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The enhanced navigator for the touch screen: A comparative study on navigational techniques of web maps

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ABSTRACT

Nowadays the web map (E-map) is an indispensable wayfinding tool in the Internet-based society. However, its usability will vary with a different navigational technique or input device. The navigational techniques currently adopted by various web maps were investigated and analyzed. Moreover, two input devices, i.e., the mouse and the touch screen, were operated in four navigational techniques to study the differences in their functions and performances. Later, the research findings were utilized to develop a new navigational technique. The research was divided into two stages. During the first stage, all the navigational techniques in current use were investigated and compared. Then, based on the results of analysis, the enhanced navigator with continuous control (ENCC) was designed. During the second stage, the searching and browsing techniques of different web maps were simulated. Afterwards, the mouse and the touch screen were employed separately to conduct simulation tests in the following navigational techniques: (1) combined panning buttons (CPB), (2) distributed panning buttons (DPB), (3) ENCC, and (4) G&D. A total of 36 participants took part in the trials. At the end of the experiment, the operational performances of the participants were studied through the two-way analysis of variance (ANOVA); besides, the subjective evaluation questionnaires were answered. It was discovered that the mouse did better than the touch screen in the four navigational techniques. Besides, among the four techniques, ENCC showed the best performance. Capable of continuous control and continuous display, the ENCC interface was upgraded in terms of operational speed and directional control. The findings can be used as a reference in the design of web maps. Also, it is suggested that ENCC should be widely applied to touch screens and mice so that the navigation of information space may be facilitated.

1. Introduction

With the progress of science and technology, the input device which previously relied on the mouse will gradually opt for the touch screen. Characterized by intuitive input, the touch screen is learned and operated more easily by the user [1]. Up to the present, it has been widely used in interactive kiosks, ticket machines, automatic teller machines (ATM), and so forth. Thanks to its features, the interactive kiosk has been used by the public more and more frequently [2]. It is indicated by some studies that, surrounded by a strange environment, the average person will usually turn to a kiosk, accessing the web map to get familiar with the new place. Therefore, the usability and functionality of the web map have been highlighted as an important issue [3,4]. As the web map is browsed, its navigational technique, or how it is presented, is a key factor influencing the user's viewing and operation [5]. A well-designed navigational technique can successfully lead the user to browse the information space of the webpage; furthermore, the user can explore its content by activating various functions [6]. It has been demonstrated by some researchers that, if the user is unfamiliar with the conceptual model, he/she will be inclined to commit operational errors. As a result, he/she will probably suffer a sense of frustration and take less interest in the web map [7].

For most people, the mouse is the most common input device. In fact, almost all the user interfaces, including web maps, depend on the mouse for navigation and are designed as well as operated correspondingly. If the mouse is replaced by other input devices, like touch screens, the user may have some difficulty in operating and suffer lower efficiency [8,9]. In the past, there have been only a few researches centering on different input devices operated in different navigational techniques, and comparing their performance difference. Consequently, it is currently impossible to tell whether the navigational techniques compatible with the mouse can perform equally well when they work together with the touch screen [10,11]. This research focuses on how the navigational techniques are currently combined with the touch screen, exploring their operational restrictions. Then, based on the findings, a new

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navigational technique fully compatible with the touch screen is developed. Moreover, with the mouse and the touch screen employed separately, the new navigational technique as well as the existing ones undergoes the in-field, simulated tests so that the difference in functionality and usability may be determined.

2. Case study of the map interfaces operated

2.1. Survey of web maps

In July, 2008, the major search engines, i.e., Google and Yahoo, were employed by the authors, the keyword "web map" was entered, and both Chinese and English map websites were searched. Based on the search result, some of the websites ranking among the top 80 were singled out with respect to the following criteria: (1) being capable of interaction, (2) having such control functions as panning, moving, and zooming, (3) rejecting those that had been out of service or had an unstable connection speed, and (4) choosing only one website from those which provided similar functions. Moreover, to facilitate the subsequent comparisons, the domestic maps were confined to those using the Chinese language while the foreign maps were limited to those using the English language. In the end, eight web maps in total were selected for the research under discussion, as is shown in Table 1.

2.2. Analyzing the control functions of web maps

Navigation can be described as the task of determining position within the information space and finding the course to the envisaged information and other related information. To put it another way, the purpose of navigation is to help the user explore information spaces that are too large to be conveniently displayed in a single window [6]. As for the spatial navigation of the two-dimensional (2D) map, its control functions are mainly composed of zooming, panning, scrolling, and moving [6,11,12]. After the presentation the overview and details are analyzed, it is discovered that panning, zooming, and scrolling not only enable the user to view the overview and details in the information space but also offer interface operations on different levels [6,10]. However, scrolling is incorporated by some researchers into the category of panning [6]. Depending on the arrangement of the arrow buttons, panning is performed in three operational modes, i.e., combined panning buttons (CPB), distributed panning buttons (DPB), and scrolling. As for zooming, it includes four functions: re-center, original center, zoom-in by marquee, and zoom by fixed scales. With regard to moving, it consists of move by re-center and G&D [6,11]. Futhermore, there are three navigational techniques adopted by web maps, namely, continuous control and continuous display (CCCD), discrete control and continuous display (DCCD), and discrete control and discrete display (DCDD)[13].

The eight selected web maps were operated to analyze the difference between navigational techniques; besides, 11 control functions in total were identified eventually. The navigational techniques differ from one to another in the combined functions. The control functions of web maps include six zooming functions (Table 2), three panning functions, and two moving functions (Table 3). As is mentioned above, there are three navigational modes available, i.e., continuous control and continuous display (CCCD), discrete control and continuous display (DCCD), and discrete control and discrete display (DCDD). Different combinations of functions will definitely affect the user's performance and strategy in operating web maps.

Table 1
The map websites selected for this research.

No	Web map server	Internet address (URL)
1	Gi map	http://www.gismap.com.tw/gismap2008/index.cfm?CFID=247990&CFTOKEN=19152581
2	Go map	http://maps.google.com.tw/
3	M24 map	http://www.uk.map24.com/
4	MM map	http://plasma.nationalgeographic.com/mapmachine/
5	P map	http://map.pchome.com.tw/
6	U map	http://www.urmap.com/
7	Y map	http://tw.maps.yahoo.com/
8	MI map	http://whereis.mit.edu/map-jpg

2.3. Observing users operating the interfaces

During this stage, the main job was to observe the participants conducting the trials and to analyze the experimental results. There were eight participants in all, with males and females in equal numbers, who were all right-handers and had some experience in operating computers. Their ages ranged from 22 to 33 ($M = 26.57$, $SD = 3.55$). The hardware used was the touch screen (3M LCD/MD17-5MS). Then each of the eight web maps mentioned above was operated in its own navigational technique, with the procedures described below. (1) After the map website was successfully visited, the searched destination was entered, such as National Cheng Kung University and Manhattan, New York. After that, the destination map was displayed. (2) The control functions, including zooming, panning and moving, were activated by clicking the corresponding buttons to actually operate the map. (3) In the process of actual operation, the functions, operational modes, operational performances and image designs of the map websites were observed as well as recorded by the researchers.

Table 2
Analysis of zooming functions.

Function	Zooming					
	Zoom-in (re-center)	Zoom-out (re-center)	Zoom-in (original center)	Zoom-out (original center)	Zoom-in by marquee	Zoom by fixed scales
Gi map						×
Go map	×+					×
M24 map					×	×+⁎
MM map	×+⁎		×+⁎#	×+⁎#		
P map						×
U map						×
Y map						×
MI map			×	×		×

Note: × – denotes available function available, ⁎ – denotes continuous control, + – denotes continuous display, and # – denotes multi-touch.

Table 3
Analysis of panning and moving functions.

Function	Panning			Moving	
	CPB	DPB	Scrolling	Move by re-center	Grab & Drag
Gi map	×+			×+	×+
Go map	×+				×+
M24 map				×	
MM map	×+⁎				×+
P map		×+⁎		×+	×+
U map				×+	×+
Y map				×+	×+
MI map		×		×	

Note: × – denotes available function available, ⁎ – denotes continuous control, and + – denotes continuous display.

Supported or unsupported, the arm and wrist operating the component | The control component occluded by the finger | The area covered by the user's fingertip

Fig. 1. The different ways the hand manipulates the navigational technique.

2.4. The result of observation and analysis

By making experimental observations as well as collecting and analyzing the user feedback, the following results have been obtained by the researchers, as is shown in Fig. 1.

1. When operating the DPB, the right-hander will span the right arm over the screen to reach the left-view image and to press those leftward panning buttons. At that time, the arm will be suspended above the map and occlude much of it from view.
2. With the CPB employed, the wrong button is apt to be pressed by the user because the desired button is too small in size.
3. With the CPB employed, one of the buttons may be pressed so hard as to distort the finger. In such a case, the area covered by the fingertip is so large that another adjacent button is also pressed. As a result, the system cannot detect the pressing correctly and even cannot recognize it at all.
4. When operating the DPB, the user will spend more time in moving the hand as the distance from the hand to the button increases. It is because the buttons are scattered on all the edges of the map.

Based on the above observations and analyses, this study has identified the restrictions on the existing navigation of the touch screen and taken the proper course to develop the new navigational technique. The following aspects of design must be emphasized and enhanced: (1) The area, where the fingertip contacts the screen should be decreased to eliminate the wrong pressing. (2) The cases, where the hand spans the screen and occludes the view must be reduced. Likewise, the pain of the muscles and bones arising from the suspended arm must be lessened. (3) The arrow buttons must be enlarged so that they may be pressed with ease. (4) The relative distance between the hand and the arrow button must be shortened so that the moving time of the arm may be decreased. (5) The operational stability and controllability must be upgraded. The fruits of subsequent designs are to be presented in the coming paragraphs.

3. Design development

3.1. Basic theory of input devices

The input device is the physical hardware which produces the interaction between the user and the operating platform. It can convert the information entered by the user into the form intelligible to the computer. The input device varies with the command to be executed. Based on the different operational modes, input devices include the following: keyboards, mice, joysticks, touch screens, touchpads, chord keyboards, track balls, digitizer tablets, light pens/light guns and voice command devices [13,14]. Among them, the mouse is the most popular tool used by the public, controlling the movement of the screen cursor through the pointing device. Of all the computer operations, two-thirds are performed with the mouse [15]. With four different input devices (the mouse, joystick, step keys and text keys) employed, a study was conducted to compare their text input performances [16]. The findings indicated that the mouse performed better than the other three input devices in terms of positioning time, error rate, and moving speed. Besides, to enhance the usability of the input device, a newly-designed Fluid DTMouse was proposed by some researchers, which would improve the switch from one fixed mode to another, ensure the stability of the cursor, and enable the user to input accurately [17].

With the constant advancement of the touch screen technology [18], its cost is getting lower and lower [19]. The touch screen boasts the following advantages: (1) As its control interface overlays the monitor, there is no need for such an extra device as the mouse, which needs a space-occupying carrier and operating environment. (2) Compared with other mobile input devices, the touch screen is much more robust and durable [2]. In the past, many studies have been conducted to investigate the functions of the direct-touch and tabletop displays [17,20–25]. In addition, there have been other studies towards the gestures connected with operating the touch screen [25–27]. The touch screen is superior to the mouse or other input devices because of its natural operation by directly touching the image elements [20].

As is indicated by related studies, despite the abovementioned advantages, the touch screen is not completely superior to the mouse in terms of operational performance. For example, the touch screen was compared with the mouse in the single-touch mode [9]. It was discovered that, when target ranging was more than 4 pixels, the selection time needed by the mouse was the same as that needed by the touch screen. However, when target ranging was less than 4 pixels, the selection time needed by the mouse was shorter than that needed by the touch screen. While the touch screen did worse than the mouse in the single-touch mode, the former did better than the latter in the double-touch or multi-touch mode [20,27]. To keep up with the advantages of the touch screen, a new user interface is being developed which will be operated in the multi-touch mode and enable the user to select the smaller target easily through the menu [26].

Regarding the evaluation and study of input devices, different input devices have been compared in respect to operational speed and accuracy in cursor positioning [28]. It was discovered that the following devices ranked in descending order of operational speed: the touch screen, light pen, digitizer tablet, trackball, force joystick, position joystick, and keyboard. Furthermore, in terms of accuracy, the following ranked in descending order: the trackball, digitizer tablet, force joystick, position joystick, and keyboard, with the light pen and the touch screen performing worst. The input devices were divided by some researchers into two groups [29], one being the combination of the keyboard and the mouse while the other being that of the keyboard and the joystick. It was discovered that the mouse was faster for both tasks in spite of the reduction in homing time shown by the joystick and keyboard combination. The performance of three-year-olds who operated the mouse, joystick, and trackball was studied by some researchers [30]. It was discovered that, whether before or after training, the mouse performed best. In other words, the mouse is the most suitable input device for a three-year-old in comparison with other input devices. To compare the tracking performance of touch screens, mice and joysticks, the three devices were studied as they were operated by children aged from 5 to 10 [31]. It was discovered that the touch screen performed best of all. Moreover, the performances of the single finger, two fingers, and multiple fingers operating the touch screen were compared [27]. The participants were required to select the all-blue targets; meanwhile, orage distractors scattered around were disturbing the participants. It was discovered that, in terms of selection time, the multiple fingers and two fingers performed best, the single finger performed fairly, and the mouse performed worst. The miss rates of the mouse, single finger, two fingers, and multiple fingers were 8.51%, 7.29%, 10.45%, and 13.75% respectively. In another study, the mouse, touch screen, and digitizer tablet were investigated which were operated by the aged people [8]. It was discovered that, in terms of task completion time, the mouse performed best, and the touch screen ranked second.

Different input devices display different characteristics. The functionality of mice, touch screens and other input devices were evaluated by some researchers [14,32]. Based on their findings, an analysis of single/multi-touch and direct/indirect touch was made by this research, with the overall results shown in Table 4. The above mentioned studies were mainly directed towards the functions of input devices. So far there have been few studies evaluating the operational performance of the mouse or touch screen which is applied to the navigation technique.

3.2. Basic theory of navigational techniques

Navigational techniques are used to restructure the information space so as to present it adequately on the screen [10]. The operations of stylus, mouse and other input devices, such as click, double click, and drag, have been clearly defined [11]. The operations offered by navigational techniques enable the user to navigate the map space. The navigational operations of web maps are control functions composed of panning, zooming, moving, and scrolling [6,11,12].

Zooming alters the scale of the information space to obtain the distant or near view of an object so that it may be viewed by the user more clearly or fully [5]. Panning refers to changing the position or changing the center of the map [6]. Panning and zooming are two control functions complementary to each other. As is pointed by some studies, when the web map is operated, panning or zooming alone cannot work satisfactorily. Instead, a single function will cause much inconvenience to the user [33]. Scrolling provides the user with a view window which can scroll horizontally or vertically. As a result, the user is enabled to pan the information space or drag it to the desired position. When the information space is rather small, panning produces a satisfactory effect; however, when the information space is relatively large, the user will easily get impatient [33]. Moving means that the cursor can directly move the map by dragging and thus change the position of the map in the information space [11].

When navigational operations are performed, the different control components of the technique must be operated to pan and zoom the map. To enhance the efficiency of the navigational technique, speed-dependent automatic zooming (SDAZ) was proposed, which combined scrolling and zooming [34]. In the SDAZ, as the speed of scrolling increases, that of zooming will decrease proportionally. It is indicated by some relevant studies of web maps that, compared with independent scrolling, panning or zooming, SDAZ has a higher efficiency [35]. Another technique is Pad++, which integrates panning into zooming and is suitable for information-browsing within a limited screen. Its zooming function can alter the size, appearance, and details of the information space and object, in addition to making it appear or disappear through visualization [36]. Still another technique called zone zoom was proposed by some researchers, which is an input device compatible with the smart phone [37]. With this technology, the searched image can be divided into nine units, each of which is represented by one of the cell phone buttons. By pressing the corresponding button, the user can pan or zoom the unit on the screen. What is more, a design different from others was proposed by some researchers, which was named a zoom-enhanced navigator (ZEN) [10]. The ZEN can display the overview and details on the small screen simultaneously. In the center of the screen is a square and inside the square is a circular icon. With the help of a stylus, the user clicks the circle to pan the map or clicks the square to zoom it.

3.3. Deciding on operational techniques

As is indicated by Fitt's Law, with the DPB scattered on the edges of the screen, the relative distance gets longer [38]. To oper-

Table 4
Comparison of input devices for computers.

	Graphic tablet (with puck or stylus)	Joystick	Light pen	Mouse	Trackball	Touch screen
Single/multi-touch	Single	Single	Single	Single	Single	Both
Direct/indirect	Indirect	Indirect	Direct	Indirect	Indirect	Direct
Space required*	Medium–large	Small	Small	Medium	Small	Small–large
Training requirements*	Low	Low	Low	Low	Low	Non-Low
Ease of use*	0	0	+	+	0	+
Suitability for						
Prolonged use*	0	0	–	0	+	–
Rapid pointing§	0	–	+	+	0	+
Accuracy pointing§	0	0	–	+	+	–

Adapted from +: Advantage, 0: Neutral, −: Disadvantage.
* [13].
§ [31].

ate such buttons, the user's arm will be moved over a longer distance and thus more time will be spent in doing the pressing. Consequently, it will take the user more time to browse a certain map. Moreover, by means of experimental observations, it was discovered by this research that the DPB causes the right-hander's arm to be suspended over the map involuntarily. The suspended arm occludes the map from view and easily creates the pain of the arm muscles and bones [39]. In view of the above, the new navigational technique designed by this research adopts the centralized operation instead of the distributed operation.

In employing the navigational tool, the user has to click different arrow buttons, panning or zooming the interface. However, it has been discovered that some of the control components are not adequately designed, with problems including a tiny size, unacceptable proximity, and redundant clicking. Such problems lead to the mutual interference between the buttons and decrease the efficiency of the interface [10]. Also, it has been discovered that the surface area, where the fingertip contacts the screen exerts an effect on whether the arrow button will be clicked or pressed precisely [20]. To solve the abovementioned problems, the single control ball is adopted by this research instead of the arrow buttons; therefore, grabbing or dragging the ball is performed instead of clicking or pressing the button.

As for directional control, either CPB or DPB has just eight directions available and restricts mobility. Therefore, the control ball has been selected, which offers a 360° motion and facilitates smooth operation. Besides, the two-speed control has been added to the newly-designed navigational technique. The high or low speed is determined by the distance between the ball and the center of the circle. There are two zones, corresponding to the two kinds of speed. When the ball is within one zone, the speed remains constant and low. But, when the ball is in the other zone, its speed increases in proportion to its distance from the circle center.

3.4. Prototype of the enhanced navigator with continuous control

The concept of human engineering, or ergonomics, is featured by this research. Based on a series of researches, observations and analyses, the design of the enhanced navigator with continuous control (ENCC) has been presented, as is shown in Fig. 2. The main design elements are described as follows: (1) Grabbing and dragging are the acts needed to operate the control ball (Fig. 3). (2) The distance between the ball and the circle center is directly related to the speed of motion. (3) The high or low speed zone is marked in a different color. (4) The interface is operated through grabbing and dragging in the continuous control mode. Therefore, the user can execute the command without repeating the same action. Furthermore, the muscles and bones of the hand will not be overworked, with their burden reduced.

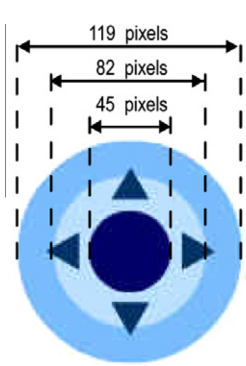

Fig. 2. The idea of ENCC.

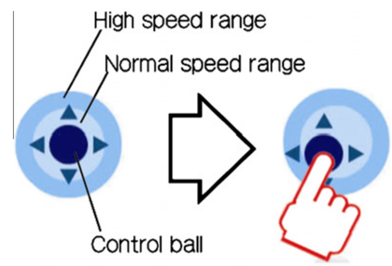

Fig. 3. Control Acts.

4. Methodology

4.1. The considered techniques

The experimental interfaces of this research were intended to be operated within a small-sized map under certain restrictions. To minimize the interfering factors, the continuous control and continuous display navigation mode (CCCD) was adopted throughout the simulated tests. Meanwhile, the multi-level zooming was also adopted as the zooming technique. As for the panning tool, both CPB and DPB were employed. Since none of the selected web maps adopted scrolling as one of the navigational techniques, scrolling was excluded from evaluation. It was presumed that scrolling was more suitable for the browsing of the webpage and the limited map than for unlimited information space. As for moving, "Grab & Drag" was employed while "move by re-center" and "zoom-in re-center" were excluded, for the latter techniques would easily cause the user to get confused. Ultimately, the experimental interfaces were successfully designed which combined multi-level zooming with one of the four control functions, namely, CPB, DPB, ENCC, and G&D.

4.1.1. Multi-level zooming

If the slider scale capable of multi-level zooming is grabbed and dragged, the image inside the map frame will be zoomed in or zoomed out increasingly or decreasingly, as is shown in Fig. 4. Currently, multi-level zooming is the most widely-used tool of web maps. Its main advantage lies in the fact that the zooming ratio is indicated by the graphics. In consequence, the user is always well aware of the zooming ratio presently in use. The sliding piece is 40×30 pixels in size.

4.1.2. Combined panning buttons (CPB)

The arrow buttons used to pan the map frame are put together. Such a combination of buttons provides the most commonly-found function in web maps. When any of the buttons is continually pressed by the finger or cursor, the image inside the frame will keep moving in the same direction. Not until the finger or cursor leaves does the image stop moving, as is shown in Fig. 5. A single arrow button is 30×30 pixels in size.

4.1.3. Distributed panning buttons (DPB)

To pan the map frame in eight directions, eight panning buttons are independently arranged at the centers of the four sides and at the four corners on the map, as is shown in Fig. 6. The DPB is operated in the same way as the CPB. A single arrow button is 30×692 pixels in size.

4.1.4. The enhanced navigator with continuous control (ENCC)

Like the CPB, the enhanced navigator with continuous control (ENCC) is intended for directional control in the function area; however, there is a notable difference between them. To be exact, the ENCC is operated by grabbing and dragging the control ball. In

Fig. 4. Multi-level zooming.

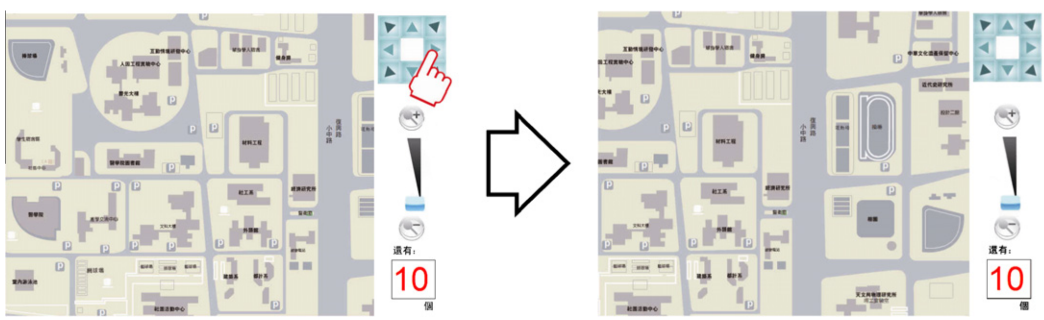

Fig. 5. The experimental interface integrating CPB with multi-level zooming.

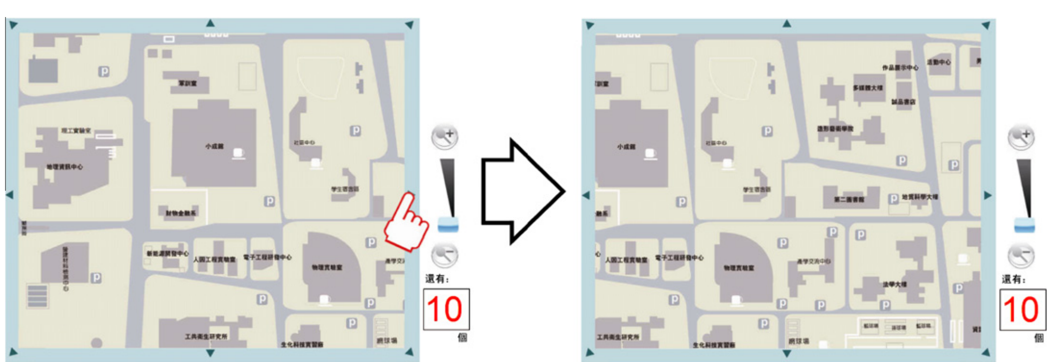

Fig. 6. The experimental interface integrating DPB with multi-level zooming.

contrast, the panning button of the CPB has to be pressed to control the movement of the map image. Thus, to change the direction, another arrow button should be pressed by the cursor or finger. With the ENCC, the user just grabs and drags the control ball to move freely in all directions, without needing to press the ball repeatedly, as is shown in Fig. 7. As soon as the finger leaves the ball, panning function is stopped and the ball returns to the center of the circle. With the ENCC employed, panning will become much easier and faster. Moreover, ENCC enables the user to pan the map at his/her designated speed. The farther the control ball is from the circle center, the faster the map is panned.

4.1.5. Grab & Drag (G&D)

"Grab & Drag" is the most common function found in the web map. Unlike the three panning operations mentioned above, G&D needs no control component. Instead, the finger or cursor directly grabs and drags the image inside the map frame, moving it in the desired direction, as is shown in Fig. 8.

4.2. Participants

There were 36 participants in total, with males and females in equal numbers. Their ages ranged from 21 to 32 ($M = 26$,

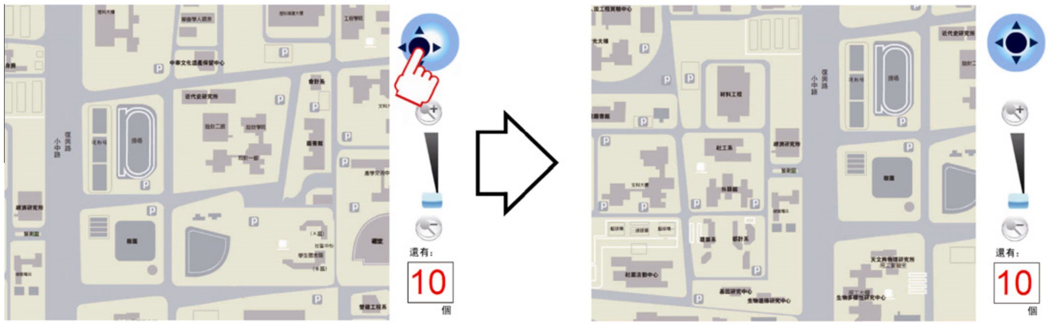

Fig. 7. The experimental interface integrating the ENCC with multi-level zooming.

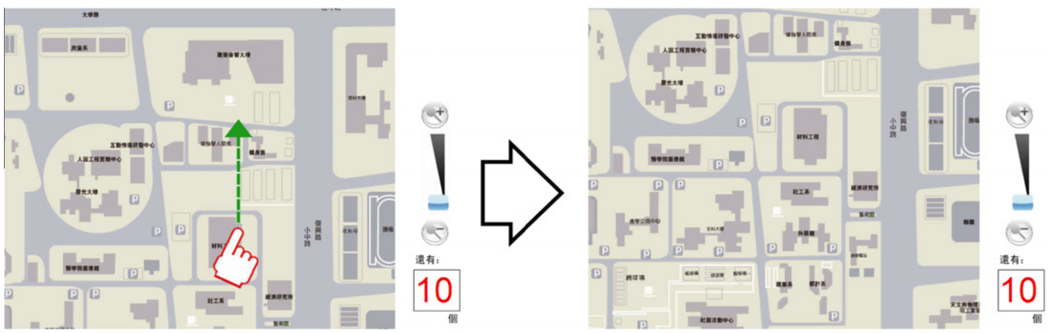

Fig. 8. The experimental interface integrating G&D with multi-level zooming.

SD = 3.6). This research was targeted at the students of National Cheng Kung University (NCKU), from whom volunteers were recruited through the Internet advertisement. Each of the participants received a sum of NT$70 as a reward. The web map interface used in the simulated experiment had to be operated in the single-touch mode although the current touch screen can be operated in the multi-touch mode with two hands. Seemingly, the average navigational function can be performed in the multi-touch or single-touch mode. However, in practical applications, only zooming allows multi-touch control while panning and moving allow single-touch control only. Besides, this research was aimed at comparing the performance of the mouse with that of the touch screen in a certain navigational technique. Now that the mouse was operated with only one hand, the participants were required to operate the mouse or touch screen with the habitually-used hand only. They were free to operate in the favorite way they felt to be comfortable. All the participants in this experiment were right-handers.

4.3. Materials and stimuli

The experimental equipment was divided into the following two categories. (1) Hardware: A desk-top computer was accompanied by a touch screen (3M M170). The specifications of the touch screen are listed below: viewable size (H × V) being 337.9 × 270.3 mm (17 in. diagonal), maximum resolution being 1280 × 1024 pixels, frame rate being 70 Hz, contrast ratio being 450:1, brightness being 260 cd/m^2, and response time being 16 ms. When the touch screen was used as the input device, it was placed on the central line ten centimeters away from the front edge of the desk. Also, it slanted at an angle of 40° so that the user's muscles would not feel tired easily [40]. In compliance with the recommended height of the workstation, the desk was 1100 mm in length, 700 mm in width and 720 mm in height while the chair was 420 mm in height [41]. Alternatively, the input device could be replaced by the wireless mouse (Logitech LX8). (2) Software: The sample web map was simulated with the help of Macromedia Flash and played with Flash Player. The experimental data were reorganized with the help of Microsoft Excel and then were analyzed with statistical software (SPSS 12.0 for Windows).

4.4. Experimental procedures

The experiment was a within-subject design, or repeated-measures design. The mouse and the touch screen were operated separately by the participant in the four different navigation techniques, i.e., CPB, DPB, ENCC, and G&D. In other words, a total of eight experiments would be conducted. The task of each experiment was to be performed on the same map. The image area of the map was 1656 × 1912 pixels; the size of the zooming button was 40 × 30 pixels; the target was 15 pixels in size and could be zoomed in to 46 pixels. The experimental order followed the principle of counterbalance. That is to say, the order in which the interface was operated by the participant varied with his/her experimental order. The experimental order of each participant was encoded as M1234, M2134, M4312…T1234, T2134, T4312. The first English letter stood for the input device, namely, M for the mouse and T for the touch screen. The numbers 1, 2, 3, and 4 stood for the four navigational techniques respectively. Before each experiment, the participant was allowed to practice for three minutes in order to get familiar with the navigational technique. During the experiment, the participants were required to utilize the navigation techniques to locate the designated destinations on the map, which were represented by red points. To enable the participants to use the techniques to the full, the red points would appear at five randomly-selected sites. Only one red point would appear at a time. After the red point was found, the map had to be zoomed in to the maximum and the red point had to be clicked. Right after being clicked, the red point would disappear. After that, the participant had to locate another red point until all the five points were located and the task was successfully accomplished.

After the task was finished, the participant was required to fill out the subjective evaluation questionnaire about the navigational techniques. The questionnaire, as per ISO 9241-9, was adopted to evaluate such areas as effort, accuracy, speed, fatigue, comfort and smoothness [2,42]. The ISO questionnaire is designed to conduct a seven-point rating evaluation. Higher scores denote a better rating, from 1 (most negative) to 7 (most positive).

The experimental procedures are set forth below:

(1) The purpose, methods and procedures of the experiment were explained to the participant.
(2) Personal information, like name, class, department, and former experience in web maps, was filled out by the participant.
(3) The written instructions on the experiment were read by the participant.
(4) The participant practiced for three minutes.
(5) In accordance with the experimental order, each participant was required to locate five designated destinations, which were represented by red points, on the map. As soon as a correct point was found, the map image had to be zoomed in to the maximum and then the point had to be clicked. Right after being clicked, the point would disappear and the participant could start to find the next red point.
(6) After a simulated test was successfully performed, the subjective evaluation questionnaire about the navigation technique was filled out by the participant.
(7) After a navigational technique was tested, the participant continued to test another technique, repeating procedures 3 through 6.

4.5. Analysis of the collected data

The mouse and the touch screen were separately employed by each of the 36 participants to operate the web maps in the four navigational techniques. A total of eight experimental tasks had to be performed by each participant. As each participant was observed repeatedly in eight task conditions, eight task completion times, eight user interface actions and eight subjective evaluations were obtained finally. In other words, the mean completion time of different tested samples came from the same group of participants, which means a repeated measures design. Moreover, the two variables, i.e., the input device and the navigational technique, were interdependent samples of the repeated measures. Consequently, the two-way analysis of variance (ANOVA) was adopted to determine whether there was an interaction between the two variables. Afterwards, the least significant difference (LSD) method was used to compare the difference between them. The statistical software (SPSS 12.0 for Windows) was used to analyze the test results, with $p \leqq .05$ taken as the standard of significant difference.

5. Result

This research was aimed at two targets explained below. (1) Based on previous findings as well as the test results obtained from this research, a new navigational technique fully compatible with the touch screen would be developed. (2) With the mouse and the touch screen employed separately, the newly-developed technique (the ENCC) as well as the three existing ones would receive the simulated tests. This way, the differences in task completion times, user interface actions and subjective evaluation might be identified.

5.1. Analysis of task completion times

This research was meant to study the differences in task completion times, user interface actions and subjective evaluation after the mouse and the touch screen were employed separately to operate the web map in one of the four navigational techniques. The results of analysis of variance (ANOVA) for task completion times and user interface actions are shown in Table 5. Regarding task completion time, the times needed by the mouse and the touch screen in different navigational techniques reach the level of statistical significance ($F_{1,\ 35} = 15.63$, $p < .001$), which means that the task completion time spent by the participant varies with the input device. Similarly, different navigational techniques result in different task completion times and the effect is statistically significant ($F_{3,\ 105} = 15.76$, $p < .001$), which means that the task completion time spent by the subject varies with the navigational technique. Furthermore, the interaction between the input device and the navigational technique reaches the level of statistical significance ($F_{3,\ 105} = 6.73$, $p < .001$), which means that there is an interaction between the input device and the navigational technique in terms of task completion time. As is shown by Fig. 9, when combined with CPD, DPB or G&D, the mouse performs remarkably better than the touch screen. However, when combined with ENCC, the mouse performs as well as the touch screen. In addition, with the mouse used, the navigation techniques ENCC and G&D perform better than the other techniques. By contrast, when the touch screen is used, ENCC alone performs best.

As is shown in Table 6, task completion times needed by different input devices in the four navigational techniques are compared through analysis of variance (ANOVA). Based on the results, it is discovered that the task completion times consumed by the mouse

Table 5
ANOVA for task completion times.

Source of variance	SS	*df*	MS	*F*	*p*
Input	30,641.95	1	30641.95	15.63	.000
	68,603.87	35	1960.11		
Navigational technique	67,010.64	3	22,336.88	15.76	.000
	148,797.90	105	1417.12		
Input × navigational technique	18,708.85	3	6236.28	6.73	.000
Subject within group	97,280.19	105	926.48		

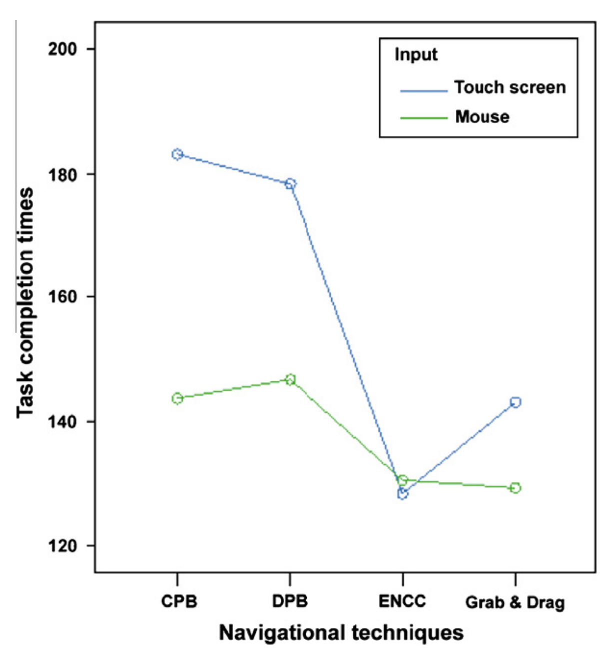

Fig. 9. Input × Navigational techniques for task completion times.

Table 6
ANOVA for task completion times of different inputs in four navigational techniques.

Source of variance	Direct-touch	Mouse	*F*	*p*	Least significant difference (LSD) method
CPB	183.16 (45.23)	143.79 (32.80)	15.33	.000	[mouse] < [direct touch]
DPB	178.37 (49.67)	146.79 (33.26)	10.91	.002	[mouse] < [direct touch]
ENCC	128.45 (32.26)	130.65 (33.04)	.141	.710	–
G&D	143.13 (36.61)	129.37 (34.98)	5.19	.029	[mouse] < [direct touch]

and the touch screen in the four navigational techniques reach the level of statistical significance. After the least significant difference (LSD) method is used to analyze and compare the results, it is discovered that, when the ENCC is employed, there is no statistically significant difference between the mouse and the touch screen. By contrast, when the other three navigational techniques (i.e., CPB, DPB and G&D) are employed, the touch screen performs worse than the mouse; additionally, the results reach the level of statistical significance. In other words, the task completion time needed by the mouse is less than that needed by the touch screen.

It is discovered through the two-way ANOVA that the effect of different navigational techniques on task completion times is statistically significant (Table 7). When the touch screen is used, the four navigational techniques exert a significant effect on the task completion times ($F_{3,\ 105} = 17.95$, $p < .001$). After the least significant difference (LSD) method is applied, it is revealed that ENCC and G&D take a shorter time than either CPB or DPB. Similarly, when the mouse is used, the effect of the four navigational techniques on task completion times is statistically significant ($F_{3,\ 105} = 3.15$, $p < .05$). After the LSD method is applied, it is revealed that ENCC and G&D take a shorter time than either CPB or DPB. In short, whether the mouse or the touch screen is employed, ENCC and G&D perform better in terms of task completion time.

5.2. Analysis of user interface actions

It is discovered through the two-way ANOVA that the effect of different navigational techniques on user interface actions is statistically significant (Table 8). Concerning user interface actions, the interaction between the input device and the navigational technique is also statistically significant ($F_{3,105} = 3.93$, $p<.05$); that is, in terms of user interface actions, there is an interaction between the input device and the navigational technique. As is shown by Fig. 10, when G&D is employed, the touch screen performs considerably better than the mouse. As for the other two navigation techniques, namely CPB and DPB, there is no significant difference in the performance. In short, the effect of different navigational techniques on user interface actions is statistically significant ($F_{3,105} = 80.50$, $p < .001$), which means that the participant's interface actions vary with the navigational technique.

As is shown in Table 9, the effect of different navigational techniques on user interface actions is statistically significant. When the touch screen is used, the effect of the four navigational techniques on the user interface actions is statistically significant ($F_{3,105} = 39.47$, $p < .001$). After the LSD method is used to compare the result, it is discovered that G&D requires the largest number of actions, CPB and DPB come next in number, and ENCC needs the fewest actions. Similarly, when the mouse is used, the effect of the four navigational techniques on user interface actions is statistically significant ($F_{3,105} = 62.52$, $p < .001$). With the LSD method applied, the same result as that generated by the touch screen is found. Namely, G&D requires the largest number of actions, CPB and DPB come next in number, and ENCC needs the fewest actions.

Table 8
ANOVA for user interface actions.

Source of variance	SS	*df*	MS	*F*	*p*
Input	1995.01	1	1995.01	1.93	.174
	36,219.24	35	1034.84		
Navigational technique	304,174.69	3	101391.57	80.50	.000
	132,257.06	105	1259.59		
Input × navigational technique	8831.24	3	2943.75	3.93	.011
Subject within group	78,688.51	105	749.41		

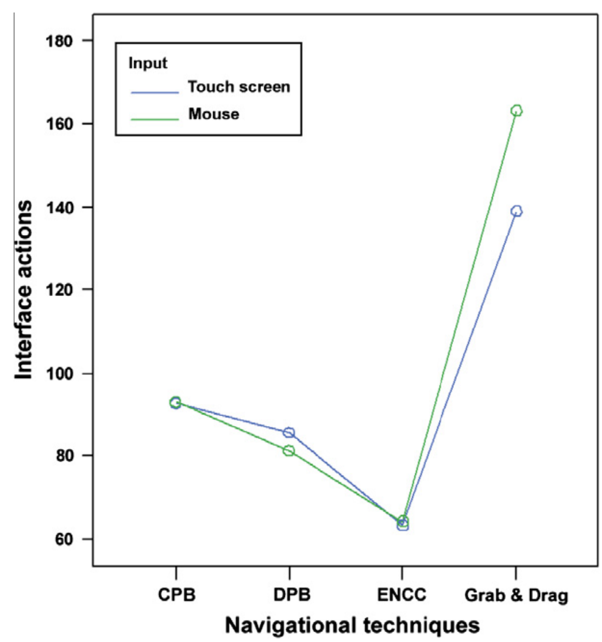

Fig. 10. Input × Navigational techniques interaction for interface actions.

5.3. Subjective evaluation

The subjective evaluation of the navigation techniques is not statistically significant. Judging from the average scores, T-ENCC performs best in speed, comfort and smoothness, M-G&D performs

Table 7
ANOVA for task completion times of different navigational techniques with direct-touch vs. mouse.

Source of variance	[1] CPB	[2] DPB	[3] ENCC	[4] G&D	*F*	*p*	Least significant difference (LSD) method
Direct-touch	183.16 (45.23)	178.37 (49.67)	128.45 (32.26)	143.13 (36.61)	17.95	.000	[3], [4] < [1], [2]
Mouse	143.79 (32.80)	146.79 (33.26)	130.65 (33.04)	129.37 (34.98)	3.15	.028	[3], [4] < [1], [2]

Table 9
ANOVA for user interface actions of different navigational techniques with direct-touch vs. mouse.

Source of variance	[1] CPB	[2] DPB	[3] ENCC	[4] G&D	F	p	Least significant difference (LSD) method
Direct-touch	92.69 (40.07)	85.56 (25.78)	63.39 (21.99)	139.06 (37.97)	39.47	.000	[3] < [1], [2] < [4]
Mouse	93.00 (33.00)	81.19 (30.38)	64.39 (24.06)	163.17 (43.75)	62.52	.000	[3] < [1], [2] < [4]

Table 10
Mean subjective rating.

	Effort	Accuracy	Speed	Fatigue	Comfort	Smoothness
T-CPB	3.44	3.97	5.42	3.08	5.50	5.69
T-DPB	3.56	4.11	5.08	2.89	5.64	5.58
T-ENCC	3.58	3.81	**5.69**	3.11	**5.83**	**6.08**
T-G&D	3.64	**4.28**	5.58	2.72	5.42	5.72
M-CPB	3.50	3.83	5.39	**3.25**	5.78	5.94
M-DPB	3.75	4.17	5.42	3.00	5.19	5.50
M-ENCC	3.33	3.94	5.64	3.06	5.47	5.81
M-G&D	**3.81**	4.00	5.56	2.64	5.56	5.92

T: Touch screen; M: Mouse. From 1 (most negative) to 7 (most positive).

best in effort, T-G&D performs best in accuracy, and M-CPB performs best in fatigue (Table 10). The highest score for each evaluated item is marked in black bold letters.

6. Discussion

The interaction between input devices and navigational techniques exerts a significant effect on task completion time ($F_{3,105}$ = 6.73, $p < .001$) and user interface actions ($F_{3,105}$ = 3.93, $p \leqq .05$). Whether the mouse or the touch screen is used, ENCC performs best in terms of both task completion time and user interface actions. Additionally, when CPD, DPB and G&D are adopted, the mouse performs better than the touch screen in terms of task completion time. Moreover, it is discovered that the input device has an effect on the performance of the navigational technique. When the mouse is employed, ENCC and G&D perform better than the other techniques. In contrast, when the touch screen is employed, ENCC performs best of all.

Regarding the task completion time needed by the navigational technique (Table 7), it is discovered that, whether the touch screen ($F_{3,105}$ = 17.95, $p < .001$) or the mouse ($F_{3,105}$ = 3.15, $p < .05$) is employed, CPB and DPB take more time than the other two navigational techniques. The above result agrees with the conclusion reached by other researchers. When the arrow buttons of CPB are operated, the size of the area, where the user's fingertip contacts the touch screen will affect whether the arrow button can be clicked or pressed accurately [20]. Sometimes the arrow button is pressed so hard as to distort the finger. At other times, the area covered by the fingertip is so large that the wrong button is also pressed. Consequently, the system can not detect the pressing correctly and even cannot recognize it at all. Equipped with the CPB, the touch screen requires a far larger number of pressings than the mouse does. That is, in terms of task completion time, there is a remarkable difference between the two input devices.

In terms of task completion time, the mouse performs better than the touch screen in the three navigational techniques, i.e., CPB, DPB, and G&D. However, when ENCC is adopted, there is no significant difference between the mouse and the touch screen. Besides, whether the mouse or the touch screen is employed, the four navigational techniques are compared with one another. G&D performs better than CPB and DPB in terms of task completion time; however, the former performs worse than the latter in terms of user interface actions. When ENCC works together with the mouse or the touch screen, it performs equally well in terms of task completion time and user interface actions. As a result, ENCC is suitable for both the mouse and the touch screen while G&D is more suitable for the mouse. With the small screen employed, the performances of different navigational techniques were investigated by other researchers [10]. It was discovered that the use of G&D did not cause the pressing of the wrong button or the low accuracy rate of pressing. However, to move for a long distance on the map, the user must grab and drag several times before reaching the destination. Therefore, G&D performs worse than the other three navigational techniques in terms of user interface actions. By contrast, CPB and DPB are capable of continuous control and continuous display; as a result, their operations need not be repeated to reach the destination, and they perform better than G&D in terms of user interface actions.

So far the operational experiments with computers have not shown any difference in the injuries caused by the single-click and the double-click [43]. However, according to some relevant studies, if the mouse is frequently used to perform repetitive movements, it is a risk factor of musculoskeletal disorders, which happen to the side of the upper arm, elbow, wrist, and fingers operating the mouse [44,45]. Therefore, considered from the standpoint of ergonomics, it is suggested that the hand-controlled devices should involve as few repetitive movements of the fingers as possible to minimize the muscular injuries [41]. ENCC can reduce the double clicks of the hand and so gives the user a better performance. ENCC is capable of not only continuous control and continuous display but also continuous directional control and speed control. Needless to say, ENCC performs better than the other three navigational techniques in terms of user interface actions, achieving a remarkable performance. Although ENCC performs nearly as well as G&D in terms of task completion time, the former performs remarkably better than the latter in terms of user interface actions. When ENCC is adopted, the control ball must be constantly pressed. However, when considered from the angle of movement economy [46], ENCC requires the minimum movements of the body whether the mouse or the touch screen is used. ENCC requires the fingers alone or the fingers and the wrist to move, but rarely requires the movement of the arm. By contrast, in the G&D, the arm must often be used to drag the large image.

It is discovered that, whether the mouse or the touch screen is employed, ENCC performs best among the four navigational techniques in terms of task completion time and user interface actions. The reason for the excellence of ENCC may be as follows. Containing only one single component, i.e., the control ball, ENCC has no button at all, so it is operated by dragging instead of by clicking. Owing to that kind of control function, the ball will never encounter such a problem as pressing the wrong button. In addition, the target width of the control ball is large enough, so the accuracy of choice is ensured [20,38]. That is why ENCC performs better than CPB in terms of both task completion time and user interface actions. Likewise, when G&D is employed, the user does not press any button but moves the finger or cursor onto the map surface in order to transfer the map. In consequence, the user will never press the wrong button or press the button improperly in the G&D.

The touch screen is widely different from the mouse as far as the ways of operation are concerned. It is discovered that, when CPB and DPB are employed, the touch screen consumes more task completion time than the mouse. In addition, it is discovered by other relevant researches that, when operating DPB, the right-hander is apt to span the right arm over the screen. Consequently, with the arm suspended above the map, much of the image is occluded from view, and this will easily cause ache and pain to the arm muscles and bones [39].

It is indicated by the experimental results (Tables 7 and 9) that the difference between CPB and DPB in task completion time is statistically significant, whether the touch screen or the mouse is employed. However, the difference between CPB and DPB in user interface actions is not statistically significant. The main reason is that, when CPB is operated, its button is too small for the user to use smoothly. Moreover, the distance between two buttons is so short that the performance in task completion time is lowered. To avoid operational errors, the user tends to reach out the hand more slowly before pressing the button [9]. Meanwhile, the user is so preoccupied with the accurate pressing that the task completion time is lengthened unintentionally [47]. In contrast, as the buttons of DPB are scattered on all the edges of the map, the user must move the hand for a longer distance before clicking the correct button. According to Fitt's Law, the longer the relative distance is, the more time the cursor needs to locate a destination [38]. These two factors account for the lower performance in respect of task completion time.

At present, as a common interface adopted by domestic and foreign web maps, CPB has the following disadvantage. That is, the distance between the two adjacent buttons is so short that the user is easily subject to the interference between the components and thus fails to operate the interface efficiently [10]. It is indicated by this research and other studies that, the size of the area, where the user's fingertip contacts the touch screen will determine whether the arrow button is clicked or pressed in a time-saving way [20]. It is proposed by some researchers that the vertical distance between two adjacent buttons on the touch screen should be at least 12 mm and the horizontal distance should be at least 14 mm [48]. In accordance with the abovementioned findings, the buttons on the newly-designed ENCC have been enlarged. Furthermore, regarding directional control, ENCC is more agile and diversified than the other three navigational techniques, for it can move easily in all directions imaginable. On the other hand, both CPB and DPB are capable of moving only in eight fixed directions. When operating ENCC, the user need not press any arrow button to alter the direction; therefore, there is no need to worry about the accuracy of pressing. Besides, the control ball of ENCC needs to be dragged for only a relatively short distance. Consequently, with the relative distance shortened, its task completion time becomes shorter. In addition to continuous control and continuous display, ENCC boasts directional control and speed control. If the control ball is pressed constantly, directional control is effortlessly performed. Also, the speed of movement will get higher as the ball is farther away from the circle center. The user can choose to browse the information space quickly or slowly by means of speed control. This reduces the boredom caused by the arrow buttons in the larger information space [33]. As a result, ENCC performs comparatively better in our research.

While there is no significant difference in the subjective evaluation, an evaluation of the participant's fatigue levels is conducted after the experiment. It is discovered that G&D gives the user the largest amount of fatigue whether the mouse or touch screen is used. As for user interface actions, G&D obviously requires a greater number than the other navigational techniques. In consequence, the participants tend to feel more fatigue after employing G&D.

7. Conclusion

Although the touch screen is increasingly popular, the navigational techniques provided by the various systems are largely compatible with the mouse rather than the touch screen. To keep up with the increasing popularity of the touch screen, not merely hardware but also the operational interface has to be upgraded. With the navigational techniques of the web maps investigated, it is shown by this research that ENCC is compatible with both the touch screen and the mouse. Even though G&D performs well in terms of task completion time, it performs poorly in respect of user interface actions. Generally speaking, when user interface actions are too large in number, much pressure will fall on the arm muscles and bones, leading to the user's fatigue.

In designing an interface, the designer should give priority to adding as many user-controlled elements as possible to it. ENCC performs better than the other three navigational techniques because it is equipped with continuous control and continuous display (CCCD); additionally, it enhances directional control and speed control. In consequence, ENCC enables the user to adjust the browsing speed, with its functionality greatly enhanced. Thanks to such advantages, ENCC may be applied to a wide variety of electronic products, including GPS, cell phones, PDA, and web maps.

It has been proved by the research findings that the navigational techniques currently suitable for the mouse are not necessarily compatible with the touch screen. As the touch screen will be widely used in the future, both software and interfaces must be reconsidered and redesigned to provide the user with better interfaces.

After the new navigational technique ENCC is developed, the simulated interfaces are designed and the simulated tests are conducted on it. With the touch screen and the mouse employed separately, ENCC has been thoroughly evaluated in respect of operational performance. Also, the performances of different input devices in the four navigational techniques have been studied. The input device and the navigational technique which have performed better are recommended as a reference for scientific research and practical application.

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