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A Haptic and Auditory Assistive User Interface: Helping the Blinds on their Computer Operations

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***Abstract*—In this paper, a study of assistive devices with multi-modal feedback is conducted to evaluate the efficiency of haptic and auditory information towards the users' mouse operations. Haptic feedback, generated by a combination of wheels driven by motors, is provided through the use of the haptic mouse. Meanwhile, audio feedback either in the form of synthesized directional speech or audio signal. Based on these interfaces, a set of experiments are conducted to compare their efficiencies. The measurement criteria used in this experiment are the distance regarding to the target circle in pixels, the operational time for the task in milliseconds, and opinion in term of understandability and comfortability towards each modal of the tested user interfaces in discrete indices. The experimental results show that with the proper modalities of feedback interfaces for the user, the efficiency can be improved by either the reduction in operational time or the increase of accuracy in pointing the target. Furthermore, the justification is also based on the user's satisfaction towards using the device to conduct the predefined cursor movement task, which occasionally is difficult to understand and interpret by the user. For example of the application adopting the proposed interface system, a web browser application is implemented and explained in this paper.**

***Index Terms*—haptic mouse, assistive device, assistive application.**

I. INTRODUCTION

Computers have become an integral part of our daily life, that the number of computers owned by households has been growing everywhere over the past decade [1]. The same trend also applies for disabled people, as approximately 50% of their population has computers at their home [2]. Statistically, the number of disabled and elderly people has been increasing especially in developed countries [3]. In order to encourage them towards independently living as it is infeasible to cope with the problem by increasing the number of caretakers regularly [4]. Towards this aspect, we aim to develop a user interface that efficiently facilitates these people on their computer operations.

For visually-impaired people, the conventional input and output devices are inconvenient as the devices rely heavily on visual information. Though many studies introduce the use of other modalities of sensation for user interface to act as a supplement for the absence of vision, they are still not equivalent to what the vision is to the people [5].

Recent works have shown the progress of developing in assistive technologies in different modalities, in this paper we focused on assistive technologies using either haptic or auditory feedback. In term of haptic sense, letting the user interact with computer through the haptic interface device is an efficient way to provide assistance to the user [6]. A broad range of tactile mice have been developed to either assist the user or increase users perception towards objects from a multi-modal tactile mouse [7], a texture display mouse [8], to a commercial product of Logitech iFeel Mouse [9]. The result from [10] showed that there is no significant improvement in operation time by combining the use of the tactile and auditory feedback for ordinary people. On the other hand, a study on cursor movement using tactile mouse was conducted in [11], the result shows that the tactile feedback can reduce the operation time of the same task by around 2 percent which is not significant but the subjects supported the presence of tactile feedback when the cursor is inside the target area.

Moreover, there are many studies that try to assist the visual disabilities through web browsing by integrating the hardware to display the web contents based on the concept from [12]. An example of integrating the tactile interface with the web browser by displaying the content onto the pad consisting an array of pins that can represents Braille characters and images was conducted in [13], [14]. Although they proposed good applications for interface devices, they did not provide any evaluation on their systems. Furthermore, another type of application [15] stated that using auditory combined with haptic device can make the user perceive the map of USA better, still there was no significant result due to the fact of the user's unfamiliarity with the device.

II. SYSTEM ARCHITECTURE

Generally, interfaces between computer and user can be varied based on the requirement of the application and user's condition. For non-disabled people, standard human machine interfaces usually are well-suited to their needs. In order to assist the people with visual-disabilities, we introduce a system that provides feedback to the user. The flow of the proposed system is as shown in Fig. 1.

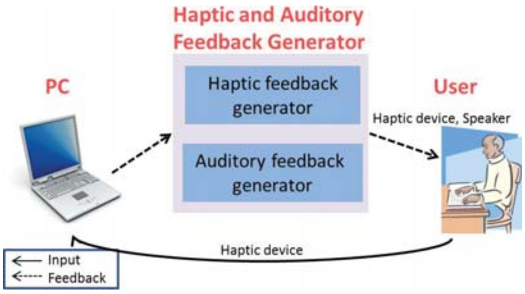


Fig. 1. System architecture for providing haptic and auditory feedback proposed in this paper.

The main focus of this paper lies in the Haptic and Auditory feedback generator part, as we want to determine a good combination of the two types of interfaces. The implementation detail of the components will be described in the next section.

III. HAPTIC AND AUDITORY FEEDBACK GENERATOR

In order for the user to perceive the input, output and current state of the computer in the absence of the vision, those information has to be translated and passed on to the user in the form that is recognizable and understandable to the user. In a previous study [16], the concept of single wheel mouse to generate the haptic feedback to track the cursor towards the target in single-dimension was introduced. As an attempt to improve the system, this study adopts the enhanced version of Haptic mouse and also introduces the use of auditory information towards the cursor tracking problem.

Section III-A provides a brief description about the haptic mouse, which is the component for haptic feedback generator. Section III-B describes about how the auditory feedback generator used in this paper.

A. Haptic Mouse

The input device for the system is as shown in Fig. 2. It is a mouse equipped with wheels rotated by motors to provide feedback. In the previous version of the Haptic mouse (Fig. 2a), user can perceive distance information using the single wheel attached to the mouse by perceiving the friction of rotation at the wheel. The main drawback of the single wheel feedback is it can represent only one axis information at a time. In order to improve on that aspect, a pair of small wheels is now added to provide haptic feedback for the second dimension (Fig. 2b).

The secondary wheel (smaller wheel) makes use of bearing to provide haptic feedback to the thumb finger. In this case, the feedback is provided in a different manner compared to that of the primary wheel previously described, the secondary wheels move in perpendicular motion towards the skin surface such that the haptic feedback can be perceived by touching the wheels. This approach of providing the haptic feedback is necessary to provide a clearly distinguishable form of the feedback to the haptic feedback provided by the main wheel with which is provided by the friction between the skin and the wheel. The structure that supports both movement types is as shown in Fig. 3. Although the feedback different in form of rotation can be achieved, the range becomes much shorter compared to the primary wheel's. Therefore, using two wheels for representing information of one dimension on them is preferred to increase coverage range.

(a) (b)

Fig. 2. Haptic mice (a) v.1 equipped with only one wheel, (b) v.2 extends the previous version by adding two secondary wheels on top and bottom of the primary wheel (as touched by the thumbs).

The feedback depends on the cursor's position or motion detected by the sensor in the mouse and in the context of the application, *i.e.*, in order to point a target in the screen, the cursor position related to the target can be sensed with haptic feedback generated from the wheels equipped with the mouse. The signal to drive the motor, for the haptic feedback, is generated by the haptic mouse controller embedded inside the mouse using the context provided by the personal computer as shown in Fig. 4.

The rotation angles with which the wheel represents the haptic feedback are determined according to the distance between the cursor and the target as described in Fig. 5. The haptic mouse controller then receives the cursor's present state and recalculates the angles for the wheels in x- and y- axes in order to change them according to the present state of the cursor towards the target point, *i.e.*, changes of distance in minus direction decreases the angle and on the contrary for the positive direction.

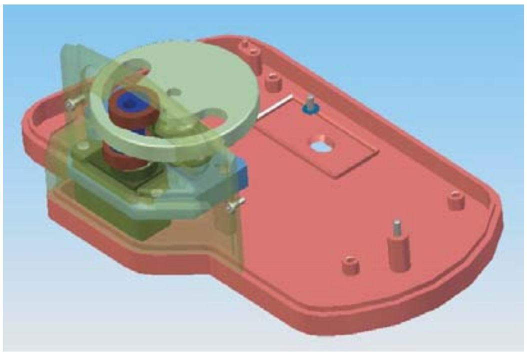


Fig. 3. Internal structure haptic mouse v.2 on wheels, illustrates how the secondary wheels' non-centered rotation can be performed simultaneously to the primary wheel.

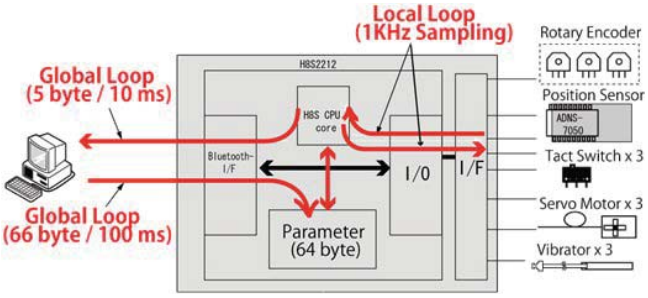


Fig. 4. Loop control information flowchart between haptic mouse and PC (From [16]).

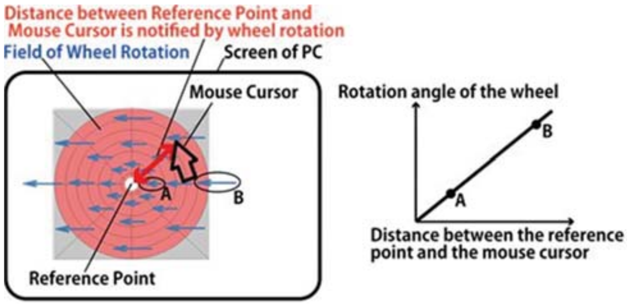


Fig. 5. The angle calculation used by the haptic mouse to control the wheels' angles (From [16]).

The haptic mouse v.2 (Fig. 2b) uses three wheels to represent two dimensional axes, which offers distance in bidirectional instead of unidirectional distance offered by the previous version (Fig. 2a). Such improvement broadens the usability of the haptic mouse towards real world application.

B. Auditory Feedback

Other than the haptic feedback, auditory interface can also be used as a substitute for vision-based on computer systems. For example, the screen reader is widely used as an assistive interface for the visually disabled people. The drawback of the screen reader is its non-real-time nature, *i.e.*, prompt perception of the situation is impossible as the user have to wait for a message to be read. Two types of auditory feedback are used in order to conduct a study on this kind of delay problem, *i.e.*, directional speech and the context-based audio signal, which are differed in term of response behavior. In this paper, the auditory interface is either used solely or as a complementary to the haptic mouse.

1) Directional Speech (Audio-Type I): This type of auditory assistive is only activated when the application received a command, which introduces some delay in response time due to its duration. The directional command can be generated by comparing the current position with the target, which is either in the direction that the user can follow or the application's information beneficial to the user (*e.g.*, "go up", "go down", "45 degrees"). The speech output is then generated from the command using the Microsoft Speech Application Program Interface (MSAPI) to synthesize the command speech.

2) Context-Based Audio Signal (Audio-Type II): Real-time based response can be acquired using the alteration of frequency and the gain of the audio regarding the current state of the application. The current state of the application can be promptly updated to the user. Creative Labs' Open Audio Library (OpenAL) is used to generate the sound waves.

The context-based audio signal is generated in every update cycle, *e.g.*, 100 milliseconds. With its gain and pitch varied on distance between the current point and the target.

IV. EXPERIMENTAL RESULTS

In this section, we will present the results of the experiments conducted for the proposed system. The evaluation criteria for the experiment are distance measured between the target point and the point selected by a user, the operational time, and satisfaction in terms of understanding and comfortability. The detail for the evaluation criteria, data collection, and the results are as shown in the following subsections.

A. Modalities of Assistive Interface used in the Experiments

1) Haptic mouse only: (referred to as Type I) by using only the Haptic mouse v.2 (Fig. 2b).

2) Audio-Type I only: (referred to as Type II) by using only the directional command speech generated via the use of MS Sam voice with its content in combination of brief description of the current position towards the target either "out of target area", "inside target area" or "near the target" and appropriate four directional of "up", "down", "left", and "right".

3) Combined use of Haptic mouse and Audio-Type I: (referred to as Type I+II) by combining the use of the Haptic mouse as mentioned in IV-A1 and IV-A2).

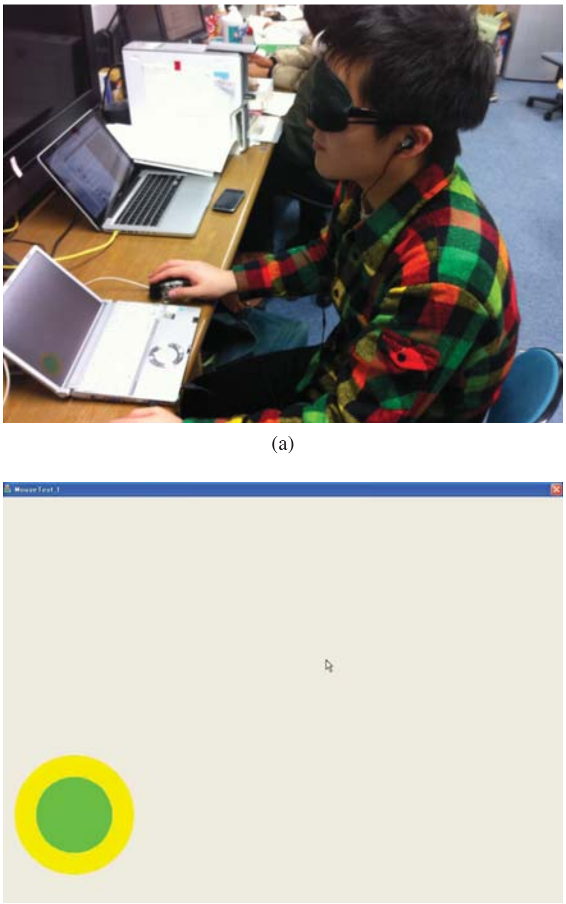
4) Audio-Type II only: (referred to as Type III) by using only the audio signal generated regarding the current state of the application, *i.e.*, the distances of two directional axes are mapped in to pitch and gain of the audio signal.

The signal settings are as follows: the frequency=440Hz, sample rate=22000 samples per second with pitch range in 0.0 to 0.5 and gain from 0.0 to 1.0 to reflect the distance in x and y axis distance, respectively.

5) Combined use of Haptic mouse and Audio-Type II: (referred to as Type I+III) by combining the use of the Haptic mouse as mentioned in IV-A1 and IV-A4).

B. Data Collection

The data is collected from nine subjects, eight males and one female aged between 23 to 28 years old who use ordinary mouse for their computer operations. The user is briefly instructed of how to operate the device and play with it for 5 minutes before conducting the experiment tasks, except the *Audio-Type II*-based interface that requires training in order to understand, which the user is allowed to train with the system until he/she understand how it works. To simulate the blindness, the test subjects were asked to wear an eye mask in order to prevent them from looking at the screen. A snapshot of a subject performing the task using the system and the screenshot of the experimental application are as shown in Fig. 6a and Fig. 6b, respectively.



(a)

(b)

Fig. 6. (a) A subject with his eyes masked performing the task in the experiment, (b) The experimental program screenshot. The circle represents the target, where the area of the color are defined as green for accept without error and yellow for area near the target which with Type II user can know such nearness.

The target circle consists of inner and outer circle, in which the inner serves as the target and the outer one would let the user aware of the nearness towards the target (specific to Type II interface). The radius of inner and outer are set to 60 and 90 pixels, respectively. Unless the point is in the inner target circle in which its distance is zero, the distance can be calculated using distance measured from the target circle and the selected point regarding the circular equation.

For each iteration of the experimental routines, the subject was asked to move the mouse cursor into the center of the target circle. The target circle itself is randomly positioned again after the user confirms the target position by clicking on the primary button of the mouse. Every subject was asked to perform the task ten times for each of the modality. The timer for the experimental routine started when the space key was pressed indicating the start of the experimental routine, from that point onwards the timer is recorded and restarted once the user selects a point. This is repeated until all iterations are completed. The experimental platform, from which the data was collected, are configured and set as listed in Table I.

TABLE I
PLATFORM SETTINGS FOR EXPERIMENTS CONDUCTED IN THIS PAPER.

CPU	Intel Centrino ULV @ 1.06 GHz
OS	Microsoft Windows XP© SP3
Screen	10.4” @ 1024x768
Haptic Device	Haptic mouse v. 2 (Fig. 2b)
Audio Device	earphone

C. Results

In this section, the results of the evaluation of the proposed modalities of interfaces are presented. The performance of each type, estimated using the average and standard variation of every subject data, is as shown in TABLE II.

The understandability and the comfortability are collected in discrete indices where the higher means the interface satisfies more of the evaluation criteria by the user, which are prompted for inputting after the completion of the experiment with each modality of interfaces as shown in TABLE III.

The analysis of the distribution on distance and time in normalized scale are provided through the histogram and ANOVA as shown in Fig. 7 and Fig. 8, respectively.

TABLE II
INTERFACE TYPES PERFORMANCE MEASURED BY DISTANCE AND TIME FROM ALL SUBJECTS.

	d_μ (pixels)	d_σ (pixels^2)	t_μ (ms)	t_σ (ms^2)
Type I	2.00	4.04	14089	7282
Type II	2.65	11.05	28131	26712
Type I+II	**0.92**	**2.54**	15747	7520
Type III	9.87	27.21	22458	20893
Type I+III	1.45	3.36	**10307**	**8583**

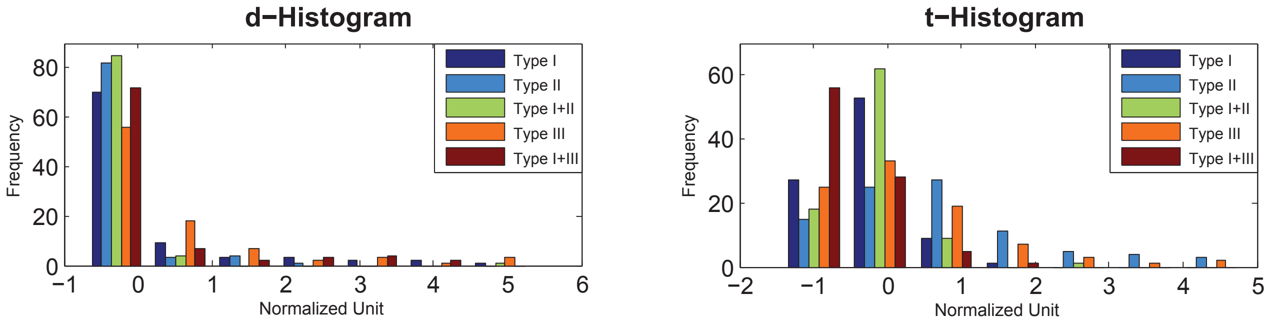
TABLE III
UNDERSTANDABILITY AND COMFORTABILITY OPINION FROM ALL SUBJECTS REGARDING EACH INTERFACE TYPE.[a]

	Understandability Index				
	Type I	**Type II**	**Type I+II**	**Type III**	**Type I+III**
μ	3.56	3.22	4.33	2.78	**4.56**
σ	0.96	1.13	0.67	1.13	**0.50**
	Comfortability Index				
	Type I	**Type II**	**Type I+II**	**Type III**	**Type I+III**
μ	3	3	**4.11**	1.78	3.33
σ	0.67	0.89	**0.32**	0.84	1.56

[a] the index is ranged from 1 to 5 for the least and the most satisfiable, respectively.

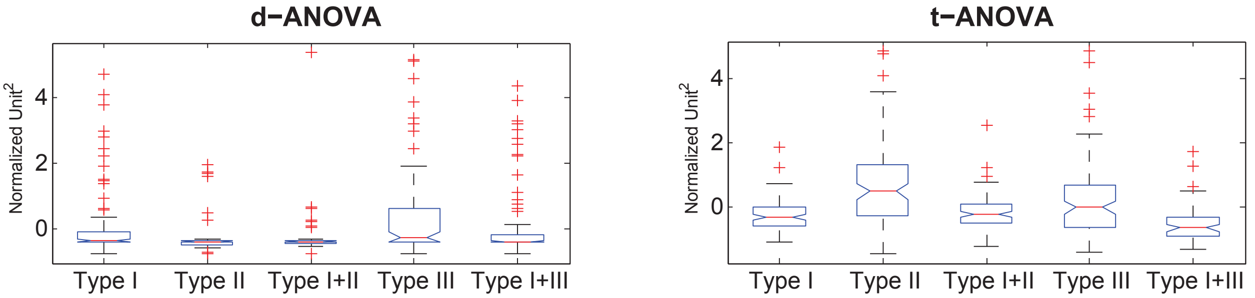
D. Discussions

It is shown that for combination of the Type I+II, the error is minimum compared to other types and also is the most comfortable from the users’ point of view. In term of operational time, Type I+III is the fastest due to its nature of real-time response it provides with the haptic feedback from the mouse as supplementary. Furthermore, such modal also got a satisfactory understandability index when the users learn its feedback context.



(a) (b)

Fig. 7. The operational performance in normalized scale shown in the form of histogram distribution of (a) distance and (b) operational time for each interface type.



(a) (b)

Fig. 8. The operational performance in normalized scale shown in the form of ANOVA (a) distance and (b) operational time for each interface type.

From the experimental result distribution, it is also shown that combining the use of different types is better than solely using one type of feedback interface especially in term of distance. On the contrary, taking into account that Type II feedback introduces some delay and user relies on its information to increase the accuracy, the operational time observed in Type I+II becomes slower compared to the solely use of Type I. Furthermore, Type I+III makes use of the real-time feedback that the user can perform the action faster.

It is also notable that for some subject, Type II-based has high variance in distance due to the unnaturalness of the speech that the user cannot recognize the direction the system provided. Furthermore, from close observations, the subjects confused with the feedbacks due to the lack of direction in Type III-based signals, *i.e.* gain has no negative value which confuses the subjects on the direction towards the target, though they have the rough information of the target point.

The proposed multi-modal of haptic and auditory feedback has the main advantage of making the user aware of the current position towards the target in absence of vision. Although the concept of providing the haptic feedback through the use of wheels equipped on the mouse can assist the blind efficiently, the three channels can easily overwhelm the information for the user to perceive using only the thumb's fingertip.

In next section, an example of how the proposed system can facilitate blind people on their computer usage will be described in term of a web browser application using a multi-modal of haptic and auditory senses to provide assistance.

V. WEB BROWSING WITH HAPTIC AND AUDITORY FEEDBACK

One of the most popular uses of computer applications nowadays is the web browser. Since most of the contents on the Internet are provided in an easy to access mean for the web browsers. Towards the assisting of visual-disabled people on their computer operations, this kind of assistive web browser application becomes an important task for researchers conducting the research upon the assistive interfaces for them.

The limitation of the application is the same as what the experiment conducted in this paper is, the solely use of speech describing the context lacks the promptness to serve the user in a real-time manner, while the solely use of the haptic mouse is on the contrary provides no meaningful information in the page's context for the users. Though, the combination of both types could complement each other that the user can access the information faster using the haptic mouse to aware of the targets on the screen and in the meanwhile using the speech to explore the context of the context pointed at by the cursor.

In this application, the combination of the haptic mouse v.2 (Fig. 2b) and screen reader application (Amedia's Voice surfing screen-reader [17] (available in Japanese)) are used to provide assistance to the user. The arrow keys (up and down) on the keyboard can be used to move the reference point (marked by the highlight of the text) on the screen. The distance and the angle can be tactually perceived by the use of haptic mouse and the content of the point are read out as audio by the screen-reader. For demonstration of the information searching on the internet, Google's search engine is used as the information provider. The user can change the search string dialog and refresh the screen to search for other contents of interest.

For example, the screenshot shows the result of searching the "Tokyo Institute of Technology" in the search string dialog as shown in Fig. 9.

Fig. 9. A screenshot of the web browser application, using "Tokyo institute of Technology" as search keyword.

VI. CONCLUSION

In this paper, we conducted an experiment to assess the efficiency of a combined use of assistive interfaces towards the focused group of blind people simulated by eye-folding.

The multi-modal of haptic and auditory feedback can provide a better assistance to users than solely use one of them alone. In other words, speech command is good in increasing the accuracy towards the target. The context-based audio signal can be perceived faster than the speech but requires more training in order to understand. The tune or sound has to be carefully selected, otherwise it can irritate the users on their system operations. In term of operational time, Type I+III achieved 40% faster compared to Type I, while Type I+II error is less than Type I by 50% in distance error. Furthermore, Type II is clearly inferior in term of operational time and Type III is inferior than Type I+II and Type I+III in term of distance error, respectively.

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