Toward Motor-Intuitive Interaction Primitives for Touchless Interfaces

Debaleena Chattopadhyay
Human-Centered Computing Department
School of Informatics and Computing
Indiana University
535 W. Michigan Street
Indianapolis, IN 46202, USA
debchatt@iupui.edu

ITS '15, November 15-18, 2015, Funchal, Portugal
ACM 978-1-4503-3899-8/15/11.
http://dx.doi.org/10.1145/2817721.2820985

Abstract
To design intuitive, interactive systems in various domains, such as health, entertainment, or smart cities, researchers are exploring touchless interaction. Touchless systems allow individuals to interact without any input device—using freehand gestures in midair. Gesture-elicitation studies focus on generating user-defined interface controls to design touchless systems. Interface controls, however, are composed of primary units called interaction primitives—which remain little explored. For example, what touchless primitives are motor-intuitive and can unconsciously use our pre-existing sensorimotor knowledge (such as visual perception or motor skills)? Drawing on the disciplines of cognitive science and motor behavior, my research aims to understand the perceptual and motor factors in touchless interaction with 2D user interfaces (2D UIs). I then aim to apply this knowledge to design a set of touchless interface controls for large displays.

Author Keywords
Gesture-based interfaces; novel interaction techniques; touchless interaction; motor-intuitive interaction.

ACM Classification Keywords
H.5.2 [User Interfaces]: Interaction Styles; Theory and Methods

Introduction

Touchless interfaces allow individuals to interact with systems using freehand gestures in midair. Because touchless controls can draw on gestures that are commonly used in everyday life, touchless interactions are deemed 'natural' and characterized as Natural User Interfaces (NUI) [16]. NUIs promise to employ users' prior knowledge and to relieve them from orienting toward an input device for an interaction. This potential has prompted the emergence of touchless systems in various domains that involve sporadic and coarse-grained interactions—such as entertainment [12], health [13], visualization [6], or collaboration [1].

To fulfill the promise of naturalness, touchless system design—still in its early stages—is either exploring user-focused gesture-elicitation studies [12] or system-focused interaction techniques [8]. Both of these approaches seek intuitive touchless controls, but user studies found that certain interactions—that were earlier described as suitable or were effectively supported by the system—were difficult to perform during evaluation or perceived less effective [8, 12]. I argue that to explain these limitations, we need to investigate touchless interaction *primitives*, the basic units that constitute an interface control [16]. Thus, instead of assuming that our familiarity with everyday gestures in the physical world directly translates into our ability to perform those exact gestures in touchless interfaces, we need to examine what makes a touchless primitive motor-intuitive. Or which primitives allow unconscious application of our pre-existing sensorimotor knowledge (e.g., visual perception or motor skills) during touchless interactions?

Toward designing easy-to-use touchless interfaces, the goal of my research is to understand motor-intuitiveness of touchless primitives [5]. In interaction design, primitives sit right in the middle of system-recognized actions and interface controls [16]; a proper subset of what is actually recognized by a system makes up a set of primitives, which is then expanded into a larger set of controls (Figure 1, right). Thus, my research complements the ongoing pursuit of user-defined touchless interface controls and system-focused recognizable gestures. Specifically, (a) I investigate perceptual and motor factors in touchless interaction with 2D UIs while drawing on the disciplines of cognitive science and motor behavior. With this knowledge, (b) I then aim to design a set of interface controls for touchless interaction with large displays.

Background

Touchless Interaction

To design intuitive touchless systems, elicitation studies seek to identify interface controls that are based on everyday metaphors, such as preference for a 'wiping' hand movement over a static hand sign to trigger a 'delete' action [7]. On the other hand, system-focused studies design interface controls drawing on mouse, pen, or touch interfaces [8], or based on sensor capabilities [1]. However, when interaction controls—designed by either of these approaches—are evaluated, some are found to be less effective. While such findings are common [8, 12], these interaction limitations are little understood. Exploring touchless interaction primitives, the building blocks of interface controls, may explain the sensorimotor factors that affect user performance in touchless systems.

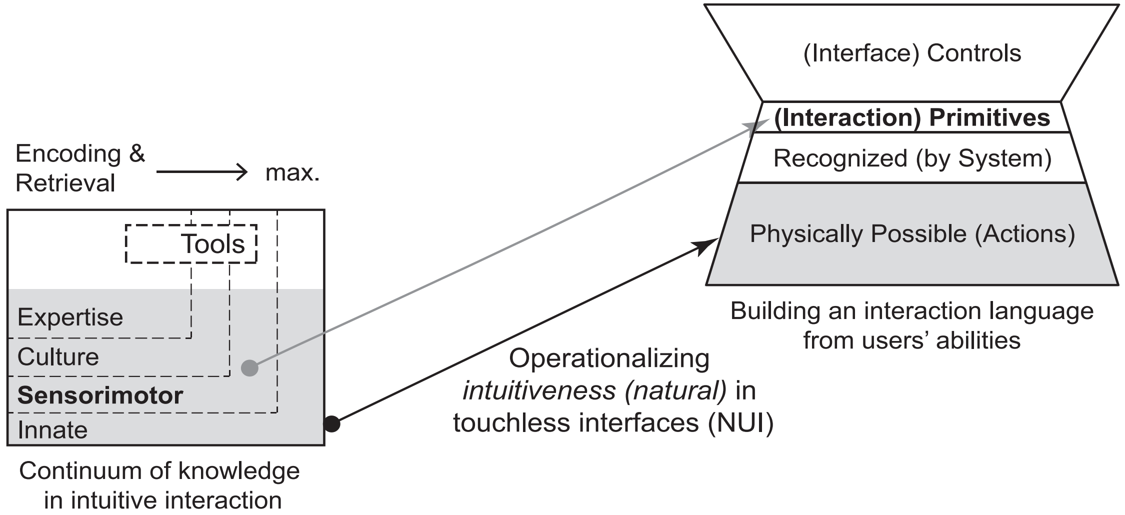

Figure 1: Interface controls often constitute of basic units called interaction primitives (right, [16]). We argue that the intuitiveness of touchless interaction primitives (and thus of a touchless interface) can be classified using the continuum of knowledge in intuitive interaction (left, [9]). For example, gestural controls building upon sensorimotor knowledge would be more intuitive than those drawing upon expertise. To illustrate this, we designed and evaluated a touchless interaction primitive (mid-air, directional strokes) that draws on our sensorimotor level of knowledge (image schemas, more specifically the up–down and the left–right space schemas) [5] (© 2015 Oxford University Press, reprinted with permission).

Role of Perceptual Factors in Touchless Interaction

Touchless gestures lack haptic feedback, thus solely depending upon visual feedback and proprioception. Although auditory feedback for mid-air gestures have been explored, their role in providing guidance also remains unclear. Because of this lack of guidance, touchless gestures are less efficient and more fatiguing than device-based gestures (e.g., touch or gyro mouse). Specifically, in touchless interaction with distant 2D displays, the 3D input space and the 2D display space are decoupled. Because of this decoupling, users need to mentally couple their actions and the feedback on the display—thus making the stimulus-response compatibility difficult. Thus, although touchless gestures can—in theory—draw on our daily-life gestures, interacting with a 2D interface generates a perceptual situation unlike how seeing and acting is related in our familiar 3D world. Because, in daily life, actions and feedback both occur in 3D space and are tightly coupled. I argue that because of this mismatch between visual perception (a 2D UI) and motor action (3D input), psychological principles affecting visual perception will affect touchless interactions [4].

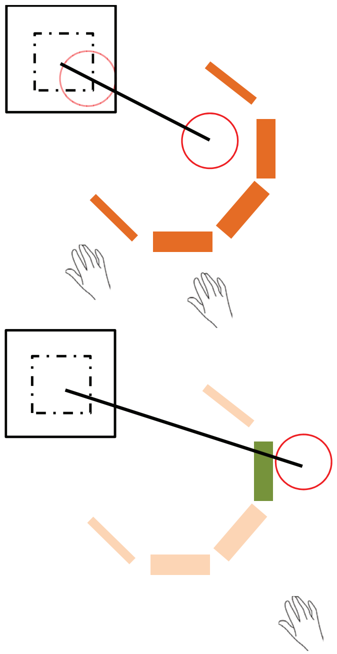

Figure 2: To illustrate motor-intuitive touchless interaction primitives, we designed Touchless Circular Menus (TCM). With TCM, users do not need to comply strictly with system-defined postures, such as a pinch or a fist, but could select commands by making directional strokes in mid-air. Compared with contextual linear menus with grab gestures, TCM were more than two times faster in selecting commands and caused overall lower workload. However, TCMs were less accurate than the static gesture grab [2].

Role of Motor Factors in Touchless Interaction
Apart from the effect of visual feedback in motor control and motor learning, other psychological factors such as grouping or holism may also affect touchless interactions with 2D interfaces. For example, recent research has shown that four fundamental Gestalt principles [15] in perception also apply to the control of motor action—holism, constancy, mutual exclusivity, and grouping in apparent motion [10]. Indeed, gestures following the Law of Pragnanz [15] were found to be more efficient than gestures without meaningful chunking [10]. Furthermore, exploring the user performance of touchless interactions in preferred and non-preferred hands could inform the design of bimanual touchless interfaces [8].

In summary, interacting with a 2D surface (that lacks a 3D worldview) using 3D freehand gestures is unlike gesturing in a 3D world. Thus, to effectively design touchless interfaces, it is crucial to understand the perceptual and motor factors at play.

Understanding Perceptual and Motor Factors in Touchless Interactions

My preliminary studies on touchless interfaces spun off the Wall Display Experience Research—which explores novel interaction techniques and technologies for collocated collaboration around large displays. Specifically, for the last three years, I have explored ways in which we can draw on our motor and cognitive abilities to effectively design touchless interfaces. For example, grounded in prior findings of how visual cues affect motor learning and motor control, I studied visual feedback in touchless interactions; by drawing upon our sensorimotor level of knowledge, such as image schemas, I proposed motor-intuitive interaction primitives [5]. Then, building upon these prior works, I designed a command selection technique (Touchless Circular Menus, [2]) and a feedback language for touchless interfaces (fusing pseudo-haptic and visual feedback [3]). Moving forward, in the spirit of use-inspired basic research—in my dissertation—I am assimilating (1) the broader implications of cognitive theories in touchless interactions (e.g., Gestalt theories [4]) and (2) understanding how these findings can be applied toward designing touchless interaction with 2D UIs (e.g., large displays).

Theoretical explorations of my research is largely complete, and currently I am focusing on using the perceptual and motor factors—that were uncovered during my preliminary research—to design interaction techniques and UI components for large-display touchless interfaces. By participating in this doctoral symposium, I aim to garner feedback from senior researchers and peers about how can I translate these basic research findings effectively into touchless interface design. In what follows, I briefly describe some of the key perceptual and motor factors that I explored in my prior work, and where applicable, the interaction techniques designed based on them.

Image Schemas. In pursuit of intuitive touchless gestures, we proposed motor-intuitive interactions: interactions that unconsciously draw on our pre-existing sensorimotor knowledge, such as basic movements like pulling, pushing, moving up or down. Such movements are based on image schemas like up-down or near-far [5]. Instead of using system-defined postures as interface controls, we then proposed using

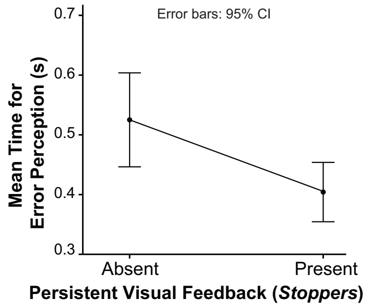

Figure 3: When users' gestures went out of the display range, persistent visual feedback improved users' recovery efficiency, because lack of visual feedback was often perceived as a system error.

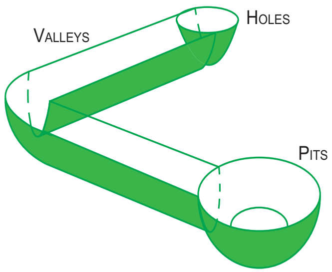

Figure 4: Topography primitives (e.g., holes, valleys, or pits) operate as virtual surfaces that overlay on an interface and modify cursor movements to improve the precision of touchless interactions.

motor-intuitive interaction primitives to build UI components, like Touchless Circular Menus (TCM, [2], Figure 2). We found that users were more efficient with TCM compared with the grab-based linear menus and perceived less workload, but TCM lacked interaction precision.

Perceptual and Motor Gestalt. While exploring touchless interaction precision, we observed that UI elements demonstrating Gestalt principles of perceptual grouping, such as similarity of orientation decreased efficiency, but continuity of UI elements that formed a perceptual whole increased accuracy[4]. Also, following the motor gestalt [10], users often made holistic gestures that minimized energy expenditure [4, 5].

User Feedback. Continuous visual feedback played a crucial role: We found that users perceive lack of visual cues as system errors and slow down. Similar to findings in motor literature, persistent visual feedback (Figure 3) and terminal visual feedback improved user performance. To further improve touchless accuracy, we modified the control-display gain, generated a virtual topography (e.g., holes, valleys, and pits), and provided pseudo-haptic feedback [3] (Figure 4). Results found that interface topographies increased accuracy in difficult steering tasks.

An advantage of the non-dominant hand. Prior research exploring lateral asymmetries in input devices found support for the theory that dominant and non-dominant hands primarily differ in their use of sensory feedback control [10]: Right-handed individuals possess a right-hand superiority for sequential processing of feedback and a left-hand superiority for open-loop, parallel processing. Echoing previous work, our preliminary results suggest that the lack of haptic feedback in touchless interactions facilitates open-loop processing (or pre-planned motor plans). For example, users were far more accurate with longer directional strokes than shorter strokes as longer mid-air strokes require preplanning but shorter strokes primarily depend on sequential processing of feedback (Figure 5, [5]). Similarly, right-handed users were more accurate in touchless steering with left hand than right hand (in a difficult, circular steering-targeting task, Figure 6).

The Next Steps

A central premise of my research is that interface controls are made up of interaction primitives and designing intuitive touchless interfaces would thus require intuitive touchless primitives. This largely assumes that as touchless interface design matures, it will mirror the compositional nature of GUIs. However, an alternative to an additive approach would be to design semantic interactions that are task-oriented, such as gesture sets suggested for touch interfaces [14]. Nevertheless, my research findings could still inform such use-centric design of touchless interfaces.

As a possible user scenario, I am interested in applying my findings into designing touchless interfaces for large display interaction—specifically during collocated collaboration [1] and information visualization [6]. However, interacting with large displays is not a monolithic experience—users may simply brainstorm and use coarse-grained gestures sporadically, or engage in fine-grained, frequent actions, such as collaborative text-editing. While the former kind of interactions would benefit from touchless gestures that relieve users from tethering to devices and allow more

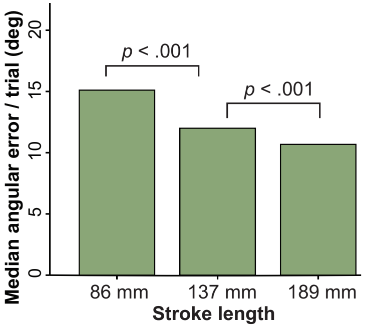

Figure 5: Stroke length significantly affected the angular error of mid-air strokes, $p < 0.001$. Interestingly, participants made significantly less angular error with increase in stroke length, $p < 0.001$.

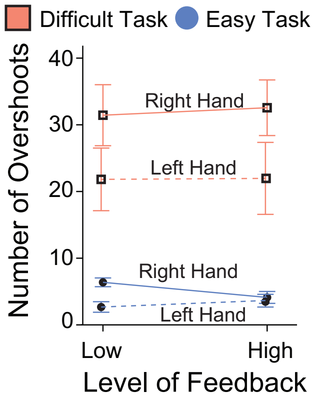

Figure 6: In a difficult circular steering task, right-handed users were more accurate with left than right hand.

spatial mobility, the fine-grained interactions would be more befitting for other interaction modalities (e.g., tablets, tangible controllers, etc.). So, I would like to understand the use-cases in large-display interaction to explore how some of these scenarios can be supported with touchless interaction techniques and what are some of the major interaction challenges in doing so.

Acknowledgements

I would like to thank my advisor Davide Bolchini for his guidance and UITS AVL for the use of their facilities. This research was partially funded by an IUPUI RSFG.

References

1. Bragdon, A., et al. (2011). Code space: touch+ air gesture hybrid interactions for supporting developer meetings. *Proc*. *ITS*, 212–221, ACM.
2. Chattopadhyay, D., et al. (2014). Touchless circular menus: Toward an intuitive UI for touchless interactions with large displays. *Proc. AVI*, 33–40, ACM.
3. Chattopadhyay, D., Achmiz, S., et al. (2014). Holes, pits, and valleys: Guiding large-display touchless interactions with data-morphed topographies. *Adjunct Proc*. *UbiComp*, 19–22, ACM.
4. Chattopadhyay, D. (2015). Exploring Perceptual and Motor Gestalt in Touchless Interactions with Distant Displays. *Proc*. *TEI*, 433–436.
5. Chattopadhyay, D., et al. (2015). Motor-intuitive interactions based on image schemas: Aligning touchless interaction primitives with human sensorimotor abilities. *IWC*, *27*(3), 327–343.
6. Dostal, J., et al. (2014). SpiderEyes: Designing attention-and proximity-aware collaborative interfaces for wall-sized displays. *Proc*. *IUI*, 143–152, ACM.
7. Grandhi, S. A., Joue, G. and Mittelberg, I. (2011) Understanding naturalness and intuitiveness in gesture production: insights for touchless gestural interfaces. *Proc*. *CHI*, 821–824, ACM.
8. Guimbretière, F., et al. (2012). Bimanual marking menu for near surface interactions. *Proc. CHI,* 825–828, ACM.
9. Hurtienne, J., & Israel, J. H. (2007). Image schemas and their metaphorical extensions: intuitive patterns for tangible interaction. *Proc. TEI*, 127–134, ACM.
10. Kabbash, P., et al. (1993). Human performance using computer input devices in the preferred and non-preferred hands. *Proc. CHI*, 474–481, ACM.
11. Klapp, S. T., & Jagacinski, R. J. (2011). Gestalt principles in the control of motor action. *Psychological bulletin, 137*(3), 443.
12. Nebeling, M., et al. (2014). Web on the Wall Reloaded: Implementation, Replication and Refinement of User-Defined Interaction Sets. *Proc. ITS,* 15–24, ACM.
13. O'hara, K., et al. (2013). On the naturalness of touchless: putting the "interaction" back into NUI. *TOCHI*, *20*(1), 5.
14. Schmidt, S., Nacenta, M. A., Dachselt, R., & Carpendale, S. (2010). A set of multi-touch graph interaction techniques. *Proc. ITS,* 113–116, ACM.
15. Wagemans, J., Elder, J. H., et al. (2012). A century of Gestalt psychology in visual perception: I. Perceptual grouping and figure–ground organization. *Psychological bulletin*, *138*(6), 1172.
16. Wigdor, D. and Wixon, D. (2011). *Brave NUI World: Designing Natural User Interfaces for Touch and Gesture.* Morgan Kauffman, Burlington, MA.