A Comparative Study of Tilt Gestures and Traditional Interface Navigation Techniques in Mobile Digital Libraries: Postprint

Authors: Li Yajie

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Abstract

[Purpose/Significance] By adopting high-performance interface navigation techniques, this study partially addresses the issues of low user interaction performance and poor user experience in the use of mobile digital libraries, aiming to improve the interaction performance, usability, and applicability to diverse usage scenarios of mobile digital libraries. [Method/Process] Using actual digital library resource location operations as experimental tasks, quantitative experiments were conducted to collect data on task completion time, accuracy, and participants' subjective evaluations between the adopted interface navigation technique and traditional navigation techniques during task completion; statistical analysis of the experimental data was performed using RM-ANOVA in SPSS 25. [Results/Conclusion] The adopted interface navigation technique demonstrated a 68% improvement in experimental task completion efficiency and a 29% improvement in accuracy compared to traditional navigation techniques; it was also significantly superior to traditional techniques in terms of participants' reported subjective preference and eye fatigue; the adopted technique supports single-handed operation and 'blind operation,' enabling better adaptation to the diverse usage scenarios of mobile digital libraries than traditional techniques.

Full Text

Preamble

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A Comparative Study of Tilting-Gesture-Based and Traditional Interfacial Navigation Techniques for Mobile Digital Libraries

Li Yajie
Library of Lanzhou University, Lanzhou 730000

Abstract

[**Purpose/Significance**] This study proposes an efficient interfacial navigation technique for mobile digital libraries (MDLs) to partially address the problems of low user interaction performance and poor user experience, thereby enhancing the interaction performance, usability, and applicability of MDLs to diverse usage scenarios. [**Method/Process**] Using actual digital library resource location operations as experimental tasks, a quantitative experiment was conducted to collect data on task completion time, accuracy, and subjective evaluations of the proposed and traditional navigation techniques. The experimental data were analyzed using repeated measures ANOVA (RM-ANOVA) in SPSS 25. [**Results/Conclusions**] Compared with traditional navigation techniques, the proposed technique improved task completion efficiency by 68% and accuracy by 29%. It also significantly outperformed traditional techniques in terms of subjective preference and eye fatigue reduction reported by participants. The proposed technique supports one-handed operation and "eyes-free" interaction, making it better adapted to the diverse application scenarios of MDLs.

Keywords: mobile digital libraries; digital libraries; mobile computing devices; interfacial navigation; interaction performance; tilting gesture

1. Introduction

Mobile digital libraries (MDLs), leveraging the portability of mobile computing devices, enable digital libraries (DLs) to be used in multiple application contexts, providing convenience for DL usage. However, in practice, MDLs are significantly inferior to typical web-based DLs in terms of usefulness, usability, and flow experience. MDLs have not been widely accepted like e-commerce mobile apps despite the widespread use of mobile devices. With continuous hardware advancements, modern mobile computing devices now surpass the desktop systems for which DLs were originally designed in terms of processing and storage capabilities. Nevertheless, the diverse usage scenarios of mobile devices dictate their portable and compact nature, and they typically lack conventional input devices such as keyboards and mice. The inherent characteristics of mobile computing devices determine that interaction methods suitable for them differ significantly from traditional desktop-based approaches. However, existing MDLs are essentially simplified versions of DLs designed for desktop computers, with interface designs that still follow patterns created for traditional desktop systems—clearly not fully suitable for mobile computing devices.

The primary factors affecting users' choice to adopt MDLs are human-computer interaction issues. Currently, the typical interaction mode for mobile devices is multi-touch, which universally suffers from finger occlusion of interface content and insufficient operational precision—the "fat finger" problem. For small-sized mobile devices, these issues are even more pronounced than on general touch devices. Mobile computing devices are typically used in diverse scenarios where two-handed operation may be inconvenient, making one-handed operation necessary. Furthermore, "eyes-free" operation is safer when users are engaged in transportation. If such problems are not effectively addressed, they will inevitably impact MDL usage.

In the field of human-computer interaction, extensive and in-depth research has been conducted on interaction techniques for mobile computing devices in recent years. These studies consider the characteristics of mobile devices and the diversity of application scenarios, designing new technologies that leverage the unique potential of mobile computing devices and adapt to varied usage contexts, providing valuable references for MDL development.

In recent years, numerous scholars have begun focusing on the integration of MDLs and human-computer interaction. Most studies examine how different factors affect user interaction performance and experience when using DLs from an HCI perspective. When using MDLs, a critical operation is navigating from the homepage to required resources—namely, interfacial navigation operations. However, few studies have investigated specific interfacial navigation techniques in MDLs.

This study adopts an interfacial navigation technique suitable for MDLs that can handle diverse application scenarios and exploit the unique interaction potential of devices. Through quantitative experiments comparing this technique with existing DL navigation techniques, the high efficiency of the proposed technique is validated.

The significance of this research lies in: (1) For MDL applications, the proposed tilting-gesture-based navigation technique demonstrates higher interaction performance and navigation accuracy than traditional techniques, can adapt to diverse MDL application scenarios, and reduces potential safety risks during MDL usage; (2) By applying cutting-edge HCI techniques to MDLs, this study aims to draw domestic peers' attention to this research direction.

2. Related Research

This study relates to three research areas: mobile digital libraries, interfacial navigation techniques for mobile computing devices, and HCI research on digital libraries or MDLs.

2.1 Mobile Digital Libraries

MDLs have become a hot research topic in library and information science in recent years. Related research can be broadly categorized into 13 aspects, with most studies focusing on four main areas: (1) Design and implementation methods for MDL system functions under different conditions or for specific functional modules; (2) Survey research on the development status of MDLs, typically employing longitudinal and comparative approaches to describe development trends and provide recommendations; (3) User-centered research investigating user needs and experiences to improve system quality; and (4) Personalized services for different user groups.

Beyond these four main areas, other issues have received attention: user authentication and service authorization, digital resource copyright protection, semantic and visual search, mobile reading technologies, resource sharing in mobile environments, technologies for special user groups (e.g., blind users), usage scenario comparisons, learning activities based on MDLs, and HCI research on MDLs.

2.2 Interfacial Navigation Techniques for Mobile Computing Devices

Marking menus, evolved from pie menus, map menu commands to specific directions in 2D space, thus supporting "eyes-free" operation. For proficient users, marking menus do not require visual components on screen, making them suitable for small devices like mobile computers. Research has investigated compound vs. simple marking operations in cascading marking menus, their use on multi-touch interfaces, and 3D marking menus using gesture-capture cameras.

Smartphones and tablets can use tilt angles as basic input data through built-in sensors. Tilt angles have been applied to various interaction tasks: document scrolling, zooming, panning, screen orientation changes, menu navigation, target selection, and text input. Two mapping methods exist between tilt angle and controlled objects: position control and velocity control, with position control showing higher interaction performance. Studies show that people have good control over tilt angles for interaction tasks, whether spatially partitioned or divided according to ergonomic angles of the palm and forearm. Tilt angle input for HCI tasks is commonly called tilting gestures. Because users can distinguish different input ranges through proprioception without visual feedback, tilting gestures are independent of visual components and screen size, support "eyes-free" operation, and are well-suited for mobile computing devices with diverse usage scenarios. They also solve problems of hand occlusion and "fat finger" issues in touch interfaces while supporting one-handed operation.

Finger-counting menus have also been explored for rapid navigation on touch devices. By matching the number of fingers used for interaction with numeric labels of menu commands, finger-counting menus solve hand occlusion and "fat finger" problems since finger position on screen is unrestricted. Users can determine the number of extended fingers without visual confirmation, supporting "eyes-free" operation, though they do not support one-handed operation.

2.3 HCI Research on Digital Libraries

HCI research on DLs includes: (1) Studies on how different factors affect user interaction efficiency and experience, typically using questionnaires and statistical analysis; (2) Research on information display technologies for DL resources on specific devices; (3) Studies on HCI technologies for special populations; (4) Design and implementation frameworks for DLs from an HCI perspective; (5) Research on interaction between users and librarians or among users; and (6) Comparisons between MDLs and web-based DLs regarding usefulness, usability, interaction performance, and user preferences.

3. Comparative Experiment: Mobile Interface Technology vs. Traditional Navigation

3.1 Experiment Purpose

Based on literature review, tilting gestures were identified as best meeting the requirements of diverse MDL application scenarios and were selected as the interfacial navigation technique for this study. Using Lanzhou University Library as an example, this experiment compares the performance differences between traditional navigation and tilting-gesture-based navigation for locating DL resources. According to previous research, over 95% of users regularly use no more than four DL services, so the comparison focuses on locating resources for these four high-frequency services.

3.2 Equipment and Procedure

The experiment used a MI Max 2 smartphone running Android 7.1.1 with a Snapdragon 625 octa-core processor (max 2.0GHz), 4GB RAM, built-in gyroscope and other sensors, a 6.44-inch screen with 1920$×$1080 resolution.

First, the homepage of Lanzhou University DLs and the navigation pages for four high-frequency services identified in previous research were saved locally. JavaScript code was embedded to respond to page events, while experimental logic and data recording were implemented in Android code. JavaScript and Android were connected via JavaScriptInterface. The main experimental program was developed in Android Studio using Java, tested in an emulator, and installed on the experimental device. The program loaded saved DL pages via Android's embedded WebView, pseudo-randomly determined target resources for each trial, automatically recorded completion time and accuracy, and saved data locally as Excel files.

3.3 Participants

Twelve readers (9 male, 3 female) were randomly recruited from Lanzhou University Library. All were current students aged 22-32, right-handed, with over five years of smartphone experience familiar with touch, tilt, and gesture operations, but no prior "eyes-free" operation experience. The group included 3 undergraduates, 6 master's students, and 3 PhD students (one also a university teacher), representing the primary user group of university libraries.

3.4 Experimental Tasks

Participants performed navigation tasks under two conditions (walking and standing) using both tilting gestures and traditional navigation to locate webpages for "Electronic Resources," "Chinese Database List," "Foreign Language Database List," and "China CNKI Academic Database" (the four high-frequency services at Lanzhou University Library). In each condition, participants located 20 webpages from the target set, with proportions based on Baidu statistics from previous research.

For tilting-gesture navigation, participants started from a baseline phone position (back facing user, screen roughly horizontal with $ $10° angle to horizontal plane) and tilted the screen forward/backward/left/right. When the screen angle exceeded 30°, the WebView loaded a corresponding high-frequency service page. The two most frequently used resources were mapped to backward and rightward tilts (natural joint movements for left-handed phone holding), while the two least frequent were mapped to forward and leftward tilts (counter-natural movements). Returning to baseline reset the navigation.

For traditional navigation, participants held the phone in their non-dominant hand and used their dominant hand for interface adjustment and target selection. Each trial began with loading the library homepage and ended after completing the required number of link clicks. Resource navigation level was defined as the number of clicks needed from homepage to target page without backtracking. The navigation levels for the four resources are shown in Table 1
.

3.5 Experimental Procedure and Design

Before formal testing, each participant had approximately five minutes to familiarize themselves with the tasks through explanation, demonstration, and practice (practice data not recorded).

Twelve participants completed three blocks of tasks. Each block included 80 navigation operations: 2 navigation techniques × 2 movement states × 20 targets. The full experiment comprised 12 Subjects × 3 Blocks × 2 Techniques × 2 Movements × 20 Targets = 2,880 trials, lasting approximately 45 minutes per participant.

If a target was selected incorrectly, the phone played a warning tone and the target reappeared until correctly completed. Each participant received a printed list of target resources for each block matching the experimental program's order. The mapping between resources and tilt directions was also provided as a printed diagram. The order of the four technique-movement combinations was balanced across participants using a 4$×$4 Latin square.

After quantitative tasks, participants completed a subjective questionnaire rating eye fatigue, hand fatigue, and personal preference for both techniques on 7-point scales (1 = worst, 7 = best), plus an open-ended comment section.

The study tested 12 hypotheses regarding effects of Block, Technique, Movement, and Resource Level on completion time and accuracy, plus interaction effects.

3.6 Experimental Results

Data were preprocessed and analyzed using 3 Blocks × 2 Techniques × 2 Movements × 3 Resource Levels repeated measures ANOVA in SPSS.

3.6.1 Task Completion Time Analysis Sphericity tests passed except for Block×Movement×Resource Level ($^2(9) = 18.9$, $p < 0.05$).

(1) Main effect of Block. Block significantly affected completion time ($F(2,22) = 21.35$, $p < 0.0001$). Mean navigation time decreased from 7,800ms in Block 1 to 6,849ms in Block 2 and 6,515ms in Block 3. Post-hoc comparisons showed significant differences between Block 1 and Block 2 ($F(1,11) = 25.24$, $p < 0.0001$), but not between Block 2 and Block 3 ($F(1,11) = 2.34$, $p > 0.05$), indicating performance stabilized after the first block.

(2) Main effect of navigation technique. Technique had a highly significant effect ($F(1,11) = 4{,}239.28$, $p < 0.0001$). Tilting gestures (mean = 3,414ms) were substantially faster than traditional navigation (mean = 10,695ms), reducing resource location time dramatically.

(3) Main effect of movement state. Movement state significantly affected completion time ($F(1,11) = 110.78$, $p < 0.0001$). Walking (mean = 7,473ms) was slower than standing (mean = 6,636ms).

(4) Main effect of resource level and interaction with technique. Resource level significantly affected completion time ($F(2,22) = 360.34$, $p < 0.0001$). Mean times for levels 1, 2, and 3 were 4,157ms, 7,041ms, and 9,967ms respectively, with all pairwise differences significant.

The Technique×Resource Level interaction was significant ($F(2,22) = 326.35$, $p < 0.0001$). With tilting gestures, completion times were similar across levels (3,522ms, 3,386ms, 3,336ms). With traditional navigation, times increased dramatically with level (4,792ms, 10,696ms, 16,598ms) [Figure 7: see original paper].

(5) Technique×Movement interaction. This interaction was not significant ($F(1,11) = 2.86$, $p > 0.1$), contrary to hypothesis H6. The experimental design required participants to visually reference printed task lists, limiting the "eyes-free" advantage of tilting gestures.

3.6.2 Error Rate Analysis All sphericity tests were non-significant ($p > 0.05$).

(1) Main effect of Block. Block significantly affected accuracy ($F(2,22) = 20.14$, $p < 0.0001$). Error rates decreased from 4.3% (Block 1) to 2.5% (Block 2) to 1.9% (Block 3), with significant differences between Blocks 1 and 2 ($F(1,11) = 19.71$, $p = 0.001$) and Blocks 1 and 3.

(2) Main effect of navigation technique. Technique significantly affected error rates ($F(1,11) = 28.19$, $p < 0.0001$). Tilting gestures (mean = 2.4%) were more accurate than traditional navigation (mean = 3.4%). The Technique×Resource Level interaction [Figure 11: see original paper] revealed that for level 1 resources, accuracy was similar between techniques, but for levels 2 and 3, traditional navigation produced significantly higher error rates than tilting gestures. This occurs because traditional navigation accumulates errors across levels, while tilting gestures complete location in one step regardless of depth.

(3) Main effect of movement state. Movement significantly affected error rates ($F(1,11) = 42.92$, $p < 0.0001$). Walking produced higher errors (3.7%) than standing (2.1%), as participants had to attend to both the task and path.

(4) Main effect of resource level and interaction with technique. Resource level significantly affected error rates ($F(2,22) = 29.98$, $p < 0.0001$), with rates of 2.0%, 2.9%, and 3.7% for levels 1, 2, and 3 respectively. The Technique×Resource Level interaction was significant ($F(2,22) = 23.10$, $p < 0.0001$): tilting gesture accuracy was unaffected by resource level, while traditional navigation error rates increased significantly with level [Figure 11: see original paper].

(5) Technique×Movement interaction. This interaction was not significant ($F(1,11) = 1.15$, $p = 0.31$), similar to the time results [Figure 14: see original paper].

3.6.3 Subjective Survey Results Post-experiment questionnaires revealed:

Preference: Participants rated tilting gestures highly, finding them interesting and particularly useful when walking [Figure 15: see original paper].

Eye fatigue: Traditional navigation was perceived as causing significantly more eye strain, especially during walking when dividing attention between screen and path [Figure 16: see original paper].

Hand fatigue: Both techniques received moderate ratings for hand fatigue, with tilting gestures scoring slightly worse. Participants noted that continuous clicking or wrist rotation was tiring, but actual MDL use would involve less continuous navigation [Figure 17: see original paper].

4. Discussion and Conclusion

This study examined the operational performance of tilting-gesture-based navigation for real DL resource location. Compared with traditional navigation, the new technique demonstrated superior speed and accuracy. It also reduces safety risks when accessing DLs during transportation.

However, limitations exist. First, following HCI experimental design standards, all tests were conducted indoors for control and safety, differing from actual mobile usage contexts. Future research should incorporate real-world scenarios like bus travel when safe. Second, participants were all students/faculty—primary library users with good representation—but other user groups (e.g., elderly users) should be considered. Third, human control of tilt angles has limits, restricting the number of simultaneous navigation items.

Current MDL apps largely reformat traditional DL resources without fully exploiting mobile device capabilities or addressing inherent issues like one-handed operation, "fat finger" problems, hand occlusion, and safety. Interdisciplinary research combining HCI and MDLs deserves attention.

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Note: Figure translations are in progress. See original paper for figures.