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An Analytical Approach to Creating Multitouch Gesture Vocabularies in Mobile Devices: A Case Study for Mobile Web Browsing Gestures

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This study proposes an analytical approach to the creation of multitouch control-gesture vocabularies applicable to mobile devices. The approach consists of four steps: (a) identifying target commands, (b) extracting gesture features of the target commands, (c) analyzing usage patterns based on elements that consist of multitouch gestures, and (d) creating gesture vocabularies based on the gesture features and elements. Usefulness and practicality of the proposed approach were validated in a case study. The case study created 11 mobile web browsing gestures to improve short-cut interactions. Six volunteers created gestures based on systematic procedures and practical methods. A total of 314 gestures were created in the case study, and the results were compared with those of a previous study that used an empirical approach to design control gestures. The proposed approach helped designers to create appropriate gestures for various commands on mobile devices. It was very practicable for all designers, including even novice users.

1. INTRODUCTION

A multitouch gesture is defined as a hand gesture on a multitouch screen (Fu, Goh, & Ng, 2010), and is classified as a natural user interface (NUI). Although most computer interfaces use separate controllers, which users must learn to operate, NUIs allow users to conduct relatively natural motions, movements, or gestures that they can quickly discover how to use. NUIs are very easy to use for novices who are not familiar with computers. NUIs are also expected to replace traditional interactions using the currently normal combination of windows, icons, menus, and pointing devices, because they provide users with a more realistic and pleasant experience than windows, icons, menus, and pointing devices. For example, users can directly manipulate objects with various hand motions instead of using a mouse button to select an icon or menu (Bjørneseth, Dunlop, & Hornecker, 2012; Jetter, Zöllner, Gerken, & Reiterer, 2012; Lepreux, Kubicki, Kolski, & Caelen, 2012; Radhakrishnan, Lin, Zeid, & Kamarthi, 2013; Villanueva, Tesoriero, & Lozano, 2012).

Use of gesture interaction in electronic products is increasing, and gestures are used to interact with such products as mobile phones, tablet PCs, and MP3 players. Representative products include Microsoft tablet PC, Apple iPhone, MacBook, and DELL Latitude XT2. Microsoft tablet PC is a table PC with a large, horizontal multitouch screen. Several users can manipulate digital content simultaneously by touching it and moving their hands on it. This device recognizes several products (e.g., cup, phone, camera, and digital card) and hand motions by using five infrared cameras hidden under the screen. The Apple iPhone supports several gestures such as tap, drag, flick, swipe, double tap, and touch and hold with one finger, and pinch open and pinch close with two fingers. The Apple MacBook has a touchpad that recognizes multiple touches by up to four fingers; this enables it to support gesture interaction to execute several commands directly, for example, scrolling the screen, zooming in/out, rotating, calling the short-cut menu, and changing tasks sequentially. The DELL Latitude XT2 is a tablet PC with a multitouch screen that also provides natural experiences such as using multitouch gesture to manipulate virtual objects realistically.

Many researchers have developed various algorithms for multitouch gestures to make interactions more natural. Innovations in sensing hardware such as DiamondTouch (Dietz & Leigh, 2001) and SmartSkin (Rekimoto, 2002) enable detection and tracking of multiple input points including complex shapes such as hand postures (Wu & Balakrishnan, 2003). Typical multitouch systems recognize position (e.g., coordinate value), motion (e.g., velocity and acceleration), contact property (e.g., size of contact area, shape of contact area, orientation and pressure), and touch events (e.g., tap and flick; Wang & Ren, 2009). Almost every multitouch gesture is recognizable by the system, and thus further research should focus on using advanced technologies to design gestures that are more natural and more useful.

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The purpose of this study is to develop a methodology for creating gesture vocabularies in mobile devices equipped with a multitouch screen. Gesture vocabularies are specified as a set of gestures for activating commands or functions of a system. In the past, gestures were collected from end-users or system developers by using empirical approaches such as interviews, surveys, and observations. Previous similar studies suggested only general procedures for collecting intuitive gestures. However, this study attempted to propose an analytical approach to creating multitouch gesture vocabularies, which is practically utilized to human–computer interaction (HCI) researchers. Systematic procedures and practical methods were developed in a case study in which uninstructed volunteers designed mobile web browsing gestures. The effectiveness of the analytical approach was compared with that of an empirical approach used in a previous study.

The previous study attempted to find intuitive gesture for 18 web browsing commands (Park & Han, 2013). Thirty-six mobile phone users were recruited in the lab, and they were asked to define their own gestures appropriate for each web browsing command. Participants expressed their gestures on the mobile phone touch screen, and all the gestures were recorded by a video camera. A total of 642 gestures were collected for the 18 web browsing commands. This study basically started from the results of the previous study, and suggested a new analytical method to complement the shortcomings of the previous one.

2. RELATED WORK

Gesture vocabularies can be designed using various approaches. The approaches differ in three perspectives: design procedures, designers, and design solution methods.

2.1. Gesture Design Procedures

Design procedures are classified into top-down approaches and bottom-up approaches (Nielsen, Störring, Moeslund, & Granum, 2004): Top-down approaches determine gestures first, whereas bottom-up approaches determine commands first. That is, a top-down approach finds appropriate commands to use predefined gestures, whereas a bottom-up approach designs the most appropriate gestures for the system commands.

The top-down approach was generally used in early gesture studies, because gesture interfaces could not recognize various postures or motions due to technological limitations. Thus, only a restricted number of gestures could be used. Researchers developed gesture recognition technology first, and then found where this technology could be applied (Grossman, Hinckley, Baudisch, Agrawala, & Balakrishnan, 2006; Rekimoto, 2002). This was a good approach to design distinguishable gestures, with the limitation that the gestures were not well matched to commands. However, the top-down approach was not used frequently after gesture technology became more sophisticated. Instead, this approach was used to validate prototypes developed in the evaluation stage. For example, intuitiveness of gesture interfaces has been validated by the top-down approach (Koskinen, Laarni, & Honkamaa, 2008; Lao, Heng, Zhang, Ling, & Wang, 2009). The subjects were asked to guess the most appropriate command for each gesture vocabulary, and the intuitiveness score was calculated by the number of correct responses.

The bottom-up approach became popular due to advances in recognition technology that allowed researchers to design a large variety of gestures and to develop intuitive gestures most appropriate to commands. Wu and Balakrishnan (2003) used the bottom-up approach to develop natural gestures for furniture arrangement tasks. Mauney, Howarth, Wirtanen, and Capra (2010) collected user-defined gestures from users in nine countries, after determining 28 commands for performing file or image management tasks. They surveyed gestures from end-users without considering technical limitations. Lao et al. (2009) also designed intuitive, simple, and precise gestures for a photo management application, after determining 14 commands in advance.

2.2. Gesture Designers

Gesture interfaces are commonly designed by developers, but sometimes the gesture vocabularies are defined by end users. Stern, Wachs, and Edan (2008) divided design approaches into centrist (authoritarian) and democratic (consensus) approaches according to who designed a gesture vocabulary for each system command.

In the centrist approach, developers design gesture vocabularies on behalf of end-users. They have wide experience in using gesture interfaces and are familiar with technological limitations. They can invent realistic gesture vocabularies by using their expertise (Broberg, Andersen, & Seim, 2011; Morris, Wobbrock, & Wilson, 2010; Sauer, Seibel, & Rüttinger, 2010). This approach is a form of an analytical approach, because they consider various issues analytically, such as observing users' mental models, analyzing usage patterns, and investigating other products (Lim & Rogers, 2008; Morris et al., 2010; Nielsen, Moeslund, Störring, & Granum, 2008; Stern et al., 2008). For example, Xiang et al. (2008) closely observed how people interact with real objects in the world and applied the real interactions to the gesture interaction. Morris et al. (2010) collected intuitive gesture candidates from three HCI experts who had experience in developing gesture systems. Lao et al. (2009) investigated previous gesture systems and benchmarked successful interaction styles to find appropriate gestures for photo management application. However, when the centrist approach does not adequately consider users' preferences or behaviors, it might develop unintuitive and difficult gestures. Semantic features of the gesture vocabulary should be closely related to the meanings of the command.

The democratic approach involves end-users and collects gesture vocabularies from them. This approach is useful in collecting intuitive gestures because a user's mental model is reflected in the gestures directly. However, the users do not consider technological limitations, and the collected gestures sometimes are unrealistic. Nevertheless, the democratic approach is commonly used due to the convenience of collecting gestures. Nielsen et al. (2008) obtained natural gestures from user interviews. They suggested a scenario-based method to increase the efficiency of collecting gestures. Mauney et al. (2010) simply surveyed users' opinions in the laboratory, where they asked the users to answer what they see as the most appropriate gesture after viewing images before and after execution of a command. Koskinen et al. (2008) designed multitouch gestures for a nuclear power system. They questioned participants on how to alter the existing mouse or controllers. Kühnel et al. (2011) elicited three-dimensional gestures from mobile phone users in the smart-home domain. The democratic approach is a kind of empirical approach, because the gesture vocabularies are generally defined after collection of a large amount of data before logical reasoning.

In addition to these approaches, gestures can be adapted and customized for each user. This approach is called the individual (customized) approach.

2.3. Gesture Design Solution Methods

The most effective gesture vocabularies are designed based on rational reasons. For example, a designer's expertise, design principles, and quantitative data allow designers to determine the best gesture for a command. The reasons help the designers solve the given problem. Design solution methods are classified into specificity, rule-based, and mathematical methods (Stern et al., 2008).

The specificity method is the main method used to develop gesture vocabularies. Designers use their expertise or intuition to define the best gestures. This method does not require any literature, guidelines, or quantitative data. The quality of the result depends only on the designer's expertise. Computer scientists commonly use this method, because their objective is not to find optimal gestures but only to find novel gestures that are recognizable accurately. Many examples exist in the literature (Bailly, Müller, & Lecolinet, 2012; Bau & Mackay, 2008; Baudisch & Chu, 2009; Derboven, De Roeck, & Verstraete, 2012; Keefe et al., 2012; Lepinski, Grossman, & Fitzmaurice, 2010; Liao, Liu, Liew, & Wilcox, 2010; Matejka, Grossman, Lo, & Fitzmaurice, 2009; Motamedi, 2008; Moyle & Cockburn, 2003; Olwal, Feiner, & Heyman, 2008; Roth & Turner, 2009; Roudaut, Lecolinet, & Guiard, 2009; Wang & Ren, 2009; Wu & Balakrishnan, 2003; Yatani, Partridge, Bern, & Newman, 2008) With the specificity method, however, it is difficult to guarantee generality of the designed gestures, because gesture design is based on the designer's subjective opinion. Thus, the design process is usually followed by a user evaluation to ensure that the designed gestures are also familiar or effective to end users.

The rule-based method uses design principles, guidelines, or concrete theoretical background to determine the best gesture candidates. For example, "gestures should be easy to learn for novice users" or "tension of hand muscle should be minimized when users start gesture interaction" are example rules in designing gestures. Sometimes this method does not specify which rules should be applied if they are general or ambiguous. Nevertheless, designers are very familiar with these rules and can use the method easily. Brandl, Forlines, Wigdor, Haller, and Shen (2008) summarized the benefits of both pen-style interactions and touch-style interactions, and then used the benefits as guidelines to design several gestures. Lao et al. (2009) used three principles—that is, intuitiveness, accuracy, and directness—to find appropriate gestures for photo management commands. Chen, Koike, Nakanishi, Oka, and Sato (2002) used Guiard's Kinematic Chain Model and summarized the basic principles for using both hands. These principles were used to design drawing and editing gestures with two hands complementarily. Some studies have summarized design principles for multitouch gestures but did not design any system. Yee (2009) suggested eight design principles to improve productivity and efficiency of developing multitouch gestures. Norman and Nielsen (2010) noted six design principles that many designers easily miss when they develop gesture systems.

The mathematical method uses quantitative data from ergonomics, hand biomechanics, cognitive science, experimental statistics, and machine recognition. This method suggests a concrete rationale more objectively than do the specificity method and rule-based method. For example, Nielsen et al. (2004) evaluated intuitiveness, memorability, and physical fatigue and compared the quantitative scores among gesture candidates. Stern et al. (2008) proposed an optimization algorithm that maximized the total intuitiveness of all gestures in the system. They invented a program that recommends the optimal gesture set automatically from the user's preference results. Wobbrock, Morris, and Wilson (2009) evaluated "good match" and "easy to perform" numerically using 7-point Likert scales, and recommended the best gestures based on these evaluations.

3. PROCEDURES FOR CREATING GESTURE VOCABULARIES

This study followed the bottom-up approach, that is, designers found appropriate gesture vocabularies for predetermined commands. The bottom-up approach can design more diverse gestures than the top-down approach. It is also a good approach for finding the most appropriate gestures, because technological restrictions are considered later. This study determined target commands first and then created the appropriate gestures for them. The designers followed a systematic procedure to create vocabularies.

The procedure consists of four steps (Figure 1).

1. Identifying target commands. Designers determine what kinds of commands require a gesture interaction. Gesture interaction has some benefits, which can be good criteria to identify target commands.
2. Extracting gesture features of the target commands. Gesture features are defined as symbolic or physical features that can

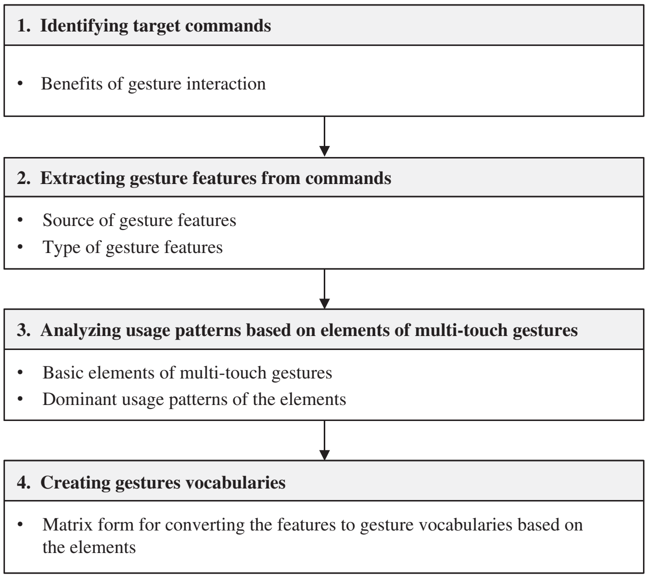


FIG. 1. Procedures for creating gesture vocabularies.

be expressed as gestures. These features semantically connect the commands to gestures. Numerous gesture features exist; designers generally derive them from predecessor tools or artifacts, real situations, and existing gestures.

3. Analyzing usage patterns based on elements that consist of multitouch gestures. The basic elements are useful materials for creating various gestures, and the usage patterns of gesture elements provide physical frames, a kind of guideline, for expressing user-preferred gestures. The gesture elements and their subelements should be identified, and their usage patterns should also be analyzed.
4. Creating gesture vocabularies based on the gesture features and elements. Designers use the dominant usage patterns of gesture elements to transform the gesture features into multitouch gestures. If the gesture features correspond to the mental models or intrinsic meanings of gestures, then the gesture elements correspond to extrinsic expressions of gestures. Therefore, gestures are created by combining the features and the elements of gestures.

4. IDENTIFICATION OF TARGET COMMANDS

First, target commands are identified. Designers should determine the commands that require a gesture interaction. The gesture interaction has some benefits, which can be used as criteria to identify target commands. Gesture interactions are commonly advantageous in the following situations.

1. Natural manipulation. Users can have the feeling that they are manipulating real objects by intuitive and direct interactions.
2. Short-cut interaction. Gestures support command execution instantly without the need to access a menu.
3. Distraction of visual attention. Users can activate gesture commands without the need to select a visual target accurately.
4. Flexible interaction. Gestures are easy to change depending on various users and environments.

TABLE 1
Web Browsing Commands That Need Gesture Interaction in Mobile Phones

Code	Command	Definition
C1	Home	Go to your home page
C2	Next	Go to the next page
C3	Previous	Go to the previous page
C4	Stop	Stop downloading a page
C5	Find	Find on this page
C6	Refresh	Refresh the current web page
C7	Top	Move to the beginning of a document
C8	Bottom	Move to the end of a document
C9	Close	Close the current window
C10	Toggle	Toggle between windows
C11	Shortcut menu	Display a shortcut menu for a link

The case study selected 11 commands (Table 1) that were thought to need gesture interaction. The short-cut commands of web browsers were considered to be gesture commands, because they are generally frequently used or important functions. Navigating or browsing commands for obtaining information were mainly selected. The selected commands include exploring web pages, searching for information, viewing on a page, controlling a window, and activating a menu.

5. EXTRACTION OF GESTURE FEATURES

Gestures were categorized as symbolic, physical, metaphorical, or abstract according to their nature (Wobbrock et al., 2009). Symbolic gestures depict visual images such as icons, symbols, and characters. Physical gestures describe physical actions, for instance, manipulating an object in the real world. Metaphorical gestures act on, with, or like something else; they usually simplify symbolic or physical gestures to express only the metaphors of the referents. Abstract gestures are purely arbitrary.

The relation or the nature of gestures is called a gesture feature in this study. That is, the gesture feature signifies a symbolic or physical feature that is used to express the referents in the gestures (the referents are the web browsing commands in this study).

A symbolic feature is defined as a static characteristic of referents, such as an image, symbol, label, or layout. For example, an image of a roof (i.e. "∧") or the first letter of a label "home" (i.e., "h") are symbolic features for expressing the *Home* command. A physical feature is defined as a dynamic characteristic of referents and includes physical actions of either objects or humans. For example, the movements of a web page, the dragging actions of a scroll bar, or the pointing actions of the finger can be used to express the *Top* command.

As an example of feature, the *Close* command has symbolic features such as the symbol X and the position of the close button, that is, at the upper-right corner, in PC web browsers. Dynamic features include various actions such as closing a book, tearing off a page from a calendar, closing a window with two hands, and closing a shutter by pulling down (Table 2).

The gesture features were taken from various sources such as PC web browsers, books, cars, and television, and from real situations such as driving, talking, and staying in the room. People use numerous gestures in their everyday life. Previous studies also emphasize that the designers should observe physical phenomena in the real world and should also consider real situations through diverse scenarios (Esenther & Ryall, 2006; Jacob et al., 2008; Koskinen et al., 2008; Maes, Amelynck, Lesaffre, Leman, & Arvind, 2013; Nielsen et al., 2004; Xiang et al., 2008).

Therefore, gesture features could be extracted from existing tools and situations. These existing sources provide familiar gesture features to users and are easy to remember. The sources included predecessor tools or artifacts, real situations, and existing gestures (Table 3). Designers can benchmark various gesture features from these sources.

A previous study conducted by Park and Han (2013) observed not only gesture motions but also users' mental models. The mental model represented the gesture features very well. This study used previous data, categorized the collected mental models into several types, and determined what gesture features could be used when expressing gestures (Table 4).

The case study extracted gesture features in a laboratory environment. Sources and types of gesture features were presented to six volunteers while they were planning gesture features for the 11 web browsing commands. Various images and photos related to each command (Table 5) were also presented

TABLE 2
Examples of Gesture Features for *Close* Command

Group	Gesture Features
Symbolic features	Symbol 'X' Label 'Close' Label 'esc' Key combination 'alt + F4' Key combination 'ctrl + w' Symbol of power button Layout of close icon on the upper-right
Physical features	TV screen fades away. Windows are closed from top to bottom. Windows are closed from right to left. Screen disappears very fast. Screen disappears like flying. Pushing home button on the smartphone. Closing the gas valve. Closing a book. Tearing off a page from a calendar. Closing a window with two hands. Closing a shutter by pulling down. Cleaning all in front of him. Covering one's eyes with two hands. Waving hand. Tapping with three fingers (existing gesture). Dragging down with three fingers (existing gesture).

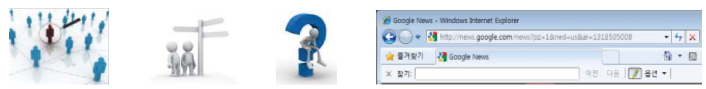
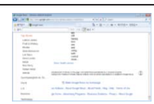
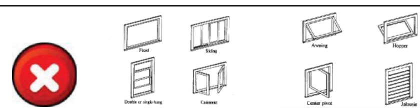
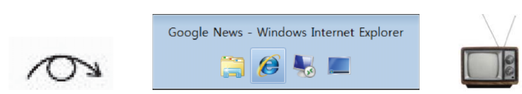
TABLE 3
Source of Gesture Features for Mobile Web Browsing Commands

Group	Source
Predecessor tools or artifacts	PC (with mouse), Phone, Game console, Book, Paper, Magazine, AV player, Calendar, Laser pointer, Navigator, Yellow book, Television, Electronic album, Note, Manual, Window
Real situations	Driving, Talking, Exploring, Visiting, Navigating, Walking, Running, Resting, Eating, Drawing, Choosing, Playing sports, Searching people, Cleaning, Farewell, In the room, In the library, In the restaurant
Existing gestures	Sign language, Gesture interface

TABLE 4
Type of Gesture Features for Multitouch Gestures

Group	Type of Gesture Feature
Symbolic feature	Image (shape, number, size) Symbol (sign, icon, punctuation mark) Label (abbreviation, naming) Layout (location, alignment, orientation)
Physical feature	Action of the human (displacement, direction, speed, duration, repetition, delay, action sequence, change of posture, amount of force) Action of an object (displacement, direction, speed, duration, repetition, delay, action sequence, animation effect)

TABLE 5
Images and Symbols Related to the 11 Web Browsing Commands (color table available online)

Command	Images
C1. Home	
C2. Next	
C3. Previous	
C4. Stop	
C5. Find	
C6. Refresh	
C7. Top	
C8. Bottom	
C9. Close	
C10. Toggle	
C11. Menu	

to the six subjects. They helped the subjects to think the gesture features easily and supplemented the limitations of the laboratory environment. The images were collected from portal sites such as Google and Yahoo.

6. ANALYSIS OF MULTITOUCH GESTURE ELEMENTS

This study investigated many examples of multitouch gestures from 69 different literature sources, including proceedings, journals, and magazines. Gestures were retrieved using keyword search in Internet bibliographic databases such as Scopus, ScienceDirect, Google Scholar, and Google. The keywords used in this survey included *gestural interface, touch interaction, multitouch, touch screen, surface computing,* and *direct manipulation*.

Most researchers designed gesture interfaces for drawing, editing, and manipulating tasks, and the gestures were applied to a painting tool, file management, photo management, and mouse manipulation, among other tasks. The gestures used in this research were diverse. For example, the number of

TABLE 6
Library of Multitouch Gesture Elements

Element	Subelement
Posture	Particular finger (thumb, index finger, middle finger, ring finger, little finger) Particular part of hand (side, palm, back) Number of fingers (1∼5 fingers, two hands) Combination of fingers Form (fist, opened-hand, corner-shaped hand, trapping-shaped hand) Direction (vertical, horizontal, tilted)
Location	Coordinate (top, bottom, left, right, upper-right, upper-left, lower-right, lower-left, edge, center) Relative location to UI component (empty area, link, on the component)
Touch	Tap, Double tap, Triple tap Press down Strong tap, Weak tap
Pose	Increase/decrease the gap between fingers (pinch open/close, tear) Touch/move with one finger while pressing down with another finger (hold & drag, hold & tap, hold & double tap) Change fingers tapping (tap & tap) Remove fingers (press down with two fingers and then remove one finger) Rotate hand direction Flip a hand/finger
Path	Drag (up, down, leftward, rightward, curve) Drag quickly, Drag slowly Flick, Accelerate, Decelerate Drag repeatedly, Flick repeatedly, Rub Draw (symbol, character)
Device	Shake Tilt (forward, backward, leftward, rightward)

fingers, combination of fingers, and pose of hand (e.g., fist, palm, vertical hand, horizontal hand, and two hands) were used for expressing gestures. Apart from the static poses of hands, hand motions such as tapping, dragging, flicking, shaking, and pinching open/close were also used for expressing gestures.

These gesture examples were categorized into six elements (Table 6): posture (hand postures), location (locations on the screen), touch (touching patterns using rhythm or force), pose (changes of the hand posture), path (movements of the hand on the screen), and device (movements of the mobile device). Because the elements of multitouch gestures were the smallest units of the vocabularies, combinations of these elements can express all the complex hand gestures. The gesture elements could possibly include more detailed elements such as the subelements in the library. For instance, path gestures could be classified into dragging quickly, dragging slowly, and flicking according to their acceleration or velocity, or they could be classified into straight path, curved path, and path-free according to their trajectory.

A previous study used an empirical approach to collect intuitive web browsing gestures from end-users, and a total of 394 gestures were collected for the 11 web browsing commands (Park & Han, 2013). This study used the results of the previous study to analyze popular usage patterns of the gesture elements.

Combination patterns of the gesture elements were analyzed for the 11 web browsing commands (Table 7). A nonparametric binomial test was conducted to statistically identify the most common group of usage patterns in each command. Patterns having no statistical difference with the largest combination pattern were classified into one group, and this group, having a greater frequency in statistical terms, was called the top group. Ten out of the 11 commands showed that the Path usage pattern belongs in the top group. The Location-Path usage pattern was included in the top group for C7, C8, and C9. The Location-Touch usage pattern belongs in the top group in C7, C8, and C10. Most commands had dominant usage patterns from one to four, except C10 (*Toggle*). Most gestures were expressed by the location, path, and touch elements; this combination could express 301 of the 394 samples (76.4%).

TABLE 7
Combinations of Gesture Elements for 11 Web Browsing Commands

	Command										
Combination	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
Path	16	24	24	15	18	23	8	9	13	8	3
location-path	2	1		1	2	2	9	8	8	1	2
location-touch	3	2	2	1	3	1	10	11	2	3	1
Touch	1			6	1	3			3	2	18
posture-location-pose	2	2	2	1	1					2	
posture-path	4	3	3		3	2			2	6	
Posture	1			6	1	1			2		5
location-touch-path					1		2	2		2	
touch-path	1	2	2				4	4	1	3	1
posture-location-path					1	2			2		
posture-pose	1				2					6	2
posture-touch	1			2	1		1		1		
Location	1			1	1				2	1	
touch-device	2					1	1	1		1	
Device		1	1	1			1	1			
Simple				2							1
posture-touch-pose											2
posture-touch-device		1	1								
posture-location											1
posture-location-pose-path			1								
posture-location-touch	1										
posture-location-touch-path										1	

Note. Underlined, shaded: statistically top groups (binomial test, $\alpha = .05$). Cn ($n = 1 \sim 11$) are commands listed in Table 1.

7. CREATION OF GESTURES BY COMBINING GESTURE FEATURES, AND ELEMENTS

New gestures can be created by using both gesture features and gesture elements. Gesture features were related to intrinsic meanings or mental models, and gesture elements were related to extrinsic actions or expressions. A gesture was created by combining these two attributes. This study suggested a matrix form to help designers use the two attributes practically.

The matrix form consists of two axes (Table 8). One axis lists gesture features and the other lists gesture elements. The designers created new gestures in the cells at the intersection of the two

TABLE 8
Example of gesture creation using a matrix form (for *Close* command)

Feature/Element	Path	Location-Path
Symbolic features	Draw an ‘X’	Drag diagonally from upper right
Symbol ‘X’	Draw an ‘X’ with one stroke	Drag from upper right to lower left
Close button is at upper-right	Draw a ‘C’ character	Draw an ‘X’ symbol at upper right
Symbol of power button	Draw power button icon (e.g. ⏻)	
Physical features	Draw a delete mark (e.g. )	Drag from top to bottom
Closing shutter by pulling down	Drag downwards	Drag downwards from top
Screen disappears like flying	Drag downwards quickly	Flick downwards from top
Windows closed from right to left	Drag diagonally to lower-left	Flick diagonally on upper right
Tearing off page from calendar	Flick diagonally to lower-left	Drag quickly from left to right
Closing book		

axes. These cells identify the dominant usage patterns of gesture elements to transform gesture features simply into multitouch gestures. For example, gesture features of *Close* command had a symbol X and a layout of a close button at the upper-right corner. The dominant usage patterns of gesture elements were Path and Location-Path. Combining these two attributes, the designers could make several gestures such as drawing an X symbol, or drawing a small x symbol on the upper-right corner.

This framework allows designers to create gestures easily by modifying and expanding predefined gestures. This analytical approach proceeds and specifies gestures step by step. The gesture designers can specify ideas systematically. The gesture features and gesture elements provide seeds for creating gestures.

Gestures are created for each usage pattern. The usage patterns of gesture elements provide physical frameworks for creating gestures. Designers can easily create new gestures by just following the dominant usage patterns and subelements in the library of multitouch elements. Moreover, by making comparisons with other movements and cells, various gestures can be created. For example, the "closing a shutter by pulling down" feature can create many similar gestures such as "drag downwards," "drag downwards quickly," "drag from top to bottom," "drag downwards from top," and "flick downwards from top."

In the case study, three teams of two people (six volunteers) created gestures individually. The teams were randomly composed and the number of team members was minimized. The volunteers consisted of four male and two female individuals, aged 26 to 30 ($M = 27.7$). They did not have any experience in designing gesture interfaces. A total of 314 gestures were created by the analytical approach, and the average was 29 gestures per command (Figure 2). *Top, Bottom*, and *Toggle* commands had relatively large numbers of gestures, because they had more diverse dominant usage patterns than did other commands. Examples of the created gestures are described in Table 9 and Figure 3.

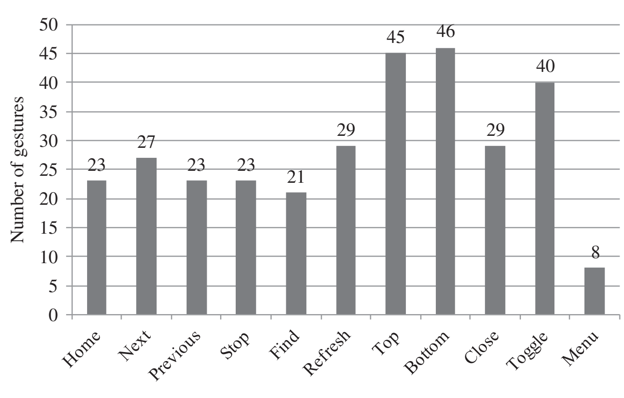


FIG. 2. Number of gestures for 11 web browsing commands.

8. DISCUSSION

8.1. Effectiveness of the Proposed Method for Creating Gestures

Gesture development methods reported in previous studies (Esenther & Ryall, 2006; Jacob et al., 2008; Koskinen et al., 2008; Nielsen et al., 2004; Xiang et al., 2008) suggested collection methods rather than creation methods. The studies only considered how to efficiently elicit various gestures from end users. They suggested scenario-based methods or general guidelines for designing survey environments. These methods depend highly on participants' creativity and cannot easily create, modify, or extend gestures efficiently. The collection methods also require too many participants in the design stage.

However, this study suggested a creation method. In this method, gesture elements and gesture features were identified before creating the gestures. Types and sources of gesture features were identified, and a library of gesture elements was also developed. Moreover, designers could come up with a variety of ideas quickly, even though the gesture vocabularies were created in a laboratory environment. Based on these data, designers can follow a systematic procedure when combining features and elements into gestures.

The participants could create gestures efficiently by following the method, even though they did not have any previous experience in designing gesture interfaces. They were able to create a large number of gestures for 11 web browsing commands in a short period. Creation work took less than 3 hr, including the time required to learn the method. On average, the participants took 15 min to think about gesture features and create new gestures.

It is quite difficult to prove the effectiveness is attributed to the proposed method rather than the ability of the designers. Although designers do not have average capability in gesture design, other characteristics of the designers may lead to a better or worse use of the approach compared with other designers. This study conducted case study with end-users instead of designers to minimize the side effect cased by design expertise. They had the same novice experience in gesture interaction with the participants of the previous study. Although they had no gesture design experience, they could create various gestures efficiently. Thus, the method suggested in this study is expected to be practical for all designers.

8.2. Comparison Between Empirical Approach and Analytical Approach

The method (analytical approach) proposed in this study was compared with a previous study (empirical approach) to determine which approach is more effective when designing gesture vocabularies. The previous empirical approach also collected multitouch gestures for mobile web browsing commands.

TABLE 9
Examples of Gestures Created Using the Proposed Analytical Approach (color table available online)

Command	Multitouch Gesture
Home	Draw an 'h' character
	Draw a circle
	Draw a triangle
	Draw a spiral into center
Forward	Drag left
	Draw the greater-than sign (>)
	Flick left
	Flick right
Backward	Drag right
	Draw the less-than sign (<)
	Flick right
	Flick left
Stop	Draw an 'X' symbol
	Drag left-right-left (three times)
	Draw an exclamation mark (e.g. !)
	Draw a stop symbol (e.g. ⊘)
Find	Draw a question mark (e.g. ?)
	Draw an 'f' character
	Draw a question mark without the dot (e.g. ʔ)
	Draw a magnifying glass (e.g. 🔍)
Refresh	Drag left-right-left way (three times)
	Draw an open circle harpoon (e.g. ↺)
	Drag left-right-left-right way (four times)
	Draw a circle twice
Top	Double tap the top
	Press down the top
	Press down and then flick upwards
	Flick upwards on the top
Bottom	Double tap the bottom
	Press down the bottom
	Press down and then flick downwards
	Flick downwards on the bottom
Close	Draw an 'X' symbol on the upper right
	Flick diagonally from the upper right corner in the lower-left direction
	Drag from the upper-right to the lower-left
	Draw an 'X' symbol
Toggle	Press down and then flick sideways
	Drag two fingers sideways
	Drag sideways with one finger while pressing with another finger
	Double tap and then drag sideways
Menu	Press down
	Press down and then tap
	Triple tap
	Double tap (Tap the screen twice)

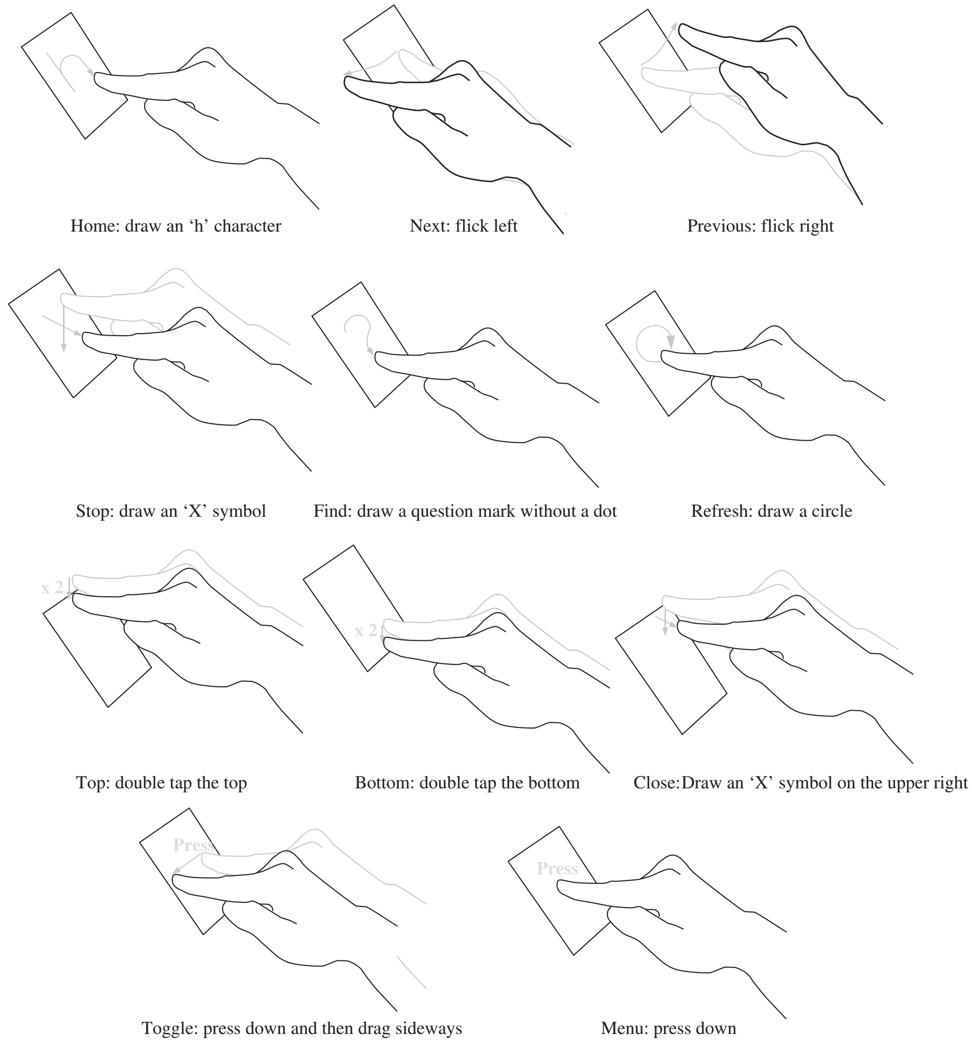


FIG. 3. Examples of gesture vocabularies for the 11 mobile web browsing commands.

The results of the comparison showed that the analytical approach was more efficient than the empirical approach in finding gestures. Thirty-six users were recruited to collect gestures using the empirical approach, but only six users were involved with the analytical approach (three teams of two). However, more gestures were identified with the analytical approach than with the empirical approach. On average, for a given command, two participants (one team) created 12 gestures, four participants (two teams) created 21 gestures, and six participants (three teams) created 29 gestures. When more than two teams were involved in finding the gestures, more gestures were created using the analytical approach than the empirical approach (Figure 4). The comparison was conducted using the number of gestures that have the same usage patterns in the two approaches, because the proposed analytical approach created gestures only within several usage patterns.

Many gestures created by the two approaches were similar or the same. Overlap between the two approaches occurred in 84 gestures; these comprised 41.3% of the 143 gestures obtained by the empirical approach and 18.8% of the 314 gestures obtained by the analytical approach (Figure 5). In sum, the analytical approach could find 41.3% of the gestures obtained by the empirical approach, with only one sixth of the participants.

Gesture candidates were selected from the gestures collected by the empirical approach and created by the analytical approach as well (Table 10). The selected candidates were evaluated by 22 subjects, who were separately recruited only for this evaluation. Their subjective satisfaction scores were compared with each other to identify the most suitable gesture vocabularies. The subjective ratings were collected by asking the subjects to evaluate whether the gesture candidates are good matches, easy to perform, and satisfying overall. The modulus magnitude estimation technique, where the subject uses a predefined standard for comparison, was used (Han, Song, & Kwahk, 1999). Users rated their satisfaction level on a scale

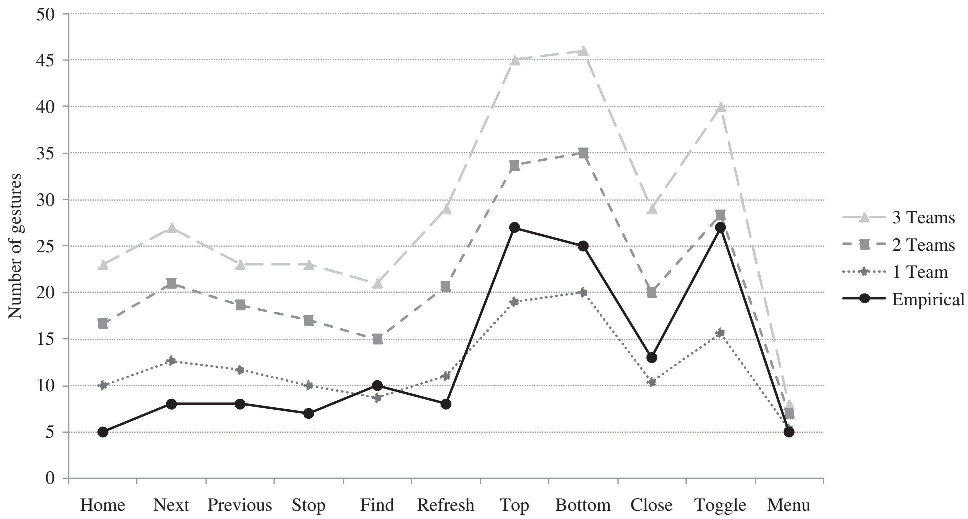


FIG. 4. Number of gestures developed for 11 web browsing commands.

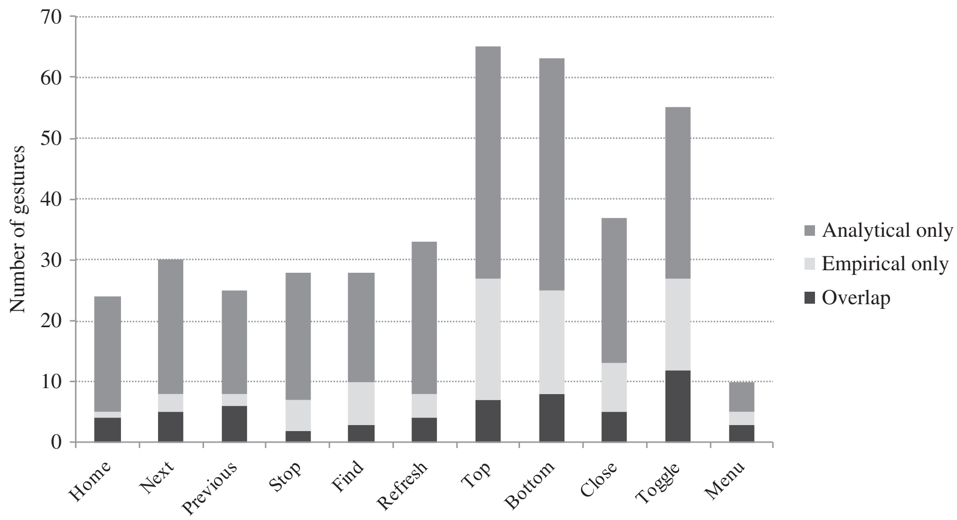


FIG. 5. Number of gestures from each approach.

of 0 to 100. A subjective rating of 0 means the subjects were not satisfied at all, and a rating of 100 means the subjects were completely satisfied. There were 16 male and six female participants, aged 19 to 29 ($M = 20.8$). They had experience using mobile web browsers and were familiar with web-browsing commands but had not used gesture interfaces in mobile web browsers. Because this study focused on evaluating gestures that would be preferred by end-users, the subjects were disqualified if they specialized in design-related majors such as computer science, ergonomics, or industrial design.

Subjective satisfactions on "good match" and "easy to perform" differed between the two approaches at the 5% significance level. Gesture candidates obtained by the analytical approach evaluated higher in the good match criterion but lower in the easy to perform criterion, compared to those obtained by the empirical approach. That is, the cognitive appropriateness was higher in the analytical approach, and the physical appropriateness was higher in the empirical approach. However, the overall satisfaction was not different at the .05 significance level (Figure 6). Subjective satisfaction ratings for each command were also summarized (Table 11).

A previous study (Morris et al., 2010) compared two gesture sets for table PCs, that is, a set of gestures created by an end-user, and a set of gestures authored by three HCI researchers and found that users preferred gestures authored by larger groups of people, such as those created by the end-user elicitation approach. However, this study found no significant difference in overall satisfaction between the empirical and the analytical approaches. More people participated in the empirical approach, but the score of good match was higher in the analytical approach. This might be due to the gesture features that were considered in the proposed methodology. The

TABLE 10
Multitouch Gesture Candidates for 11 Mobile Web Browsers (color table available online)

Command	Empirical Approach	Analytical Approach
Home	Drag a broken line like a caret (ˆ)	Draw an ‘h’ character
	Draw an ‘h’ character	Draw a circle
	Draw a pentagon	Draw a triangle
Next	Drag right	Flick left
	Flick left	Drag left
	Drag downwards and to the right	Draw the greater-than sign (>)
Previous	Drag left	Flick right
	Flick right	Drag right
	Drag downwards and to the left	Draw the less-than sign (<)
Stop	Drag to the lower-left direction diagonally	Draw an ‘X’ symbol
	Tap with two fingers	Draw an ‘X’ symbol with one stroke
	Tap with palm	Draw a stop symbol (e.g. ⊘)
Find	Draw a check mark (V)	Draw an ‘f’ character
	Draw an ‘f’ character	Draw a question mark (e.g. ?)
	Draw a question mark (e.g. ?)	Draw a question mark without the dot (e.g. ʔ)
Refresh	Draw a circle	Drag left-right-left-right (four times)
	Drag left-right-left-right (four times)	Drag left-right-left (three times)
	Draw lightning image	Draw an open circle harpoon (e.g. ↺)
Top	Double tap the top	Double tap the top
	Flick downwards	Press down the top
	Press down the top	Press down and then flick upwards
Bottom	Double tap the bottom	Double tap the bottom
	Flick upwards	Press down the bottom
	Press down the lower-right	Press down and then flick downwards
Close	Flick diagonally from the upper right corner in the lower-left direction	Flick diagonally from the upper right corner in the lower-left direction
	Draw an ‘X’ symbol	Draw an ‘X’ symbol on the upper right
	Double tap the upper right	Drag from the upper right to the lower left
Toggle	Drag sideways with one finger while pressing with another finger	Drag sideways with one finger while pressing with another finger
	Drag with two fingers sideways	Press down and then drag sideways
	Press down and then drag sideways	Press down and then flick sideways
Menu	Press down	Press down
	Double tap	Press down and then tap
	Tap with the middle finger	Triple tap

previous study obtained a set of gestures by HCI researchers based on their expertise, but this study created a set of gestures based on systematic procedures and a comprehensive investigation of gesture features. These features semantically connected the commands to gestures, and thus the gestures were better matched than gestures collected by the empirical approach. The empirical approach usually collected intuitive gestures from end-users but did not consider whether the gestures are logically or intrinsically appropriate to the commands.

The score of easy-to-perform was higher in the empirical approach than in the analytic approach. The gestures collected by the empirical approach were relatively simple and quick motions, whereas some gestures created by the analytical approach were complicated. For example, gestures using the path element had repetitive dragging motions or large movements such as “drag left-right-left way (three times),” “drag left-right-left-right way (four times),” and “drag from the upper-right to the lower-left.” Gestures using the touch element had complicated touching patterns or times such as “press down and then tap” and “triple tap.”

The score of overall satisfaction did not show significant difference between the two approaches, although the good match

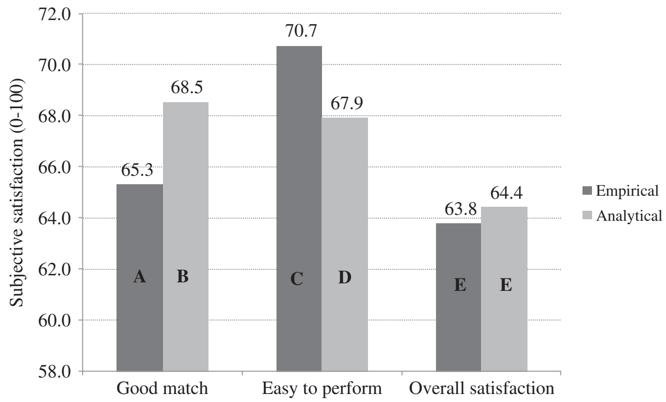


FIG. 6. Analysis of variance results of the subjective satisfaction between empirical and proposed analytical approaches.

Note. A different letter means that difference is statistically significant at $\alpha = .05$ for each criterion.

and easy to perform scores did. This implies that the analytical approach efficiently and quickly created gestures that are preferable to those created by the empirical approach.

9. CONCLUSIONS

An empirical approach to designing command gestures for handheld devices usually requires considerable resources such as subjects and experiment time. The analytical approach proposed in this study was more efficient to create command gestures. Because several designers can make various gestures easily, this approach can replace the empirical approach when resources such as people and time are limited.

The proposed methodology was able to create comprehensive gestures based on the systematic framework. The framework consists of gesture features and gesture elements, and the two attributes provided various examples for designers. The gesture features were very useful to extract draft ideas before creating gestures, and the gesture elements helped designers to transform the features into multitouch gestures. The case study validated the effectiveness of the proposed methodology and indicates that it is practical to both expert and novice designers.

The methodology was developed for multitouch gestures of mobile devices. Nevertheless, the procedures and practical guidelines can also be applied to other devices such as tablet PCs and desktop PCs. Other devices may have different gesture elements and different usage patterns, but the development framework would be universally adaptable. Not only touch-based interfaces but also gesture-based interfaces are coming in the market. In-the-air gesture interfaces such as the Kinect, Leap Motion, and hand remote control of Smart TV are also required to be intuitive and natural. For the future studies, finding gesture vocabularies for these domains would be necessary though applying the proposed analytical approach.

A methodology for finding optimal gestures needs to be researched. An integrated methodology that combines both the empirical approach and the analytical approach would be a good alternative, because each approach has respective benefits. The empirical approach is effective at finding gestures that are easy to perform, whereas the analytical approach is good at finding gestures that match well with the task. If a methodology for evaluating appropriate gestures were also proposed, the optimal gestures that users prefer could be developed efficiently and objectively.

TABLE 11
Average Subjective Satisfaction Rating of the Gesture Candidates for Each Command Between Empirical and Analytical Approaches

	Good Match		Easy to Perform		Overall Satisfaction	
Command	Empirical	Analytical	Empirical	Analytical	Empirical	Analytical
Home	54.2	65.4	57.3	66.9	51.4	62.5
Forward	59.4	69.4	77.1	79.0	61.4	67.5
Backward	58.0	69.6	76.3	78.9	60.3	68.2
Stop	54.2	78.2	64.5	59.7	51.6	65.1
Find	70.8	76.6	62.3	58.0	63.3	65.8
Refresh	64.3	59.6	64.9	53.9	63.0	54.1
Top	71.9	64.4	82.9	77.4	75.2	68.6
Bottom	71.1	66.1	78.9	75.9	71.2	66.9
Close	71.5	65.8	72.2	64.2	68.1	61.9
Toggle	73.4	72.3	63.0	62.9	64.7	63.2
Menu	69.5	66.7	78.7	70.1	71.4	64.8

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