Design and Analysis of Haptic-Audio Based System for the Visually Impaired to Shop Online

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***Abstract*—Many visually impaired customers are keen to shop online, however, they often encounter accessibility barriers such as accessing and interpreting complex designed websites and when trying to make online payment which required them to input card details by filling up payment form. In order to study whether the visually impaired could shop online without assistance, an online store which has features such as product catalogue, shopping cart and payment system was developed. The system utilizes the Falcon haptic device and voice recognition for navigation, interaction, accessing and haptic evaluation of products. Some of our qualitative analysis suggests that a framed three-section design product catalogue with directed dialogue, directional cues, audio information along with a haptic-audio enabled browser is feasible for the visually impaired to browse, select and haptically evaluate products; a XHTML and VoiceXML based shopping cart system can enable the visually impaired to interact and verify its contents; and a voice password based payment system can be used to automate forms data entry process and to help the visually impaired to make online payment independently.**

***Index Terms*—Haptics; Haptic-Audio Website; Visually Impaired.**

I. INTRODUCTION

Despite guidelines from the W3C's Web Content Accessibility Guidelines [1] to ensure accessibility, websites tend to be designed with attractive visual layout without consideration of the needs of users with disabilities. Web pages contain ambiguous links; animation, videos and graphics without alternate description; and tables with unstructured layout. Such layout design makes it difficult for those with visual impairment to understand webpage content when access using assistive technology (AT) [2]. Screen readers such as JAWS, Non-Visual Desktop Access (NVDA) and WebAnywhere are some of the popular AT devices which visually impaired people use to access web pages [3]. However, in the survey conducted by WebAIM, almost 65% of the screen reader users had the opinion that websites have become less accessible [4].

Due to the poor accessibility of online e-retailing websites, visually impaired do not shop online or if they do, they often request help from sighted people. Many researches had done to enhance the web applications by enriching the web content with an added layer of modality information, specifically through the sense of touch [5]. However, there is very little research targeting in solving how the visually impaired can shop online. Some of the reasons are lack of user's ability to point and click in order to interact with web data that requires mouse operation; the difficulties of using AT devices to interpret and interact with web content, and to input data into online forms; and web browsers are needed to be integrated with haptic devices in order to render haptic properties, but current popular browsers do not have plug-ins for popular haptic API such as H3DAPI, Chai3D and OpenHaptics, which are needed for haptic evaluation of online products.

Hence, in this study a haptic-audio based online shopping (HABOS) system is developed in order to investigate a possible solution for the visually impaired to shop online independently. The client part of the system consists of a haptic-audio enabled browser to enable the visually impaired to receive haptic feedback via a haptic device and uses speech recognition to interact with the system. The server part of the system consists of an online store with shopping features such as product catalogue, shopping cart and payment system.

The research questions investigated in this study were: (1) whether a product catalogue system with a three-section layout design and a haptic-audio enabled browser is feasible for the visually impaired to shop and evaluate online products without assistance; (2) whether a XHTML+Voice (X+V) based shopping cart system is feasible for the visually impaired to interact and verify its content; and (3) whether a voice password based payment system and an automated data entry program is feasible to help the visually impaired to fill up form for payment process. The remainder of this paper is organized as follows: Section II reviews the related work; Section III discusses the research methodology; Sections IV discusses the results and findings, and finally Section V presents the conclusion and future work.

II. RELATED WORK

Haptic technology involves human somatosensory system which includes tactile and kinesthetic sensations. Tactile sensation perceives information derived from touch inputs and kinesthetic sensation perceives physic stimuli arising within the body regarding motion and position [6]. Both have great significance in human-computer interaction, tactile sensation can be employed in the application of implementing new physical properties, such as different textures of virtual objects and kinesthetic sensation can be used in the application of simulating torque for dynamic virtual objects [7]. These can be achieved by using haptic devices to interact with rigid virtual objects of regular shapes and receive force feedback [8]. Many past researches were done to enhance web applications by enriching the content with haptic properties to allow users to get a realistic experience of touch when interacting with 3D objects. Saddik et al. [9] proposed using open source web haptic plug-in through HTML5 for haptic modality deployment in web applications; Bergamasco et al. [10] proposed a script based framework for web haptic interaction by combining a virtual reality engine and a haptic rendering engine via haptic interfaces; and Hughes et al. [11] presents a simplified authoring system that allows integration of 3D haptic contents into the web applications by using Virtual Reality Modeling Language (VRML) for the creation and manipulation of three-dimensional content.

Non-standard page layout with unstructured tables, frames, multi-media contents and dynamic contents make web pages more complex and inaccessible to the visually impaired. Many papers had discussed the difficulty for them to get a full view of the page because they have to traverse through many hyperlinks and headings in order to get some kind of page overview knowledge [12]. Using table to format page layout is confusing, as the table will contain data and alignment elements which can confused the visually impaired because they expect only data and not data with alignment information. One reason behind is that semantic and syntactic information is lost when a table is linearised for a screen reader [13].

Researches were done to improve web accessibility such as WebSpeak [14] was developed to provide an overview of web content for the user by using text-to-speech output. Goose et al. [15] had created audio browsers based on 3D sound specialization to convey information on Web pages. Also, research studies on the interactive methods of auditory modality such speech-based user interfaces for inputting commands to computers [16]. The usage of 3D sound to help navigation in immersive virtual environments has been investigated in [17]. The results showed that sound cues can be used for navigation in virtual environments.

While there are various techniques to embed haptic and audio contents into web pages and many studies done to analyze the web accessibility problems as mention above, virtually no research has been done to study and analyze the combination of both in an online shopping environment. Therefore, this paper sets out to fill this gap. Its goal is to propose a solution and study whether the visually impaired could shop online independently. The main focus lies not on the browser plug-in, but on integrating a web browser with a haptic device and developing an online system so that the visually impaired could shop and haptically evaluate products.

III. Research Methodology

The apparatus used in the system evaluation consist of a notebook with Intel i7 quad-core 3Ghz processor, 2GB memory and 3D graphic controller with 500MB memory running on Windows 7 operating system, a Falcon haptic device and a microphone headset. A questionnaire was used as one of the research instruments to gather results from the participants. A total of 15 participants of different age group and demography from the Malaysian Association for the Blind [18], who had no experience with haptic device were involved in the evaluation. Before the evaluation begins, every participant was briefed, and given sufficient time to practice on the tutorial provided in order to familiarize themselves with the usage of the Falcon haptic device and the system. The evaluation sessions were recorded on video. These recordings provided data on observations which were hard to understand and also to analyze the actions of the participants such as haptic device control and speech input.

The evaluation methodology is focused on the usability of the system which is measured based on user satisfaction. According to Pu et al. [19], satisfaction or dissatisfaction is a way in which users can express their preferences upon the completion of the assigned tasks. For statistical analysis of the evaluation result, a 7-point Likert scale [20] is used in order to offer a wider range of preferences level. According to Diefenbach et al. [21], increasing the number of scale points increases scale sensitivity and their research found that a 7-point scale is more sensitive than a 5-point scale. As the evaluation questionnaire is unique and stand-alone, thus each question is treated as a single-item Likert scale and a median is used to determine the user satisfaction rating. The scores of the 15 participants were used to determine the median which indicates the usability of the system according to the 7-point scale: 1 = ‘Strongly Dissatisfied’, 2 = ‘Dissatisfied’, 3 = ‘Weakly Dissatisfied’, 4 = ‘Neutral’, 5 = ‘Weakly Satisfied’, 6 = ‘Satisfied’ and 7 = ‘Strongly Satisfied’.

A. Product Catalogue System

Web pages are rendered by AT devices such as screen reader as a continuous stream of audio that lacks logical sections. Therefore, when web pages have a complex layout, screen readers feedback becomes ambiguous [22]. This has created accessibility problems for the visually impaired. Hence, HABOS product catalogue system is designed with a consistent framed three-section layout with static content for easy navigation and accessibility (Figure 1). Every product page is divided into three sections. The top banner section provides an option to exit the current page and display content of another page. This section usually contains the shopping cart option which allows the user to check the cart content. The middle section is used to present the data when an option is selected. The footer section contains options that are related to the data presented in the middle section. Each page is also surrounded by four frames. They are top, bottom, left and right frame which are used to inform the user that the pointer had reached the edge of the page and to give directional cues to the next option. The server side of the system was developed using XHTML, VoiceXML, H3DAPI, HAPI, X3D, C++ and Python running on the Windows, Apache, MySQL and PHP (WAMP) platform. A total of four products categories: chair, sofa, table and miscellaneous are selected to provide a wide spectrum of texture, stiffness, size and shape in order to gather a better analysis on the user’s evaluation on the haptic properties. The 3D virtual products are digitized and model into X3D format using Autodesk 3DS modeling software. H3DAPI and HAPI are used to add haptic and audio properties to customize the X3D scene nodes and fields. Different parts of the product’s model are haptically rendered separately in order to provide the user with a better perception about the model (Figure 2).

The catalogue uses the Falcon haptic device and voice command to interact with the products, thus eliminating the usage of mouse device. The system keeps track on the position of the haptic device pointer, whenever the pointer hovers over or leaves an active portion of the web page, directed dialogue will direct the user to the next available options. The product catalogue (Figure 3) will display each category of the products either via the ‘right’ button on the haptic device or responds to the voice command ‘Browser Next Page’. Selecting a product category is either via the ‘left’ button or responds to voice command ‘Browser Select’. Every product page has an introductory audio message to describe the product which is render by the Text-to-Speech engine. When the user selects a product, the product's model menu will be displayed. When a model is selected, it will be presented as a virtual 3D object for the user to evaluate. To evaluate a model, the user uses the haptic stylus to trace the product's dimension and shape, and feel the product texture and firmness. If the user decides to purchase the model, he or she can select the 'Add To Cart' option to add the model into the shopping cart (Figure 1).

Figure 1: Product Catalogue

Figure 2: Different Parts of Chair Model

In order to use web browsers to haptically evaluate online products, they need to be integrated with haptic devices. However, currently none of the popular web browsers such as Firefox, Internet Explorer and Opera have haptic plug-ins needed to render haptic properties from popular APIs such as H3DAPI, Chai3D and OpenHaptics. Hence, the client side of the system was developed to include a haptic-audio enabled Opera-based browser (Figure 4). H3D API provides the product's scene definition such as lighting, meshes, textures and friction. The data from an X3D node is routed to a Python script node in order to program the model's behavior. HAPI provides functions for handling the interaction with the haptic device through force effects, collision detection, surface effects, and thread handling. The low-level HDAL API handles Falcon device initialization, cleanup, access to device state such as position and orientation, and output force and torque. When the X3D file is loaded into the browser, a helper program is used to ensure that all the X3D data and resources are routed to the Python nodes for processing and finally rendering the product's 3D model for haptic evaluation.

B. *Experimental Procedure*

The experimental procedure is to test the participants' abilities to navigate, browse, select and evaluate the products. The procedure consists of a series of tasks in which the participants have to interact with the Falcon haptic device and issue voice command. They were required to select all the models from the four categories of products and evaluate the models' dimension, shape, texture and stiffness. After completing all the tasks, they were interviewed for their ratings to the following question: "How feasible is the Product Catalogue system in term of ease of usage, navigation, quality of product presentation and accessibility?" and "How feasible is it to use Falcon device to evaluate product's dimension, shape, texture and stiffness?" The following is the scenario:

1. For each product category
2. Select all models
3. Haptically evaluate models

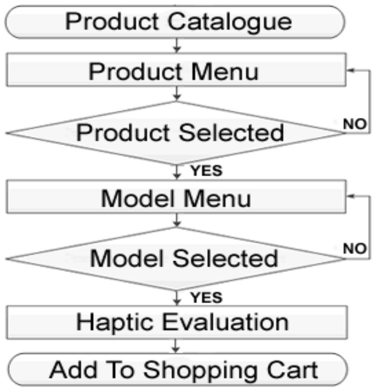

Figure 3: Product Catalogue Flowchart

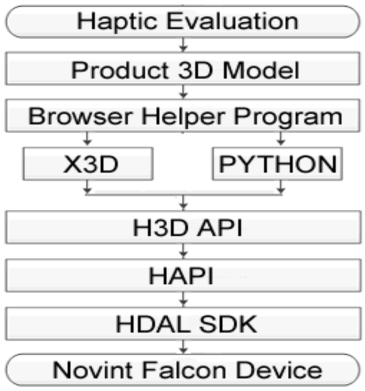

Figure 4: Haptic Browser Flowchart

C. *Shopping Cart System*

Shopping cart is an important feature for online shopping as it holds the product items that customers intend to purchase before checking out. Generally, HTML frames are used to display dynamic content stored in memory using JavaScript. However, using screen readers to read out dynamic content presented in a HTML frame could be confusing to the visually impaired. Even though the visibility of frames may be set to false, screen readers will still convey the presence of a frame and will read the elements stored in it. Hence, HABOS shopping cart system (Figure 5) is developed to provide a possible solution for the visually impaired to verify its dynamic content without using AT devices. The system was developed using XHTML + VoiceXML (X+V) which is a web markup language for developing multimodal applications created by IBM, Motorola, and Opera. X+V consists of three main standards namely XHTML, VoiceXML, and XML Events (Figure 6). XHTML is HTML 4 complies with the rules of XML. VoiceXML is a XML-based speech interface language developed by the World Wide Web Consortium. For visual markup, X+V uses the XHTML and for voice markup, it uses a subset of VoiceXML defined by the VoiceXML Form construct. For associating

VoiceXML with visual interface elements, X+V uses the Document Object Model (DOM) events framework used in the XML Events standard.

Figure 5: Shopping Cart

The visual and voice elements for user interaction are coded separately in the shopping cart application for flexibility and ease of maintenance. The visual markup components define how the user interface look like and how to response to the user inputs. The voice markup components define how to response when the user speaks to the web browser. The processing components define the event types and handlers from XHTML such as "on mouse-over" to create the correlation between visual and voice components. For visual markup, the web browser uses a graphics engine and for voice markup, the browser uses a speech engine.

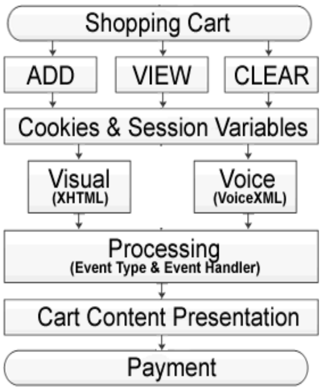

Figure 6: Shopping Cart Flowchart

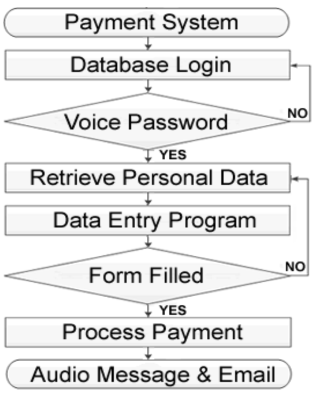

Figure 7: Payment System Flowchart

Each time an item is added, the system will use cookies and session variable to track product description, price and quantity, and calculate the total amount. When the haptic stylus hovers over the content presentation area (Figure 5), a message is prompted by a synthesized voice which directs the user to issue a voice command "Browser Proceed" or the "Click Left Button" on the haptic device in order to activate the content presentation. The code below shows a snippet of XML event and handler.

```
<table ev:event="mouseover" ev:handler="#message">
<textarea id="page.output" rows="33"cols="116">
</textarea>
```

Once, the speech recognition engine recognizes the command, the graphic engine will then display the cart content while the speech engine read out the cart content. The code below shows the snippet of VoiceXML when the shopping cart is empty.

```
<vxml:if cond="cart != cartcontent">
<vxml:value expr="intro"/>
<vxml:else/><vxml:value expr="empty"/></vxml:if>
```

After the users had verified the cart content they can proceed to pay for the items by selecting the 'Payment' option, located at the bottom section of the page (Figure 5). Also the user has a choice to either clear the shopping cart content or to exit and continue shopping.

The aim of this experimental procedure is to test the participants' abilities to interact, access and verify the shopping cart content. The procedure consists of a series of tasks in a scenario which the participants have to interact with the haptic device and issue voice command while performing the tasks. The participants were required to choose three models from any product category and add them to cart. Next, view and clear the cart content, and verify that it is empty. After completing all the tasks, the participants were interviewed for their ratings to the following question: "How feasible is the Shopping Cart System in term of accessibility, presentation, interaction and verification?" The following is the scenario:

1. Go to Product Catalogue. Select three models
2. Add to Shopping Cart
3. View, Clear & View Cart Content

IV. Results and Findings

The usability rating for the product catalogue system is 6.0 which according to the Likert scale indicates that it is usable for online shopping as the participants were satisfied in term of quality of product presentation, ease of usage in navigation, interaction and accessing of products. Based on the result, the participants able to understand the product page overview and layout, and able to browse, interact and select their desire products independently.

From the haptic evaluation result, the usability rating is 5.0 which indicates that the Falcon device is weakly usable for product evaluation. Slightly more than half of the participants were able to give the approximate sizes of the table models in the dimension evaluation; were able to correctly describe the different products' shapes ranging from hexagon to oval; were able to differentiate and describe the type of chair seat material according to their texture ranging from smooth to rough; and were able to differentiate the various sofa models according to their firmness ranging from soft to hard.

The usability rating of the shopping cart system is 6.0 which indicate that the shopping cart is usable for storing and presenting products as the participants were satisfied with the quality and accuracy of cart content presentation, ease of usage and system interaction. During the experiment, it is observed that they were able to interact, add, clear and verify item details in the cart without assistance.

The usability rating of the payment system is 6.0 which was measured based on the participants' satisfactions in term of ease of usage in payment process, effectiveness in using voice password to fill up form and using voice command to submit form for processing. The result indicates that the system is usable for online payment as the participants were able to process payment by activating the voice button to issue voice password and submitting the form via voice command.

Overall, our findings suggest that for effective product catalogue presentation in term of navigation, interaction and accessibility; the page layout need to be consistent and simple in order for the visually impaired to understand the page overview. However, for a consistent three-section layout design to work, user's browser must be able to run in kiosk mode which only displays the webpage content and nothing else. In this mode, no browser's menu options will appear in the top part of the windows which could confuse the user if navigated into this area.

For effective online product evaluation, the complete model and its different parts should be rendered separately in order to improve the user's perception about the product. However, to prevent cognitive overload due to excessive audio information, while rendering individual part, short contact sound cues should be used to indicate whether the stylus is touching or not touching the part surface. However, when rendering the complete model, audio messages describing the part in details should be used. This is to give the user an overall picture of how the different parts of the model are connected together.

For effective shopping cart presentation, the item details should be short and use simple product description. Each item detail should be read out one after another with a short pause and a longer pause before presenting the grand total amount. Each item should begin with an item number which is incremented for the next item in order for the user to keep track. The participants found the following format easy to interpret and verify: 'Item Number', 'Description', 'Price', 'Quantity', 'Total' and 'Grand Total'. Also, using Cascading Style Sheet (CSS) to control speaker's volume, stress level, speed and pause duration could improve the clarity of the audio information.

Using voice password to login to the database and retrieve personal data to automatically fill up form during payment process could minimized the exposure of username, password and credit card number to people who might be shoulder surfing behind the visually impaired user. Also, the automated data entry program could help to speed up the entry of information by finding the correct fields to fill in correct data, thus eliminating the usage of keyboard, and to relieve the user from having to remember all the form's fields which requires considerable amount of time for the user to acquire the skill.

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