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A framework for bimanual inter-device interactions ☆

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ABSTRACT

A shared interactive display (e.g., a tabletop) provides a large space for collaborative interactions. However, a public display lacks a private space for accessing sensitive information. On the other hand, a mobile device offers a private display and a variety of modalities for personal applications, but it is limited by a small screen. We have developed a framework that supports fluid and seamless interactions among a tabletop and multiple mobile devices. This framework can continuously track each user's action (e.g., hand movements or gestures) on top of a tabletop and then automatically generate a unique personal interface on an associated mobile device. This type of inter-device interactions integrates a collaborative workspace (i.e., a tabletop) and a private area (i.e., a mobile device) with multimodal feedback. To support this interaction style, an event-driven architecture is applied to implement the framework on the Microsoft PixelSense tabletop. This framework hides the details of user tracking and inter-device communications. Thus, interface designers can focus on the development of domain-specific interactions by mapping user's actions on a tabletop to a personal interface on his/her mobile device. The results from two different studies justify the usability of the proposed interaction.

1. Introduction

The benefits of tabletop-based applications have been investigated in different scenarios, such as collaboration [3] or pedestrian navigation [21]. However, it is hard to protect personal information on a tabletop. In addition, a public environment limits the usage of some modalities. For example, the usability of auditory feedback through a speaker is reduced in a noisy public environment. While a mobile device provides diverse multimodal feedback, it is limited by its small screen which makes it frustrating to browse large sets of information.

Therefore, a synergistic interaction with mobiles and tabletops integrates their merits. While previous studies have explored the benefits of combining mobile devices and a large display together (e.g., a fluent switch between individual and group work [32]), one challenge in inter-device interactions is to minimize distractions when switching between devices. Another challenge is to develop a generic solution that is suitable for various scenarios and applications. Although different techniques have been developed to support interactions in a multi-device ecology [10,19], few researchers have focused on developing a generic platform that supports a variety of applications. Recently, based on PhoneTouch [29], Schmidt et al. [31] developed a generic platform supporting a novel interaction style that fits different applications. This interaction style is featured by pairing a phone touch event with the identity of the phone through an accelerometer.

In contrast to the PhoneTouch interaction style [31], our generic framework (hereinafter referred to as MobiSurf)

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supports a bimanual interaction style using a tangible object. Our approach uses a passive tangible object to perform coarse-grained selections on a tabletop while a mobile device is held by the dominant hand for fine-grained interactions. Based on the previous studies on the tangible interfaces [13,34], we proposed various gestures (e.g., "Pointer Rotate", "Pointer Move", and "Pointer Share") that enable a natural interaction with a tabletop device. The gesture of each user on the tabletop is detected and accordingly produces a unique personal interface with multimodal feedback on the associated mobile device. The MobiSurf framework is featured by a thin client on the mobile device, which is application-independent. In other words, during the development process, the client side, which encapsulates the functions of the interface generation and inter-device communications, is generic for different applications and does not need any revision. Such an implementation allows developers to focus only on application-specific developments by translating user gestures on a tabletop to appropriate messages on an associated mobile device (see Section 3). To evaluate the usability of MobiSurf, we conducted two empirical studies that utilized different designs. The first study compared the standard tabletop interface vs MobiSurf interface whereas the second study provided insights into usability and learnability through verbalization of thought process of users interacting with MobiSurf. The results from this study showed significant improvements in the usability when using the MobiSurf interaction style as compared to the standard interface and subjects found MobiSurf easy to use.

2. Related work

Researchers have explored the combination of mobile devices and tabletops to improve the usability for collaborative tasks, such as augmenting a computer with PDAs in the single display groupware [22] or exchanging information between a personal device and a public display [9]. This sections reviews techniques for user tracking and inter-device interactions.

2.1. User identification and tracking

Because a tabletop represents a public space, it is necessary to identify the users to protect their personal data. Various approaches have been proposed to pair a user's interactions on a tabletop with a unique ID, such as hand biometrics [30], utilizing the back of a user's hand as an identifier [26], infrared light pulses through a ring-like device [27], or using a tangible interface to authenticate users [34]. However, these approaches did not support direct data sharing between a public device and a personal one. Since most tabletop/mobile devices are equipped with a camera, the computer vision technique has been commonly used to associate a mobile device with a large display. For example, BlueTable [35] implemented a vision-based handshaking procedure by blinking an infrared light or flashing the display of a mobile device to establish a connection between a mobile device and a tabletop. Similarly, Schöning et al. [28] used the flashlight and Bluetooth unit of a mobile phone as a response channel to authenticate users. Ackad et al. [1] used the color detection to implement a handshaking protocol to identify a registered mobile device placed above a tabletop. This system also used a depth camera so that a user can continuously be tracked even if the device was removed from the tabletop. In addition, cameras were used in inter-device communications to replace radio-based techniques (e.g., WiFi or Bluetooth) for information exchange, such as FlashLight [11] or C-Blink [20].

Instead of using the computer vision technique, various approaches used gestures to associate a mobile device with a public display based on built-in sensors. Tilt correlation [12] compared the touch-derived tilt angle on a public display with the tilt sensor information from a mobile device to distinguish different mobile devices. Patel et al. [24] proposed a gesture-based authentication by shaking a device according to a required pattern. PhoneTouch [29] correlated the phone touch events detected by an interactive surface and by a mobile phone through an accelerometer to identify multiple mobile devices. The above sensor-based approaches used a mobile device for both the user identification and interaction. Consequently, a user cannot interact with the mobile device during the identification process. Instead, our approach introduces a tangible object for the user tracking so that the user tracking and interaction can be performed simultaneously.

Interacting with the computers using tangible objects has been widely studied. The pioneering work by Ishii and Ullmer [13] bridged the gap between a physical environment and a cyberspace through a tangible interface. Our approach uses a tangible object for tracing users' actions on a tabletop.

2.2. Inter-device interaction

A mobile device provided gesture-based interactions and multimodal feedback; thereby making it suitable for being a remote controller for inter-device interactions [18,19]. Several approaches leveraged a built-in camera to manipulate a remote object by directly touching or moving a mobile device, such as point & shoot for remote selection [2], camera-based pose estimation for remote operation [25], a privacy-respectful input method [16], snap and grab for sharing contextual multimedia contents [17], and touch projector for interacting with surrounding displays [4]. Alternatively, by using the accelerometer, movement-based gestures were developed for interacting with a distant display [6,33].

Instead of remotely manipulating visual objects in a distant display through a mobile device, some approaches required a direct contact between a mobile device and a public display for inter-device interactions, such as placing a mobile device above a tabletop during the entire duration of interactions [7,23], or freely moving a mobile device on top of a public display. Hardy and Rukzio [10] used an NFC mobile device as a stylus for interacting with an NFC-tagged display.

Although the above approaches supported mobile–tabletop interactions, they were not generic for supporting a variety of scenarios. Recently, Schmidt et al. [31]

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