Interface Design for Single-Handed Use of Small Devices

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ABSTRACT

Mobile devices are poised to become the world's most pervasive modern convenience, yet the technology and user distribution have advanced much faster than solutions for addressing the multitude of usability challenges inherent in portable computing. The concurrent trends of shrinking device forms and increasing feature sets *alone* compromise the ease and expressiveness of interaction and presentation, while at the same time, mobile environments place increased demands on users' mental and physical resources. Among the unique constraints of mobile computing, my thesis work focuses the *physical* demands of mobility, and in particular scenarios that find users with only one hand available. My research considers the challenge of one-handed device use from two perspectives: 1) *foundations* - investigating fundamental characteristics and limitations of single-thumb interaction with small devices; and 2) *applications* - using this knowledge in developing effective solutions for the input, access and management of information with a single hand.

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INTRODUCTION

With over 2 billion mobile phone subscriptions worldwide, and experts projecting over 1 billion annual unit sales in just 3 years [9], mobile phones may be the world's most widespread personal technology. To meet customer demand for portability and style, device manufacturers continually introduce smaller, sleeker profiles to the market. Meanwhile, advances in battery power, processing speed and memory allow these devices to come equipped with increasing numbers of functions, features, and applications. Unfortunately, placing more features on smaller devices is often at direct odds with usability: limiting device input and output capabilities while at the same time providing richer information content naturally makes devices harder to use. Mobile scenarios only compound the problem; the use environment may be unstable or lack a work surface, while situational circumstances make dynamic demands of users' mental and physical attentions [6]. These varied constraints of "using while moving" each present challenges for effective device design. My own work specifically considers situations in which mobile users have only a single hand available due to requirements for carrying personal effects, opening doors, holding handrails, and so on.

While interfaces that accommodate single-handed interaction can offer a significant benefit by freeing the other hand for high-attention mobile tasks, many devices are not well-suited for such use. Small, lightweight phones are often unfriendly to thumbs due to small buttons and crowded keypads. Larger, heavier PDAs require more physical effort to manage with a single hand. Additionally, their stylus-oriented touchscreens support rich presentation and interaction designs, but do so with targets that are too small or too distant for effective thumb interaction when the environment forbids two-handed stylus use. Yet mobile scenarios may require *any* handheld device to support one-handed interaction: even those designed predominantly for two-handed use. My work seeks to expand single handed device operation to an array of device types and tasks by considering both the theory and practice of thumb interaction.

I began my pursuit by developing empirically-backed *foundational* knowledge in user behavior, preference, thumb capabilities and interaction characteristics for single-handed device use. To this end I observed device use *in situ*, polled users about general and task-specific preferences for one-handed interaction, studied thumb agility in performing low-level tasks over devices of varying forms, explored the viability of gesture-based interaction, and investigated appropriate target sizes for thumb interaction on touchscreen-based devices. I then focused on *applications* of this knowledge for facilitating one-handed interaction with a range of device data. To date I have designed, developed, and evaluated single-handed interfaces to improve two specific data access tasks: navigating among device applications, and searching large data repositories. In the remainder of my thesis work, I will broaden my goal to enabling thumb control of the full-range of operations required for touchscreen interaction by offering a generalized

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approach for making feature-rich, stylus-oriented interfaces thumb-accessible.

FOUNDATIONS

As groundwork for informing single-handed mobile device design, I have conducted five studies to understand basic human factors involved in one-handed device operation: 1) a field study to explore the extent to which single-handed use is presently showing up "in the wild"; 2) a survey to record personal accounts of current and preferred usage patterns; 3) an empirical study of thumb tapping speed to capture the influence of device size, target location, and movement direction on task performance; 4) a quantitative evaluation of the learnabilty and executability of touch-screen-based gestures; and 5) an empirical study to determine appropriate target sizes for thumb-oriented touch-screen designs.

Field Study

My interest in one-handed device design was inspired by my intuition that one-handed operation is already widespread, and not limited to a niche user segment. And yet it seemed clear that device designs were becoming increasingly unfriendly to thumbs. To motivate my work in reversing this trend, I conducted an *in situ* study to capture actual user-device behavior. The study targeted an airport environment for the high potential of finding mobile users of devices and ease of access for unobtrusive observation. The main findings from observing 50 travelers confirmed that one handed phone interaction is quite common (74%) and that hand use patterns are likely influenced by both activity (walking, standing or sitting) and hand availability [3].

Web Survey

Shortcomings of the field study were that 1) it ignored user motivation for usage patterns; 2) the device types observed were limited to phones; and 3) the tasks types observed were limited to (presumed) dialing. To broaden my understanding of device use across these dimensions, I conducted a web survey to capture user perceptions of, preferences for and motivations surrounding their own device usage patterns. The data from 228 respondents complemented those of the previous study by showing phones were largely operated with one hand. The data also supported the common assumption that users most often operate PDA devices with two hands. However, the finding that both types of user expressed interest in using one hand more often than currently practiced suggests both device styles could be improved for supporting one-handed scenarios [3].

Thumb Movement

Although input technologies and device forms will come and go, the biomechanical constraints of the thumb will persist. While the thumb has an impressive range of motion, it is most adapted for grasping activities in which it opposes the other four fingers. Thumb-based device interaction, however, typically involves pressing on a plane parallel to the palm, introducing unnatural movement and exertion requirements for the thumb. My goal therefore was to understand how device form and user task influence thumb mobility, and to use the findings as a guide for placing interaction targets in one-handed interface designs.

In designing a study to meet this goal, I hypothesized that the difficulty of a tapping task would depend on device size, thumb movement direction, and the surface interaction location. To test this intuition, I identified four common devices of varying size and shape (small candy bar phone, flip phone, large candy bar phone, and PDA), and created 3D plaster models of each to remove superficial design features that might bias results. I asked users to perform reciprocal tapping tasks between pairs of regions on each device (regions are shown in Figure 1) while a 3D motion capture system recorded thumb trajectories.

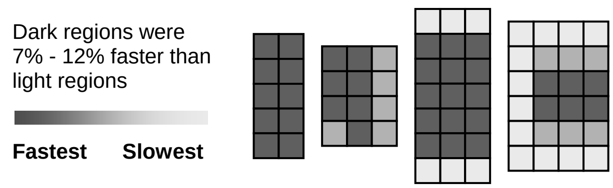

Figure 2. Tap speed by device region (devices from left to right: small candy bar phone, flip phone, large candy bar phone, and PDA).

Performance results suggested participants (n = 20, all right-handed) were able to interact with all regions of small devices with ease, but as devices grew in size, the location of interaction impacted both perceived difficulty and task performance (Figure 1). Additionally, thumb movement along the ⤡ diagonal direction was slower than for the other directions (⤢,↕,↔), suggesting a biomechanical constraint for that type of movement. A final analysis of performance across devices revealed that task times were indistinguishable within the lower-right 3x4 sub-region of the three largest devices, but that performance times degraded outside this area. This suggests devices are at a disadvantage when interaction is required beyond comfortable thumb reach.

Thumb Gestures for Touchscreens

While the goal of the thumb movement study was to quantify the effects of device and task characteristics on tapping performance in a static environment, precise targeting can be difficult for mobile users because of dynamic and unstable use environments. Single-handed use scenarios only compound the problem. Since gesture-based interaction often eliminates the requirement for precision aiming, it is an attractive complement to traditional input methods for mobile interaction.

To investigate the viability of gestures for touchscreen input, I developed two gesture-based interaction strategies for one-handed PDA operation [4]. The first approach featured large thumb-sized targets that were either directly accessible or which could be dragged within reach. For the second approach, I developed a simple gesture language which mapped thumb sweeps on the touchscreen to input commands - used to indirectly control an on-screen cursor and perform actions on objects. Each gesture in the language was uniquely defined by a slope and direction, so that each could be issued anywhere on the surface of the screen, and across any distance greater than 0.5 cm.

To understand the learnability and adoption potential for this second gesture type, I conducted an empirical study to capture user accuracy and timing performance during gesture recall and navigation tasks. I found that users (n = 20) were fastest and most accurate when a gesture had a strong semantic relationships to its associated command, as was the case for gestures UP, DOWN, LEFT, and RIGHT, which moved the cursor up, down, left and right, respectively.

Touchscreen Target Sizes for Thumbs

Another input challenge for single-handed computing is that current touchscreen interfaces are composed of widgets similar in size and function to those featured on the desktop. While typical widget dimensions are suitably large for stylus-based interaction, they are often considerably smaller than the average thumb pad in at least one dimension. This size disparity makes reliable target access difficult, if not impossible. Previous studies have suggested appropriate target sizes for mobile stylus interaction [7], and finger-based desktop use [1], but these results cannot account for the larger size of thumbs, nor the mechanical constraints of holding a device with the same hand used for interaction.

To offer guidelines for building thumb-based touchscreen interfaces, I designed a study to determine target size requirements for single and multi-target tasks. The results suggest targets 9.6 mm^2 provided a good balance between accuracy and preference for both types of task [8].

APPLICATIONS

Drawing upon the findings from these foundational studies, my goal has been to explore how the results apply in practice. Inspired by the increasing volumes of data available both on and from mobile devices, I have focused on single handed designs for two specific data access tasks: 1) navigating among device applications on a PDA and 2) searching large data sets from a mobile phone.

Application Navigation on PDAs

With advances in processing speed, memory and storage space, mobile devices are able to host larger numbers of applications. Supporting efficient navigation among these applications will help ensure the increased feature set does not compromise overall functionality and user satisfaction. Together with Microsoft Research, I explored how this issue might be addressed for single-handed use scenarios. We developed two alternative designs for a device manager that supported fluid, lightweight access to local applications (Figure 2), and conducted a comparative evaluation to capture user preferences and usability issues.

The two designs - LaunchTile and AppLens (Figure 2) - differed in the number of applications managed, the gesture styles supported, and the approaches used to maintain context during navigation. LaunchTile ensures that all interface objects are large enough for direct thumb interaction. To access distant objects, users can drag objects closer, and pure, animated zooming allows users to vary the visual context and application detail. In AppLens, command gestures control a cursor for accessing out-of-reach objects, while fisheye distortion provides high-level context for non-focused applications. The LaunchTile prototype used in our study managed 36 applications, while the AppLens prototype instead managed only 9. Both prototypes were architected to adapt to varying screen resolutions, aspect ratios, and input technologies, and were demonstrated for both a keypad-based Smartphone and touchscreen-based PDA.

Figure 2. LauchTile (top) and AppLens (bottom).

Results from our formative study of the two interfaces found users were receptive to both interfaces, but preferred direct tapping to the gestures supported in each design [4].

Accessing Large Data Sets on a Mobile Phone

While efficient access to personal data is essential, devices increasingly access large unfamiliar data sets. Finding relevant data in these repositories is commonly supported through ad-hoc keyword search. This has proven an effective model for desktop computing, but text entry is a tedious endeavor when using virtual touchscreen keyboards and phone keypads. An alternative approach for desktop search, however, holds more promise. Hearst et al. [2] have demonstrated the use of data attributes (metadata) organized into orthogonal dimensions (facets) as a method to guide query formulation and meaningfully structure results. As an intern at Microsoft Research during the summer of

2005 I investigated the viability of facet-based navigation for mobile search. FaThumb ("*fathom*") is a keypad-driven, compact query interface for browsing and searching large data sets from a Smartphone [5]. FaThumb dynamically filters search results as users iteratively navigate hierarchical faceted metadata; results may be further narrowed using incremental text entry. FaThumb is designed as a general solution for searching large data sets; our research prototype provided access to 38,000 Yellow Pages listings.

Our evaluation of FaThumb focused on the potential advantage of facet navigation over text-based methods for mobile search. We found users were significantly faster performing browse-type queries using facet navigation than using text entry, and facet navigation was much preferred overall.

PROPOSED WORK

Generalized One-Handed Application Interaction

My investigation of thumb movement has demonstrated that users do not interact with all areas of a device with equal facility, and that the regions which offer comfortable interaction vary from user to user and from device to device. In addition, I have found in my own experience and through the observation of study participants, that device users can adapt their grip to accommodate localized movement over most areas of a device, but that device control decreases dramatically with increased movement distance when the interaction area lies outside the user's comfort zone.

One solution for supporting single-handed device use, therefore, might be to cluster interaction objects within an easily reachable, compact area of the device surface. The numeric keypads of mobile phones are a good example of this approach. However, with their larger forms and richer interface designs, imposing such restrictions on PDAs would remove many of the advantages they currently offer over keypad-based mobile phones. Furthermore, when two hands *are* available, such limitations in design would unfairly restrict input efficiency. Thus, instead of studying clustering, I will investigate an interaction technique that extends the accessibility of rich stylus-based PDA interfaces to the limited motion range and noisy input of the thumb. In so doing, PDA interfaces can continue to take advantage of the available display real estate for presentation and interaction, and at the same time support one-handed scenarios.

The solution I propose is inspired by observing that tabletop and wall-sized displays both confront issues with out-of reach interface objects. In recent years, several techniques have been developed for improving access to distant objects on large displays. I believe elements of these solutions can be effectively adapted for one-handed thumb-based touchscreen interaction, which today is a challenge because interaction objects are often too distant or too small to be hit reliably with the thumb.

RESEARCH CONTRIBUTIONS

In total, my work will advance the foundations of single-handed mobile computing by: 1a) motivating the importance of single handed designs with reports of current usage patterns and preferences for one- and two-handed mobile device interaction, and by 1b) providing researchers and practitioners with ergonomic, empirically-backed guidelines for the size and placement of interaction targets intended for thumb-based interaction on keypad and touchscreen-based devices. Second, my work will advance applications of these foundations by: 2a) inspiring novel device-management designs for small screens based on fluid context switching, rich adaptive application representations, and device independence; by 2b) offering a novel single-handed solution for searching large data sets from a mobile phone without the need for cumbersome text entry; and by 2c) developing a generalized one-handed approach for interacting with rich, stylus-oriented touchscreen applications.

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