy in the easiness of understanding.
- The efficiency and effectiveness of using a browser are reflected by the average accuracy and speed of a subject to retrieve needed information. If a browsing method enables a subject to find the answers more correctly and quickly than another browsing method does, it is a better method. The accuracy is measured by the correct rate of answering the questions. The speed is measured by time spent and the rate of page changes.
- Certain qualitative indicators, such as a subject's confidence, cannot be measured quantitatively. We ask subjects to provide us feedbacks, such as what method they prefer, and why. We also collect from the subjects their suggestions on possible improvements.

3.2. The simulator

We have written a simulation program to model the interface of a small display. The screen size of the simulator is fixed, and almost the same as a real PDA screen. The size maintains the same on different simulation platforms, as shown in Fig. 1 that shows its form on a desktop PC.

We used Java Bean to implement the background server called httpsrv.95zxu. Using the http server, the simulator is insensitive to the local environment. During the experiment, a subject clicks on the directory of httpsrv.95zxu, and double clicks on startup.bat to run a Java serverlet, as shown in Fig. 2. Then, the backend will run background jzhttoSrv.jar as shown in Fig. 3. In a few seconds, the Simulator Server httpsrv.95zxu is set up, as shown in Fig. 4. The http server controls the simulator and records the elapsed time spent on each page. We also require the subjects to record the time they spent on each question.

3.3. A case study

As a case study, we revised the tutorial material of eBay for our experimental text. EBay is a popular Web site for buying and selling commodities on-line and has a large user community. Since it has strict rules on how to buy and sell, we can use the tutorial material in different presentations to test users' understanding of the

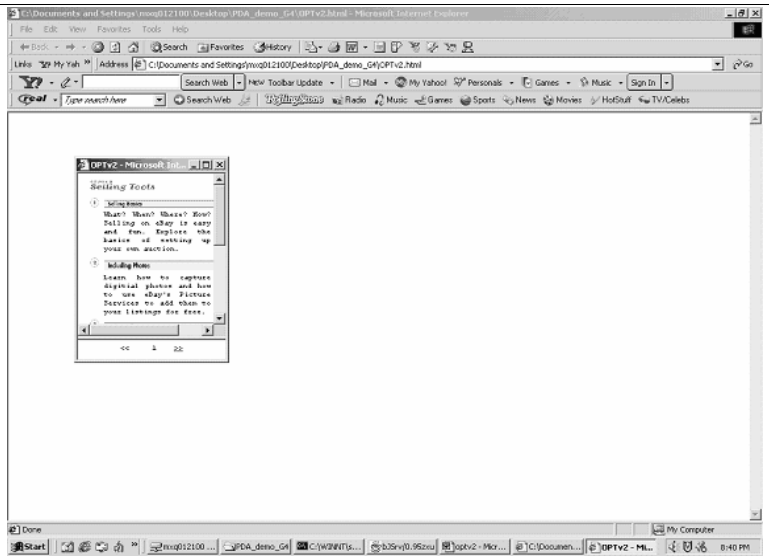


Fig. 1. Simulator interface.

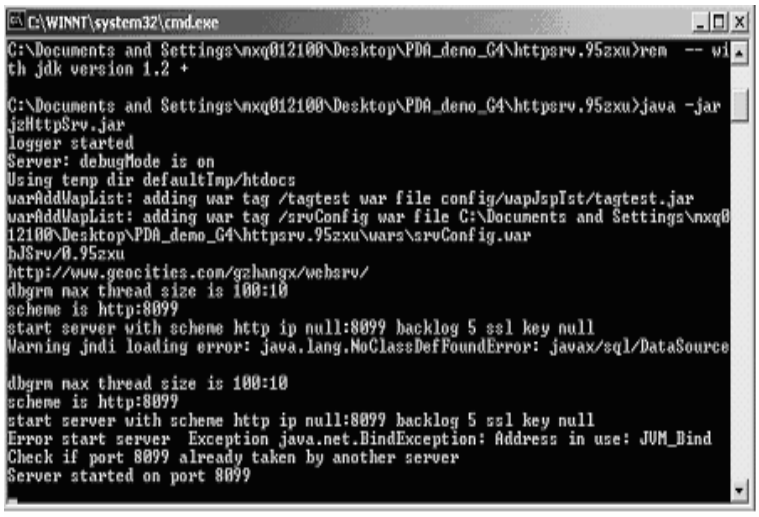


Fig. 2. Startup interface.

tutorial contents and acceptance of various browsing features. Thus, we can compare the efficiency of different Web browser design methods. Also, the tutorial has an intuitive structure and pictures, which are easy to be reorganized and presented in different styles.

We selected two tutorial texts from the eBay web site. These two texts are similar in contents and style so that the experimental results are comparable. The second text is a little longer and more complex than the first text. For each text, we wrote three Web simulation programs to simulate the three Web browsing methods. For example, the interface simulators for the first text include: OPTv1.html, Seman_v1.html, and Zoom_v1.html, corresponding to the three methods. The ones for the second text are OPTv2.html, Seman_v2.html, and Zoom_v2.html.

As shown in Fig. 5, the Presentation Optimization method supports page by page type of navigation. For example, one can only go from page 1 to page 2, then page 3, page 4, and finally page 5.

With the Semantic Conversion method (shown in Fig. 6), when clicking on the menu "Form Completion" in page 1, we get page 5 directly. Since the tutorial is organized in a tree structure, we can easily search

Fig. 3. Running background jzhttoSrv.jar.

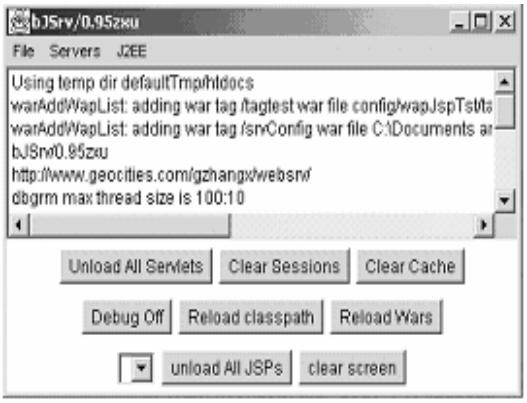


Fig. 4. Simulator server httpsrv.95zxu.

the directory and find certain subtopics in which we are interested. One needs not to click on the next button page by page to get page 5. There are also Upper/Lower-level and Home functions.

As shown in Fig. 7, the Zooming method is based on the Semantic Conversion method with an additional zooming function. For example, there is a picture in page 4. To see the picture in detail, one can click on it to blow up the full picture as in page 5 (on the right of Fig. 7). There are also Upper/Lower-level and Home functions.

The browsing structures of the three simulated interfaces are illustrated in Figs 8, 9 and 10. There are two types of links. A *linear link*, denoted by a solid arrow in the figures, allows the browsing from page 1 to page 2, and from page 2 back to page 1. A *hierarchical link*, denoted by a dashed arrow, support the direct jump from one level to another in a hierarchical Web structure. Hierarchical links are used only in Semantic Conversion and Zooming methods.

Figure 8 illustrates a total of 6 pages like the original tutorial text from the eBay Web that is contained in 6 pages. We have simply changed the screen size and use a vertical and a horizontal scroll bars to simulate the screen on a PDA. A user has to navigate the contents linearly through page by page.

Figure 9 shows the structure of the Semantic Conversion method. There are totally 21 pages based the same contents used for the Presentation Optimization method. As the number of pages increases, the size of each page decreases. There are three layers. The first page is the table of contents of the whole document, i.e. Page 1 in Fig. 6. There are two parts in Page 1. Part one is for “Selling Items”, including three sub-lists. By clicking on “Selling Basics”, we arrive at Page 2. Similarly, clicking on “Form Completion” brings us to Page 5, clicking on “Closing time” to Page 12. Part two is for “Accept Online Payments”, which includes three sub-lists: “Introduction” (in Page 19), “Select PayPal” (in Page 20), and “After the Sale” (In Page 21). Linear links are represented by solid arrows and hierarchical links, such as the Upper-level and Home links, are represented by dashed arrows.

Based on the Semantic Conversion method, the Zooming method adds the additional function of zoom-

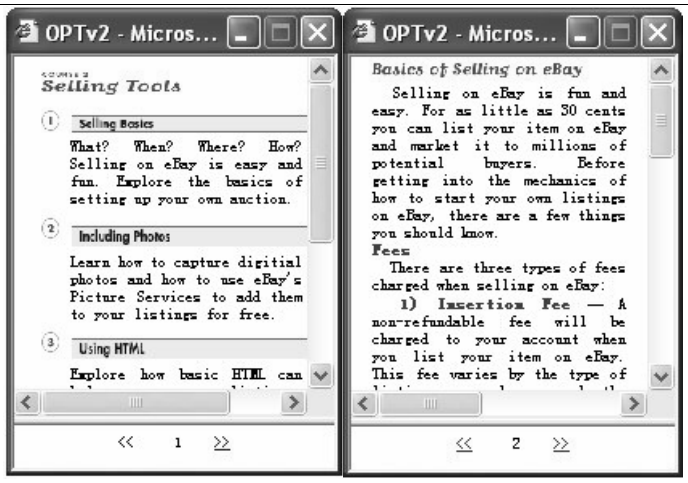


Fig. 5. Presentation optimization method.

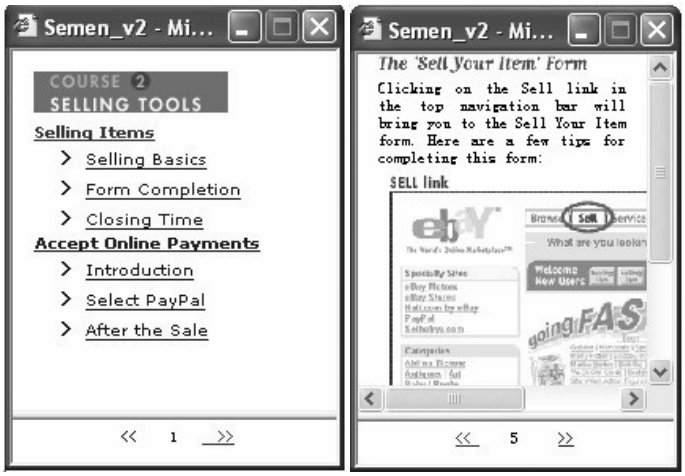


Fig. 6. Semantic conversion method.

ing. The details of some specific information, such as a graph, are represented by different icons. When clicking on this icon, we can obtain the expanded graph or details. Totally 17 pages are depicted in the browsing structure of Fig. 10, a number between the number of pages in the Optimization method and that in the Semantic Conversion method. As expected, the Zooming method has a similar structure as the Semantic Conversion method, but more concise and easier to understand.

3.4. Experimental procedure

In this experiment, 27 graduate students majoring in computer science participated as our subjects. We collected their profiles regarding their exposure to PDAs and the eBay Web site. 20 of them have not used PDA before. Of the remaining 7 subjects who have used PDAs before, only two have owned PDAs. All the subjects have heard of the eBay Web site, but none of them has read the tutoring material before. We divided the 27 subjects into 4 groups and each group includes 1 or 2 subjects who have used PDAs. We conducted our experiment on the three methods in the following arrangement in four groups:

- Group 1: OPTv1.html, Seman_v2.html.
- Group 2: OPTv2.html, Seman_v1.html.
- Group 3: OPTv1.html, Zoom_v1.html.
- Group 4: OPTv2.html, Zoom_v2.html.

We designed a PDA interface feedback questionnaire to evaluate the effectiveness of each method. This

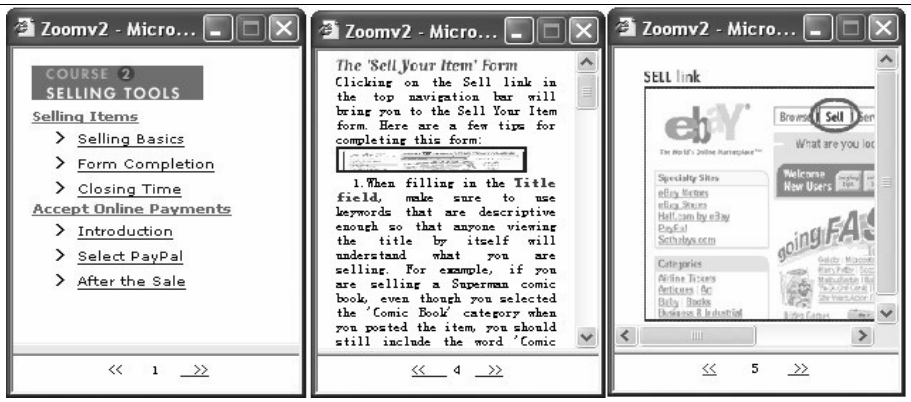


Fig. 7. Zooming method.

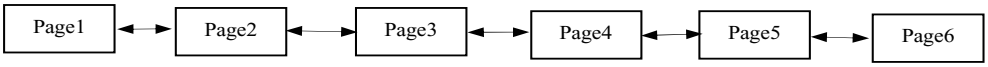


Fig. 8. Presentation optimization structure.

questionnaire contains 10 questions for the first text of the eBay tutorial, 10 for the second text and 7 general questions. The first 20 questions are tailored to quantitatively compare the effectiveness of the three interface design methods, and the 7 general questions are used for qualitatively comparing the three methods. The questionnaire is attached in Appendix A.

Of the different Web files listed above, OPTv1.html corresponds to the first text in EBayQuestion.doc using the Presentation Optimization method. Seman_v2.html corresponds to the second text in EBayQuestion.doc using the Semantic Conversion method. Zoom_v1.html corresponds to the first text in EBayQuestion.doc using the Zooming method.

The testing procedure is as follows, as shown in Fig. 11:

1. Each subject is given access to a server: http-srv.95zxu, two document files: Readme.doc, EBayQuestion.doc, and two simulator files, for example (OPTv1.html, Semen_v2.html).
2. The subject clicks on httpsrv.95zxu, and double clicks on startup.bat to run a Java serverlet.
3. Double clicking on the html file, the subject will see a small screen simulating the actual PDA screen. The subject is required to find the answers on this screen. Some questions ask the subject to select as many answers as apply. Also a subject needs to record the time he/she spent on each question and report it in a time sheet.
4. Find the answer on the PDA screen simulator. Upon completion, the subject reports the total time he/she has spent on each text. Under the directory of httpsrv.95zxu, the subject will find a file: cnt.txt, that records the information on page change rate and the number of clicks on each page. Also, the subject needs to submit this file.

4. Results

4.1. Subject responses

A total of 27 subjects participated in the experiment. In groups 1 and 2, totally 13 subjects participated the experiment of comparing the Presentation Optimization method (P) and the Semantic Conversion method (S). The result is: 3 voted for the former method and 10 for the latter as the best method. Figure 12(a) illustrates the subjects' preferences in the Presentation Optimization method verses those in the Semantic Conversion method.

Groups 3 and 4 consist of totally 14 subjects who participated in the experiment of comparing the Presentation Optimization method (P) and the Zooming method (Z). The result is: 1 voted for the former method and an overwhelming 13 for the latter. Figure 4(b) illustrates the subjects' preferences in the Presentation Optimization method verses those in the Zooming method.

4.2. Pros and cons

From the feedbacks of the subjects and the observation of our experimental results, the pros and cons of three methods are summarized below:

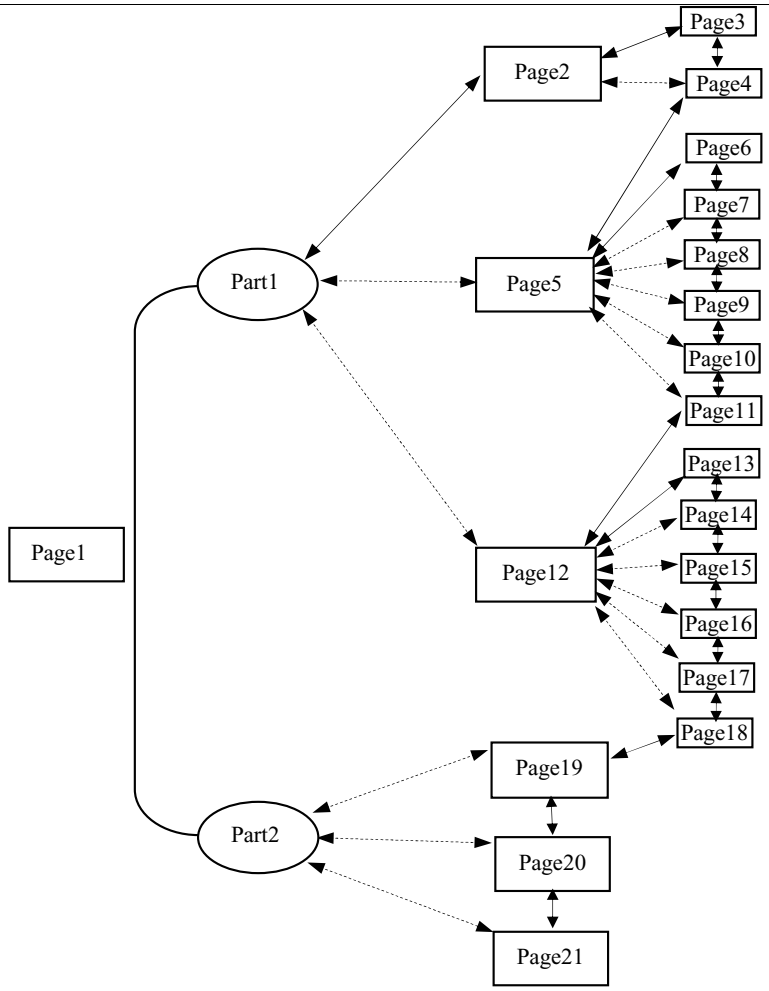


Fig. 9. Semantic conversion structure.

1. Presentation optimization method

Pros: This method is better for a novice user who wishes to learn all information in one page.

Cons: With the Presentation Optimization method, the subjects needed to read through a lot of text just to find the piece of information that they wanted. It was too difficult to search for a specific answer.

Most users do not like the scroll bar. Users are used to seeing outlines of information, simply clicking on the topic of interest, and being taken to the topic details directly. For example, one subject complained "It is annoying to have to scroll around a lot to get information." Another subject commented "It was difficult in the Presentation Optimization Method to find information because the data was less broken down. It was basically skimming the entire document."

2. Semantic conversion method

Pros: This method is easier to navigate, more organized than the Presentation Optimization method. Page contents could be clearly seen and the scroll bar could also possibly be eliminated.

Cons: Sometimes the information was presented across different pages and has to be searched from one page to another.

Again, the above conclusion was derived from the feedbacks from the subjects. For example, one subject said "I think I have to choose Semantic Conversion (between S and P) because it took me less time to finish the answers! I think it was more organized than the other one. However, the other one was pretty good too. It took me more time to finish the Presentation Optimization method. It had about 5 pages and Semantic Conversion method had about 17 pages. Even though it had 17 pages I finished Semantic Conversion one faster than Presentation Optimization method. I

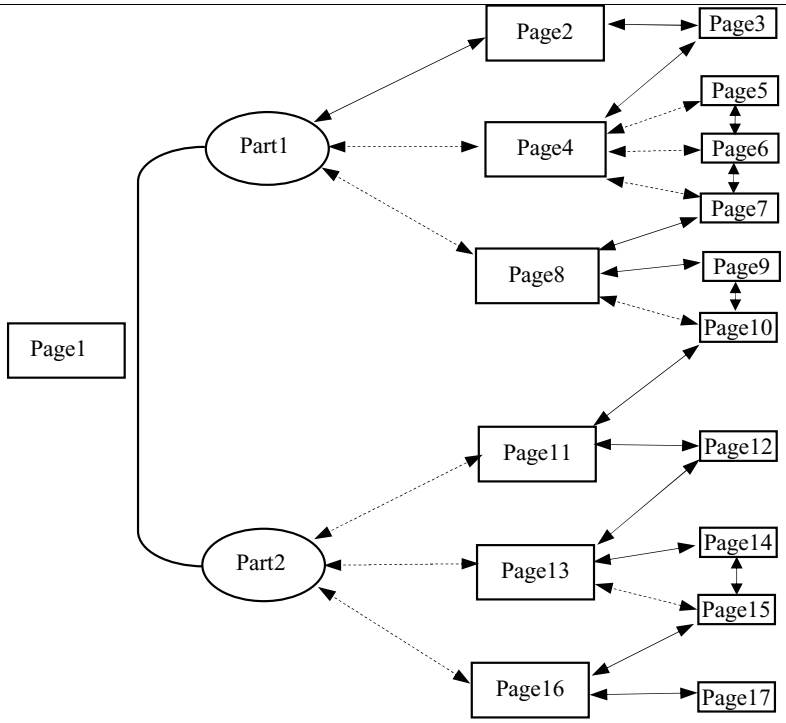


Fig. 10. Zooming method structure.

think Semantic one is more organized than the Presentation one. It was a nice experience and I learned more about PDAs". Commented by another subject, "I like the semantic conversion method (second method) best because it seems more natural and more user friendly. Plus, it is very similar to the way I interact with the web pages on a PC. In the presentation optimization method (first method), it is hard to find information and I have to search through all the pages to get to the one I want. And, I also have to read through all the information to find the information I need."

3. Zooming method

Pros: This method is easy to navigate. When looking for information, a subject only needed to return to the menu and click on the topic that seemed most related to what he or she was looking for. This helped to find the information more quickly than with the other two methods.

With the Zooming method, a subject could at least go to the general location to look for the answer. It provides an intuitive and hierarchical structure. It is easy to find and read the desired information. The method is effective for a user who wants to capture small pieces and detailed information. A browser implementing the Zooming method is better suited to this type of users.

Cons: Pictures showing on small displays cannot be very clear. The Zooming method also lacks the advantage offered by key word search due to the limited memory space.

The feedbacks from the subjects such as the following helped us to conclude as above. One subject provided quite convincing arguments: "I prefer Zooming because of its content layout, click and zoom, and organization. The Presentation optimization provides a good method of displaying the tutorial in that it fits most contents into the screen, even though one must frequently play with the vertical and horizontal scroll bars. The zoom browser does much of the same with two additional convenient features: a table of contents, rather than linear browsing as seen in the presentation optimization, and zooming into pertinent contents as needed. The latter provides an overall better version of browsing on PDA's, given their limited resolution. The zoom browser is better organized and should, in my opinion, be the software used on PDA's, an important digital tool of the future." Another subject gave a typical account by saying "With the Presentation Optimization it was too difficult to search for a specific answer. The Zoom you could at least get to the general location for looking up the answer."

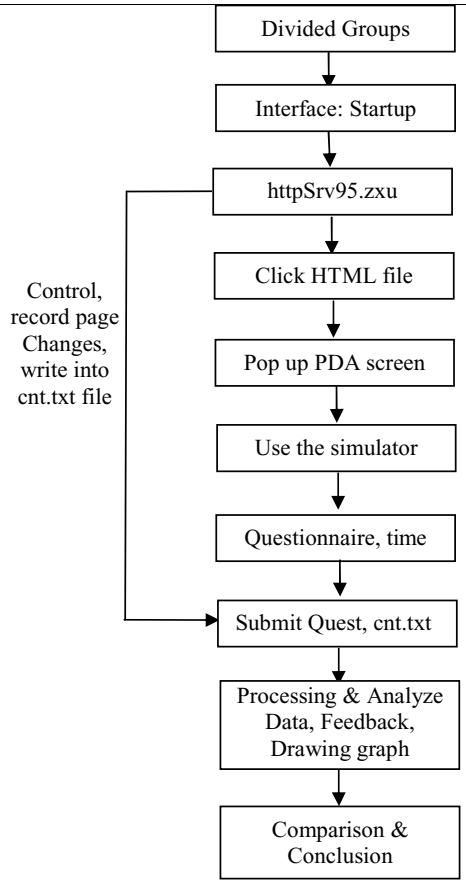
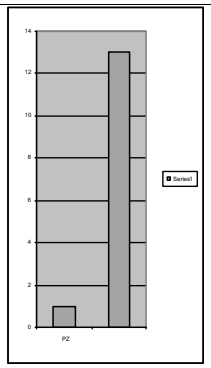
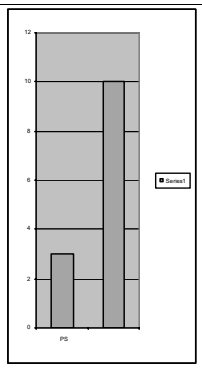


Fig. 11. Experimental procedure flowchart.



Presentation	3
Semantic	10

(a)



Presentation	1
Zoom	13

(b)

Fig. 12. Subjects' preferences.

5. Analysis and discussion

This section further analyses other characteristics of the three design methods. Section 5.1 analyses the time parameters of different methods: the average time spent on one question among all subjects, the average time spent on all questions by one subject and average total time of all 20 questions among all subjects. The time parameter reflects how easy or difficult to understand the material using different presentation methods. Section 5.2 analyses the average correct rates of one question and a total of 20 questions using different methods. The higher the correct rate is, the more efficient and effective the method used. Section 5.3 analyses the page change rates. To find a specific piece of information, a subject may need to access pages backward and forward. The lower the page change rate is, the easier for a subject to find desired contents. Section 5.4 discusses other issues in this experiment.

5.1. Time

1. Average time of one question

As shown in Fig. 13, the average time of a question using each method is obtained by averaging the time that a subject spent on each question. In Fig. 13, the time unit is minute. P stands for the Presentation Optimization method, S for the Semantic Conversion method and Z for the Zooming method.

2. Average time of 20 questions

The average time of answering all 20 questions for all subjects using different methods is shown in Figure 14 (time unit: minute). This parameter is an average on all 20 questions for each method. We can see that the Zooming method is the fastest, the Semantic Conversion method is second and the Presentation Optimization method is the slowest. all questions using different methods

3. Total time

The total time needed to finish all 20 questions using different methods is shown in Fig. 15.

From the data and figures obtained, we can see that with the Zooming method, users spent the least amount of time to answer a question, which means that the Zooming method is better in browsing the contents of Web pages. The Semantic Conversion method is also better than the Presentation Optimization method, which is the least effective in finding specific information among the three.

5.2. Correct rate

1. Correct rate: the correct rates of using different methods are listed in Table 1.

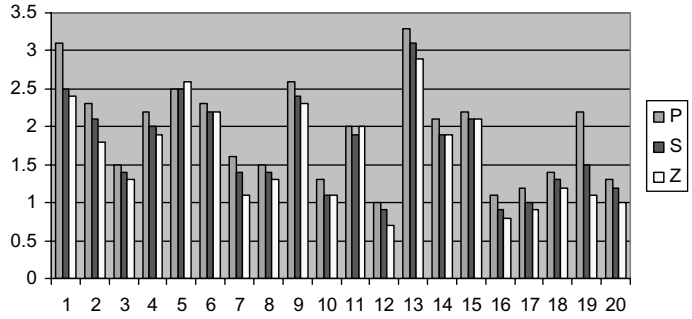


Fig. 13. Average time spent on a question using different methods.

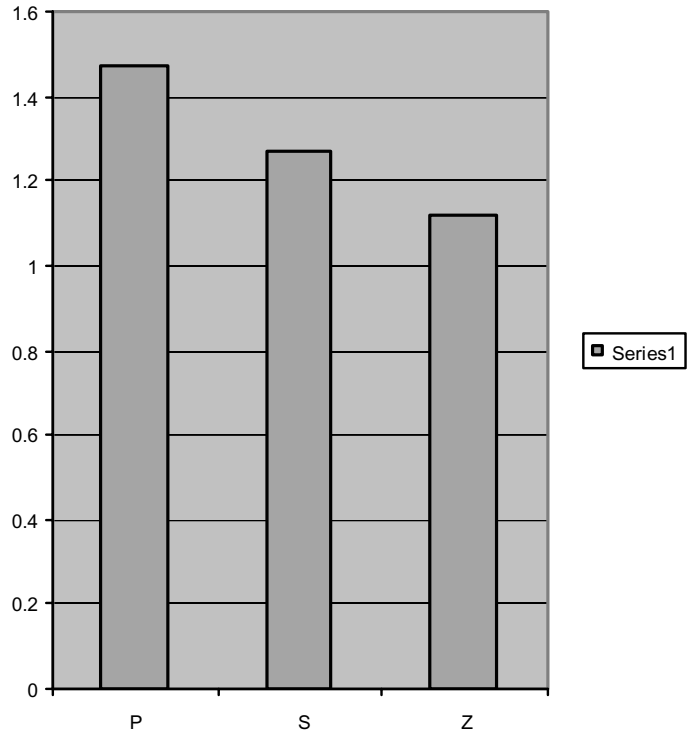


Fig. 14. Average time for answering.

2. Average correct rates for the 20 questions using different method are shown in Fig. 16.

These results show that using the Zooming method, users can easily locate detailed information and better understand the structure and semantics of the whole text. The Presentation Optimization method is the worst and Semantic Conversion method is in the middle.

5.3. Page change rate

To answer each question, a user may need to change from one page to another. The average page change rates of different method are shown in Fig. 17.

Since the questions are not arranged in the same order as the page sequence in the tutorial, a user needs to change from one page to another and jump frequently. The results show that using the Zooming method, a subject can locate specific information faster than using the Semantic Conversion method, which is in turn faster than the Presentation Optimization method.

5.4. Discussion

From the above experiment, we not only obtained data for comparing the efficiency and effectiveness of

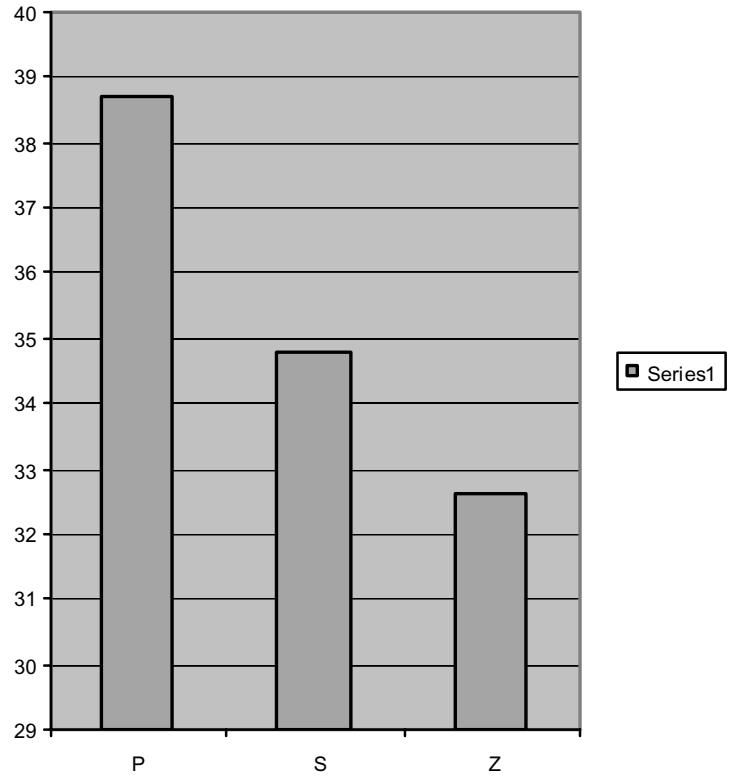


Fig. 15. Total time needed to finish all 20 questions using different methods.

Table 1
Correct rate of answering each question using different methods

	P	S	Z
1	80	80	90
2	90	80	100
3	80	80	100
4	40	50	70
5	70	80	80
6	30	40	60
7	90	90	90
8	70	70	80
9	30	40	40
10	80	80	80
11	40	40	50
12	90	90	90
13	90	90	100
14	100	90	100
15	80	80	80
16	60	70	70
17	70	70	70
18	80	80	80
19	90	90	100
20	30	40	60

these three methods, but also gained insights in how to improve Web designs. Many subjects have provided very valuable comments and discussions in Part III of the Questionnaire. We summarize their discussion as followings.

1. Adding keyword search may enhance a browsing method. One method is to allow users to click on keywords in the display text to traverse data. This will also strengthen the semantic aspect of the contents. The side-effect of this method is that searches might eat up too much memory. As commented by one subject, "The Zoom is ideal and would be perfect if you had a keyword search. Seems like with PDA's, though, the memory is an issue again and the search might eat up too much. So, if the applications stayed as they are, I would prefer the Zoom method."
2. In our experiment, the Zooming method is based on the Semantic Conversion method with an additional zooming function. We may further compare the Semantic Conversion and Zooming methods directly. Due to the limited time and the number of available subjects we had, our experiment only compared the Semantic Conversion and Zooming methods separately with the

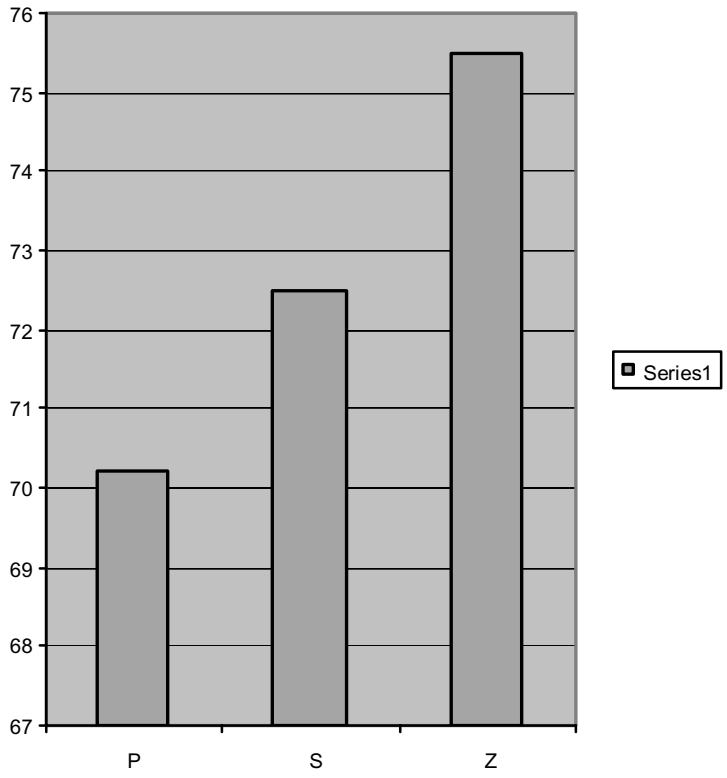


Fig. 16. Average correct rates for 20 questions using different method.

Presentation Optimization method. The relation between the Semantic method and the Zooming method is obtained indirectly. The Semantic Conversion and Zooming methods both have their own advantages and complement each other. Therefore, it will be desirable to combine the two methods in a single browsing interface.

3. Tree is a common structure in interface design. In our experiment, both the Zooming method and the Semantic Conversion method use the tree structure to represent the contents, so that the user can easily locate specific information. This complies with the way in which people learn new knowledge. The number on each page does not really help users in navigating the system.
4. The Zooming (also called scalable) method has good application potential, since it not only distinguishes structural data from semantic data in a hierarchical fashion, it is also scalable when delivering the information that the viewer is interested in. Hence, when adopting this concept, we can find a way to adapt to people's learning method and help them find useful information faster.
5. Some subjects reported that they did not like using scroll bars. This was clearly stated by a subject in the following comment: "What if the PDA displayed the data landscape ways instead of portrait? It would be easier to see the page contents and possibly eliminate the side-to-side scroll bar, which I am not very fond of. It may be a little uncomfortable on a standard style PDA but to not have to scroll both side to side and up and down would be great. This is just a thought though and I don't know what precisely you are collecting this data for." They made an interesting suggestion that the PDA display screen would be better designed in a landscape instead of portrait orientation. A landscape screen is hopefully wide enough to eliminate the need for a horizontal scroll bar.
6. Automatic adaptation or transformation of Web contents from desktop display to small display imposes various challenging issues. Transformation tools need to be intelligent enough to be capable of predicting or at least provide guidance for alternative but viable reduced displays. Our work is a useful first step towards this direction.

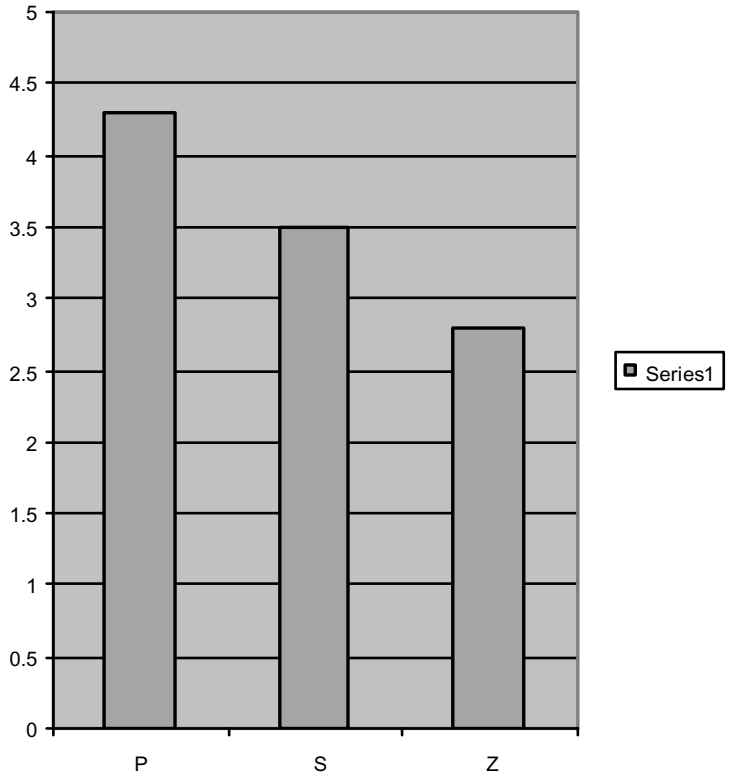


Fig. 17. Average page change rates of the three methods.

6. Related work

Much research has been conducted in the areas of interface design for small displays. Some emphasized on hardware aspect. For example, Mizobuchi et al. [5] conducted several experiments to compare target pointing performance with a pen and with a cursor key. Others concentrated on software aspect, such as text summarization, graph compression, hierarchical and dynamical interfaces, adaptation, as summarized below.

In text summarization, Buyukkokten et al. [4] presents important ideas of extracting semantics from the Web text yet greatly shortening the length of text. Usually, each text page is broken into a number of text units that can be hidden, partially displayed, fully visible, or summarized. Research has been conducted on dynamic text presentation for mobile devices using Rapid Serial Visual Presentation (RSVP) [6].

Chittaro et al. [7] have done experiments to explore the problem of graphically visualizing numerical data on the very small displays of WAP phones, especially the visualization using bar charts. The experiments are, however, not for Web navigation and presentation.

Researchers have proposed useful ideas on Web interface design, but have not performed sufficient experiments to compare different presentation methods in terms of their space efficiency. Hierarchical menu structure has been used in user interface design based on spatial organization of information [8]. For a mobile device, content hierarchy or Hierarchical Atomic Navigation (HANd) has been proposed as a new philosophy to improve Web navigation on small displays [9]. The idea is to divide an original page into zones and make the navigator page as a reduced overview of the original page. Henricksen et al. [10] addresses types of adaptation that can be applied to a Web browser in response to diverse context changes, including changes in the user context, input and output device capabilities, etc.

Buchanan et al. summarizes that there are three ways of presenting information on a limited screen [11]: **Horizontal Scroll** method: only characters across the display are shown. Users scroll to the right to retrieve remaining sentence. **Vertical Scroll** method: text is wrapped to show full sentences. **Paged** method: a long text is broken into multiple pages. Each page fits on the display screen. User hits "Next" button to get to

next page. Performance results have been reported [12] and independently confirmed [13]. The Vertical Scroll method is the fastest among the three methods. It also produced the least number of errors. Paged method was the worst, which is the reason why WAP 1.0 WML failed.

Buranatrived and P. Vickers explores whether users of different devices would experience differently [14]. Their findings indicate that usability can be maintained through multi-platform deployment, and there may also be usability advantages if the specific interaction paradigms of different mobile platforms are taken into account. This would require some means for separating not only the interface from the functionality, but also the interface functionality from the interface data. They did not further compare which browser method is more efficient. Patel et al. [15] evaluates techniques for browsing photographs on small displays, which use scrolling and zooming techniques.

Introducing an approach to the personalization-based optimization of Web interfaces for mobile devices, Hinz et al. [16] uses the ideas of structure adaptation and content adaptation to realize adaptive intelligent user interfaces. Bellotti et al. [17] developed a new tool called MADE that aimed at supporting efficient development of applications in mobile tour guide. The fundamental design of such a multimedia interface tool lies on the combination of layout adaptation and semantic adaptation.

In summary, the aforementioned related works all contain some basic ideas related to the three methods studied in this paper. They, however, investigated specific approaches without providing a thorough comparative study for different approaches. This paper has reported an empirical study using a simulator that mimics three representative browsing methods. Through on our study, we have obtained important findings that provide useful recommendations for future design of browsing interfaces on mobile devices.

7. Conclusion and future work

7.1. Conclusion

This paper has reported our experience in an empirical method to compare three design methods on small screen displays, such as a PDA screen. A controlled experiment has been carried out to reveal the characteristic of each method. The Zooming and Semantic Conversion methods are better than the Presentation Optimization method. The tree structure is a common method in the interface design for small screens.

Presentation Optimization provides a good method for displaying tutorial materials when it can fit most contents onto the screen, even though one must frequently use both vertical and horizontal scroll bars. A semantic browser does much of the same with an additional convenient feature: a table of contents, rather than linear browsing as seen in the Presentation Optimization method. A Zooming browser is better organized and allows the user to zoom into pertinent contents as needed. The latter two methods provide an overall better means for browsing small screens, given their limited resolution. They should be good choices for interface design on mobile devices. In fact, they could well be combined in single browsing interface.

From this empirical study, we have learned some basic ideas on how to design effective user interfaces and present contents structurally so that users may browse small displays efficiently. The results of this study will provide a useful guidance and reference for future investigation into the performance of browsing on small displays.

7.2. Future work

We plan to conduct further empirical studies using many more subjects with more diversify profiles. Another future work is to implement the idea of progressive delivery and scalable browsing according to user's requirements. We will research into decoupling of structural and semantic data from Web pages, and use text summarization to obtain the contents of original pages and create space-efficient pages for small display areas.

We will further exploit intelligent mechanisms for automatically adjusting existing desktop Web pages to small display browsers using structural and semantic adaptation. Applying the results of this work to the design of our graph grammar based adaptive approach [18,19], we will be able to devise more efficient and effective means for automatically transforming desktop Web pages into pages for small displays. We will focus on the issues and techniques for size adaptation and style adaptation in response to the change of device requirements and users interactions.

References

[1] L. Passani, *Building Usable Wireless Applications for Mobile Phones*, Proc. Mobile HCI'2002 – 4th International Symposium, LNCS 2411, Pisa, Italy, Sep. 18–20, 2002, 9–20.

[2] K. Marriott, B. Meyer and L. Tardif, *Fast and Efficient Client-side Adaptivity for SVG*, Proc WWW'2002, 2002, 496–507.
[3] H.M. Chen and P. Mohapatra, *A Novel Navigation and Transmission Technique for Mobile Handheld Devices*, Technical Report, CSE-2003-1, UCDAVIS, 2003
[4] O. Buyukkokten, H. Garcia-Molina and A. Paepcke, *Text Summarization of Web Pages on Handheld Devices*, Proc. Workshop on Automatic Summarization 2001, June 2001, Pittsburgh, PA.
[5] S. Mizobuchi, K. Mori, X.S. Ren and Y. Michiaki, *An Empirical Study of the Minimum Required Size and the Minimum Number of Targets for Pen Input on the Small Display*, Proc. Mobile HCI'2002 – 4th International Symposium, LNCS 2411, Pisa, Italy, Sep. 18–20, 2002, 184–194.
[6] G. Öquist and M. Goldstein, *Toward an Improved Readability on Mobile Devices: Evaluating Adaptive Rapid Serial Visual Presentation*, Proc. Mobile HCI'2002 – 4th International Symposium, Pisa, Italy, Sep. 18–20, 2002, 255–240.
[7] L. Chittaro and A. Camaggio, *Visualizing Bar Charts on WAP Phones*, Proc. Mobile HCI'2002 – 4th International Symposium, Pisa, Italy, Sep. 18–20, 2002, 414–418.
[8] G. Lorho, J. Hiipakka and J. Marila, *Structured Menu Presentation Using Spatial Sound Separation*, Proc. Mobile HCI'2002 – 4th International Symposium, LNCS 2411, Pisa, Italy, Sep. 18–20, 2002, 419–424.
[9] F.J. González-Castaño, L. Anido-Rifón and E. Costa-Montenegro, *A New Transcoding Technique for PDA Browsers Based on Content Hierarchy*, Proc. Mobile HCI'2002 – 4th International Symposium, LNCS 2411, Pisa, Italy, Sep. 18–20, 2002, 69–80.
[10] K. Henricksen and J. Indulska, Adapting the Web Interface: An Adaptive Web Browser, Proc. Australasian User Interface Conference 2001, *Australian Computer Science Communications* **23**(5) (2001).
[11] G. Buchanan, M. Jones, H. Thimbleby, S. Farrant and M. Pazzani, *Improving mobile internet usability*, Proc. 10th International WWW Conference, ACM Press, New York, 2001.
[12] B. McKenzie and A. Cockburn, *An Empirical Analysis of Web Page Revisitation*, Proc. HICSS34 – 34th Hawaiian International Conference on System Sciences, Maui, Hawaii, 2001.
[13] A. Kaikkonen and V. Roto, *Navigating in a Mobile XHTML Application*, Proc. Conference on Human Factors in Computing Systems 2003, Ft. Lauderdale, Florida, USA, 2003.
[14] J. Buranatrived and P. Vickers, *A Study of Application and Device Effects Between a WAP Phone and a Palm PDA*, Proc. Mobile HCI'2004 – 6th International Symposium, Glasgow, UK, Sep. 13–16, 2004, 192–203.
[15] D. Patel, G. Marsden, S. Jones and M. Jones, *An Evaluation of Techniques for Browsing Photograph Collections on Small Displays*, Proc. Mobile HCI'2004 – 6th International Symposium, Glasgow, UK, Sep. 13–16, 2004, 132–143.
[16] M. Hinz, Z. Fiala and F. Wehner, *Personalization-Based Optimization of Web Interfaces for Mobile Devices*, Proc. Mobile HCI'2004 – 6th International Symposium, Glasgow, UK, Sep. 13–16, 2004, 204–215.
[17] F. Bellotti, R. Berta, A.D. Gloria and M. Margarone, *Supporting Efficient Design of Mobile HCI*, Proc. Mobile HCI'2003 – 5th International Symposium, Udine, Italy, Sep. 8–11, 2003, 241–255.
[18] K. Zhang, J. Kong, M.K. Qiu and G.L. Song, Multimedia Layout Adaptation Through Grammatical Specifications, *ACM/Springer Multimedia Systems* **10**(3) (2004).
[19] M.K. Qiu, G.L. Song, J. Kong and K. Zhang, *Spatial Graph Grammars for Web Information Transformation*, Proc. 2003 IEEE Symposium on Visual/Multimedia Languages, Auckland, New Zealand, 28–31 Oct. 2003, 84–91.

Appendix A: Questionnaire Used in the Study

0. Your name: _____ Student Number: _____

Part I. Questions on the eBay Case Study

1. If you pay by personal check, how many days needed eBay to clear the bank?
   Answer: time used:
   a) 10 business days
   b) 5 business days
   c) 7 calendar days
   d) None of the above
2. How to initiate the Checkout process to complete the purchase of your item once you have been notified that you are the winning bidder?
   Answer: time used:
   a) You can do this only by clicking on the 'Checkout' button.
   b) You can do this only by clicking on the 'Pay Now' button.
   c) You can initiate this process by clicking on the 'Checkout' or 'Pay Now' button within the closed View Item page.
   d) None of the above.
3. eBay will bid on your behalf only up to your maximum bid and only if there are competing bidders.
   Answer: time used:
   a) True
   b) False
4. What are the three sections of each item page? (tick 3)
   Answer: time used:
   a) Listing Information
   b) Item Description
   c) Payment Details & Instructions
   d) Bidding & Buying Section
5. Which one below about the Feedback Score of seller on eBay is correct?
   Answer: time used:
   a) The Feedback score will tell how much sales value your seller has made on eBay.

b) The last step in buying process is leaving Feedback for the seller.
c) Leaving Feedback helps promote an atmosphere of safe person-to-person trading on eBay.
d) On Feedback score, the star corresponds to the feedback number.

6. When buying items on eBay, which factors need you to consider about the items? (tick as many as apply)
Answer: time used:

a) How much the price is the item described.
b) The quantity of the item.
c) Shipping days.
d) Types of payment the seller is willing to accept.

7. You need to watch the auction of an item the entire time like you see on TV.
Answer: time used:

a) True
b) False

8. What's the basic two ways to find items on eBay? (tick as many as apply)
Answer: time used:

a) search
b) brows
c) smart search
d) email notification

9. About smart search, which one below is correct?
Answer: time used:

a) Just type in what you want to find in the search box on the home page.
b) To use the smart search feature, click the Smart Search button on the top navigation bar.
c) To use the smart search feature, click the words "Smart Search" that appear next to the Basic Search box.
d) The smart search feature allows you to narrow your search using key words.

10. Which one below is incorrect?
Answer: time used:
You may continue to refine your search by showing only those

a) items that are completed.
b) items located in a certain region.
c) items that accept PayPal or Gift Items.
d) items that are above certain price.

Part II. Questions on Three Interface Models

1. What are the three types of fees charged when selling on eBay?
Answer: time used:

a) Insertion Fee.
b) Additional Option Fee.
c) Shipping Fee.
d) Final Value Fee.

2. Can you sell items on eBay without credit card?
Answer: time used:

a) Yes.
b) No.

3. What is the safest and easiest way for buyers to purchase their items on eBay?
Answer: time used:

a) PayPal.
b) Visa Card.
c) Check Account.
d) Money Order.

4. Which is correct about providing shipping costs & payment instructions on eBay?
Answer: time used:

a) You can reduce the number of emails back and forth between you and your buyers.
b) The buyer will take more time to finalize the sale.
c) Using a 3rd party service to manage the payment of your auctions, you need not to complete the Shipping Costs section.
d) If the buyer is interested in using a different form of shipping, he can reduce the price of the item you specified in the Payment Details.

5. If the payment to an item you sold is in the form of a personal check, for your protection you may want to wait for it to clear before shipping the item.
Answer: time used:

a) Yes b) No

6. If you would like to include a photo in your listing, eBay's Picture Services makes it easy for sellers by providing:
Answer: time used:

a) all the photos free of charge
b) each photo for only 0.30 cents
c) one photo in each listing for free

d) each photo for only 0.15 cents

7. Which of the following is correct about opening a PayPal account?
   Answer: time used:
   a) Using Paypal, you still need to open your own merchant account.
   b) There is a fixed fee for incoming payments of each transaction.
   c) It takes a few minutes to open a PayPal account.
   d) Using Paypal is free and save your time as a result of accepting credit cards and payments online.
8. Once you set up an account with PayPal, you can specify credit card and electronic check as acceptable methods of payment for your listing.
   Answer: time used:
   a) Yes b) No
9. Is it a good idea to include shipping costs when you list your item?
   Answer: time used:
   a) Yes b) No
10. Where can you get to the Checkout Summary page from? (tick as many as apply)
    Answer: time used:
    a) the My eBay page;
    b) the item listing page;
    c) the Checkout confirmation email;
    d) None of the above.

Part III. General Questions

1. Do you know what is a PDA?
   a) Yes b) No
2. Have you ever used/played with a PDA?
   a) Yes b) No
3. Which PDA function you are interested in most? (select as many as applicable)
   a) For fun (photos, MP3, games).
   b) For study (e-book, Internet).
   c) For business (phone book, calendar).
   d) For convenience (read/write note).
4. I have had ___ experience in PDA development.
   a) Long b) Some c) Little d) No
5. Of the three browser techniques, which one do you like the best?
   a) Presentation optimization: fitting the contents into the screen size.
   b) Semantic conversion: the Web contents are parsed, analyzed, and reordered based on certain psychological and statistical rules that determine the rank of importance within the page.

   Explain why here: _____
6. How much time have you spent on the answer questions using the following methods?
   1) Presentation optimization method: _____
   2) Semantic conversion method: _____
7. Any other comments (please add as much discussion as you like and use more pages as needed – THANKS):

Appendix B: User Guide to the Simulator

1. The purpose of this test is to survey the efficiency of several search methods using PDA screen.
2. In folder PDA_demo_G1, there are:
   1 folder: httpsrv.95zxu
   2 doc file: Read me.doc, EBayQuestion.doc
   2 html file: OPTv1.html, Semen_v2.html
3. Click httpsrv.95zxu, find file startup.bat. Then double click it to run javaserverlet.
4. OPTv1.html is correspondent to course 1 in EBayQuestion.doc. Semen_v2.html is correspondent to course 2.
5. Double click the html file you want to test. You will see a small sized screen which is a simulation of actual PDA screen. Find the answers in this screen. Some questions ask you to select as many answers as apply. Also please count the time you spend on each question and fill it in the time blank. There is also a background Web page, you can close that one if you feel inconvenient.
6. Find the answer in the PDA screen simulator. When you finished, report the total time you have spent on course 1 and course 2 separately.
7. After you finished all the questions on the paper, please turn in your answers.
8. Under the directory of httpsrv.95zxu, you will find a file: cnt.txt. Send back this file to me.