MOBISURF: BIMANUAL INTER-DEVICE INTERACTION

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Title

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

A shared interactive display (i.e. tabletop) provides a large space for collaborative interaction. However, it lacks a private area for accessing sensitive information. On the other hand, a mobile device offers a variety of modalities for personal applications, but it is limited by a small screen. This paper develops a framework that enables fluid and seamless interaction between a tabletop and a mobile device, and thus integrates the merits of each. More specifically, the framework can continuously track multiple users' actions on top of a tabletop, and then automatically generate a unique personal interface on a mobile device for each user. Such an inter-device interaction supplements a collaborative workspace (i.e., a tabletop) with a private space (i.e., a mobile device) having diverse modalities. We conducted a user study, which compared our approach with a standard tabletop interface. The results are promising and justify the usability of the proposed approach.

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1. INTRODUCTION

Public displays (i.e., tabletops) provide a collaborative interface for multiple users and have broad applications in various environments, such as malls or hotels. The large screen and multi-touch capacity make a tabletop suitable for public applications that may involve multiple users. However, being a public communication channel makes tabletop hard to protect personal information. In addition, the application in a public environment can reduce the usability of some modalities. For example, auditory feedbacks through a speaker can be significantly limited by a noisy environment.

Mobile devices become more and more popular in our daily life. According to the International Telecommunication Union report, there were 6.8 billion mobile subscriptions at the end of 2012, which is equivalent to 96 percent of the world population. A mobile device, being a personal device, provides diverse modalities for personal applications. With the fast development of hardware on mobile devices, various approaches are proposed to personalize a mobile application to fit personal usages. However, a mobile device is limited by its small screen, which makes it frustrating to browse a large amount of information.

Synergistic interaction with mobiles and tabletops integrates their merits. Especially, equipped with various sensors, a mobile is ideal to be used as a tangible controller and provides feedbacks with diverse modalities. In a collaborative environment with inter-device interaction, one challenge is to contiguously track the identity of each mobile, and another challenge is to provide natural interaction that seamlessly integrates a mobile and a tabletop. Different techniques are developed to support interaction in a multi-device ecology, and the usability of mobile-tabletop interaction has been evaluated and justified [Mca11]. However, there is a lack of a generic platform that supports a variety of applications in a multi-device ecology. Recently, based on the PhoneTouch [Sch10a], Schmidt *et al.* [Sch12] 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 mobile through an accelerometer.

Different from the previous work [Sch12], this paper proposes a generic framework (called *MobiSurf*) that supports a bimanual interaction style. Our approach uses a passive tangible object[1] to perform coarse-grained selections on the tabletop while a mobile is hold by the dominant hand for fine-grained interaction. The framework is designed based on the observer pattern. More specifically, any user's action through a tangible object on a tabletop is detected, and accordingly triggers an interaction event. Using MobiSurf API, interaction events can be mapped to various messages, which generate a mobile interface or produces appropriate feedbacks on the mobile device. The MobiSurf framework is featured by a mobile thin client, which is not application independent. Such an implementation may speed up the development process, in which interface developers only need to focus on translating interaction events to commands on the mobile (see details in Section 3). To evaluate the usability of the proposed interaction style, a controlled empirical study has been conducted. In the study, participants are asked to complete two tasks using both a standard tabletop interface and the MobiSurf interface. The results from this study show significant improvements in the usability and protecting the privacy.

We introduced a bimanual interaction style using mobile device and passive tangible object[2] to improve the usability features of the tabletop interfaces. We also developed a generic component based on command and event based architecture, which enables application

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[2] Passive tangible object is made of inexpensive materials such as rubber or wood and does not include any hardware or electrical device.

developers easily integrate our introduced system into their tabletop applications. MobiSurf establishes a reliable two-way communication between user's mobile device and tabletop application. The MobiSurf component captures all user's activities on the tabletop interface and maps them to set of events, which can be handled in order to take proper reaction on the tabletop or the user's mobile device. A fully customizable command framework maps all commands to designated feedback on user's mobile device. User interacts with the mobile device with dominant hand, while non-dominant hand explores the tabletop interface using a pointer device (passive tangible object). To study the usability, user-friendliness and privacy of the presented approach, a set of small software programs has been developed and a controlled empirical study have been conducted which required the participant to do a set of tasks using the existing interfaces and the proposed MobiSurf interaction style. The results from this study show significant improvement in the usability, user-friendliness, and privacy of the proposed system over the traditional interaction styles.

In summary, our key contribution is to propose a flexible, usable interaction method for tabletops, which provides diverse modality and improves the privacy of the interface. Main advantages of our approach are summarized as follow:

Generalization - The developed system and proposed interaction methods can be used in many different tabletop applications. The system encapsulates all implementation complexities and provides a simple, easy to learn and use interface for developers.

Collaborative Interaction - The proposed interaction style enables multiple simultaneous users to interact with the tabletop interface and share various contents.

Privacy - Each user has his/her private channel to interact with the tabletop, which allows multiple simultaneous interactions on the tabletop (public interface) without interfering. The system utilizes the user's mobile device as a private interface to input sensitive information such as username and password as well as output private messages and feedbacks.

Simplicity - The system is compatible with different type of smartphone devices, which are available in the market. We also used a very simple object as pointer (without any hardware integration) to continuously identify multiple users on tabletop interface. In our prototype, we used a cubic shaped rubber as the pointer.

The remaining of the paper is organized as follows. Section 2 discusses related work. Section 3 describes our design goals. Section 4 overviews the system architecture. Section 5 discusses the interaction styles. Section 6 presents user evaluation. Section 7 is discussion of the results. Section 8, provide applications to the system, followed by conclusion in section 9.

2. RELATED WORK

Some pioneering work explored the combination of mobile devices and tabletops to improve the usability for collaborative tasks, such as augmenting a computer with PDAs in single display groupware [Mye01] or seamlessly exchanging information between a personal device and a public display [Gre99]. With the popularity of large screen devices and mobile devices, various studies are conducted to compare and evaluate interaction styles in a multi-device ecology [Kra10, Mca11]. In the following description, we discuss inter-device interaction from the perspectives of user identification/tracking and interaction.

2.1. User Identification and Tracking

Since a tabletop represents a public display, it is necessary to identify users to protect sensitive and personal data. Various approaches have been proposed to pair user's interaction on a tabletop with a user ID, such as a hand biometrics based approach [Sch10b] or using a tangible interface to authenticate users [Wie11]. However, the above approaches do not set up a direct connection between a public display and a mobile device for direct data sharing. Since most tabletops and mobile devices are equipped with a camera, computer vision is commonly used to associate a mobile device with a large display. For example, BlueTable [Wil07] implements a vision based handshaking procedure through blinking infrared light or flashing the display of a mobile device to establish the connection between a mobile device and a tabletop. Similarly, Schoning *et al.* [Sch08] used the flashlight and Bluetooth unit of a mobile phone as response channels to authenticate with a multi-touch surface. Ackad *et al.* [Ack12] used color detection to implement a handshaking protocol to identify a registered mobile device that is placed on top of a tabletop. Furthermore, this system uses a depth camera to pair a user with his/her personal device so that the touches of this user can continuously be tracked even if the device is removed from the tabletop.

Instead of using computer vision, various approaches use gestures to associate a mobile device with a public display based on built-in sensors. *Tilt correlation* [Hut11] compares 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.* [Pat04] proposed a gesture-based authentication by shaking a device with a required pattern that is detected through an accelerometer. PhoneTouch [Sch10a] correlated the phone touch event detected by an interactive surface and by a mobile phone through an accelerometer to identify multiple mobile devices.

Although most approaches use radio-based techniques (e.g., Wi-Fi or Bluetooth) to exchange data (e.g., a user ID) between a mobile device and a public display, optical signals have been used as an alternative communication mechanism, such as FlashLight [Hes10] or C-Blink [Miy04].

2.2. Inter-Device Interaction

A mobile device provides a broad range of feedbacks, and thus is suitable for being a tangible input and output device to perform inter-device interaction [Mca09, Mca11]. For example, several approaches leverage a built-in camera to operate a remote object through direct touches or hand movements of a mobile device, such as Point & Shoot for remote selection [Bal05], camera-based pose estimation for remote operation [Pea09], a privacy-respectful input method [Luc08], *snap and grab* for sharing contextual multi-media contents [Mau08] and *Touch Projector* for interacting with surrounding displays [Bor10]. By leveraging an accelerometer, mobile phone gestures are designed to interact naturally with large screens [Shi09, Dac09].

Techniques are developed to support inter-device interaction, based on a direct contact between a mobile device and a public display. Especially, some approaches require a mobile device being placed on top of a tabletop during the interaction [Ech09, Olw09]. Other approaches allow a mobile device to freely touch or move on a public display during the interaction. Hardy and Rukzio [Har08] used an NFC equipped mobile device as a stylus for interacting with an NFC-tagged display.

Though the above approaches propose various interaction styles for different inter-device tasks, it still lacks a generic framework for mobile-tabletop interaction that is suitable for a variety of tasks and applications. Recently, Schmidt *et al.* [Sch12] developed a generic platform for synergistic usages of mobile devices and tabletops. Built on the PhoneTouch [Sch10a] technique, this platform uses a mobile device as a stylus to manipulate objects on the tabletop and accordingly associates touch events with the identity of the mobile phone. Our framework is different with the above approach from the following perspectives. First, our approach implements a bimanual interaction, in which the non-dominant hand performs a coarse-grained selection through a tangible object while the dominant hand holds the mobile for a fine-grained interaction. According to Buxton et al. [Bux86], bimanual input outperformed one-handed input for selection, positioning, and navigation tasks. Furthermore, the bimanual interaction is capable of tracking the path of hand's movements on the tabletop and producing contiguous feedbacks on the mobile. Second, our framework implements a thin client, which is applicable to different application without modification. The implementation of a thin client allows interface developers to focus on mapping a user action on the tabletop to command(s) on the mobile, while the framework itself can automatically produce an interface on the mobile based on the defined mapping.

3. DESIGN GOALS

Considering the basic usability characteristics of tabletop devices as public multi-user collaborative interfaces and limitations to existing approaches, focused on improving the usability of them, we identified four main design goals for our project.

3.1. Collaborative Interaction

When designing tabletop interaction techniques, the solution must not violate the main characteristics of tabletop interaction experience. These important characteristics are multi-touch, multi-user, multi-direction, and intuitive interface.

3.2. Preserving Interface Standards (Consistency)

Consistency is one the important issues in user interface design [Nie94]. Users are familiar with standard UI elements and know how to use them. Solutions, which involve new UI designs, could violate the consistency of the user interface in many cases.

3.3. Privacy

Protecting private information is important to all users. There are serious concerns when user is intending to input sensitive information such as user name, password, or social security number on a public interface such as an information desk. When it comes to collaborative interaction, users tend to have full control over not only the content but also the sharing audiences [Gre99]. Users require secure interaction methods to interact with tabletop that provide them privacy.

3.4. Multimodal Interface

Many standards and design guidelines are available for designing public interfaces [Mag99, San10] and accessibility issues [Lee04]. It is important to consider public environment limitations such as high environmental noise level (interferes voice feedbacks) or shoulder surfing (interferes direct text input) and provide reliable inputs and output alternatives.

3.5. Generalization

Any design solution must consider flexibility and customizability. The proposed system must be flexible enough to be applicable to various tabletop application interfaces as well as different mobile devices. The proposed system must encapsulate implementation complexities and provide an easy to use interface for developer to integrate it, into their applications.

4. SYSTEM DESIGN AND ARCHITECTURE

Figure 1 illustrates the overall hardware components of the MobiSurf API. This system involves three main hardware parts. A tabletop device, pointing device, which we call it pointer and a mobile phone, which is typically, could be any smart phone, or tablet device. The pointer can be designed and built in various shapes, using different materials, based on usage and users need.

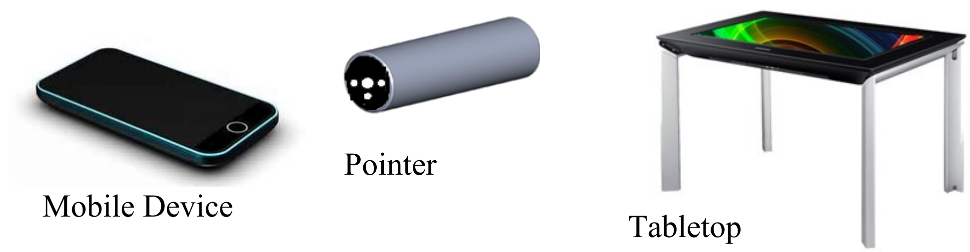

Figure 1 - System Components

4.1. System Design

One of the main aspects in designing the MobiSurf API was to provide multi-user interaction. A challenging issue in this area is to distinct different users actions on the tabletop display. We must provide a method to distinct multiple simultaneous interactions on the tabletop in a way that each user has his/her private interaction space while maintaining the collaborative interactions experience. The system must enable users to interaction with the application individually without interfere each other as well as interacting with other users. We studied the existing solutions to this issue. Schmidt proposed PhoneTouch [Sch10a], which is a synchronous timing approach using touch events time-stamp to identify individual user’s action on tabletop. An approach uses tilt correlation of the mobile device [Hut11] to distinct user’s interactions with the system. We noticed that these approaches not only increases the complexity of the system but also requires using the user's mobile device directly in touch with tabletop display which reduces the usability of mobile device as input, output device during the interaction.

Using infrared tags to track tangible objects on tabletops were practiced in various scenarios [Mag04, Ant09]. Each user has a tagged object (Figure 2) to interact with tabletop interface, which we call it, pointer. There is an infrared tag[3] (Figure 3) on each pointer and another identical NFC[4] tag. Both tags represents same unique id for the pointer. NFC tag can also include additional information for establishing the network connection between the mobile device and the tabletop application. An infrared tag consists of a geometric arrangement of infrared reflective and absorbing areas (Figure 3). A pairing process is required to pair the user's pointer and his/her mobile device. Beginning of the interaction, user lunches the client application on his/her mobile device and closes the pointer's NFC tag to the mobile device (in case of using a mobile device without NFC reader, this process can be done, manually) to establish the network connection as well as pairing the pointer ID with his/her mobile device. At the end of interaction, user disconnects the communication channel and pointer ID will release and be ready for next user. There is also an auto release functionality, which disconnects unused communication channels after specific period.

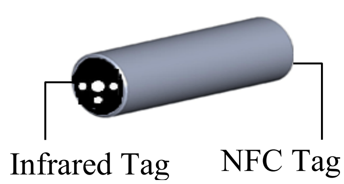

Figure 2 - Pointing Object

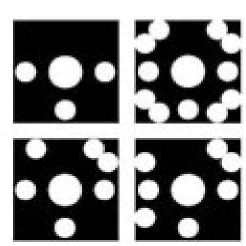

Figure 3 - Infrared Tags

[3] Tagged Object Recognition - http://msdn.microsoft.com/en-us/library/ff727854.aspx
[4] Near field communication

4.2. Software Design

MobiSurf API interaction with the tabletop application is based on event-driven architecture, while it's communication with the mobile app is based on client server architecture (Figure 4). MobiSurf API acts as an observer, listens to tabletop UI events and responses from the clients, and notifies the tabletop application through a set of events. The system can use different platforms as the communication channel between the MobiSurf API and the client mobile devices such as TCP-IP or Bluetooth network. The MobiSurf API, in one side, communicates with client mobile devices through a set of XML formatted commands and in the other side generates proper events, which can be handled on the tabletop application. MobiSurf is completely compatible with standard UI controls. Therefore, developers do not need to apply any changes to their current UI design and controls. MobiSurf provides a set of events and predefined action messages to establish a two way communicate between the tabletop app and the client app (Tables 1, 2, 3). Developers can handle MobiSurf events and take proper reaction to client activities as well as sending various messages to client mobile app. This design hides all complexity of mobile device communication and users identification from the tabletop software developers and provides them a flexible development tools to implement any combination of the

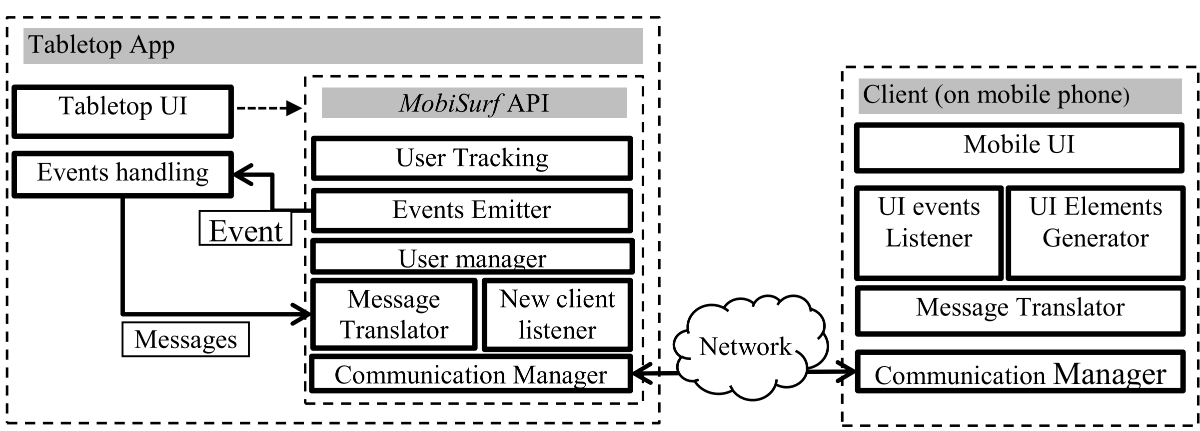

Figure 4 - Software Architecture

events and action messages in the tabletop application. This architecture increases the flexibility and minimizes the coupling so that, regardless of the mobile and the tabletop platform, the MobiSurf API can communicate with both sides. The rest of this section is talking about detail instruction of system components.

Table 1 - MobiSurf API Events

Event	Description
NewClient	New mobile client connected
ClientRemoved	Mobile client disconnected
MessageReceived	A message received from a client

Table 2 - MobiSurf UI Events

Event	Description
PointerOver	Pointer is over a UI Element
PointerRotated	User twists the pointer over a UI Element
PointerShare	Two pointers are close to each other (Content sharing gesture)

Table 3 - MobiSurf Action Messages

Message	Action on mobile device
Lighting	Flashes the LED light
Vibrate	Generates vibration
Beep	Generates a beep sound
TextMode	Shows a textbox on screen
ListMode	Shows a listbox on screen
Button	Shows a clickable button on screen
WebLink	Navigates to a web page
Speech	Reads a text
Image	Shows an image on screen
Media	Plays a voice or video file
AlertDialogue	Shows a text alert message on screen
DataRequest	Send a request to mobile phone for various data (i.e. personal user information, contact, phone ID).

4.3. Tabletop Application

Tabletop application is running on the tabletop device. The application must create an instance of MobiSurf API class in initialization phase and implements required functions to handle MobiSurf events. Based on the application design and user experience, developer decides on how to map each client event to proper MobiSurf action message or internal UI feedback. Figure 5 illustrates sequence of the actions from user interaction on tabletop device to the generated feedback on the mobile device in a sample scenario. For example, MobiSurf raises an event when user's pointing device is within UI element boundaries (PointerOver event),

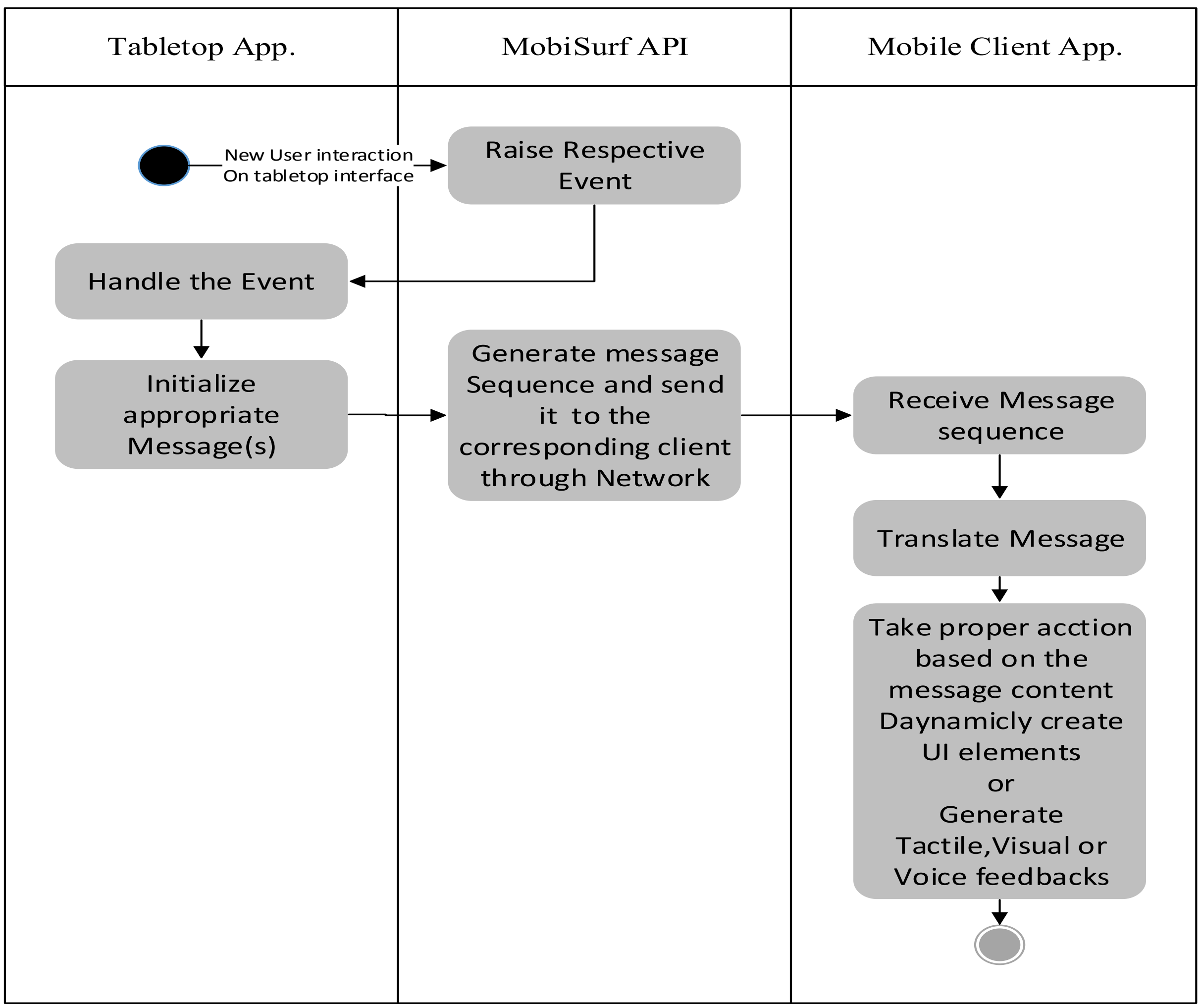

Figure 5 – UI Events Action Diagram

developer can implement a change color reaction on tabletop UI as well as a vibration or speech feedback on the mobile client app. Single or multiple action messages can be implemented for each single event.

4.4. MobiSurf API

The MobiSurf API has four main rules; each of them works in a separate thread.

a) Listen to incoming communication from new clients. Once a new device is detected, the server creates a new virtual workspace, assigns a private communication channel to it, and raises the "NewClient" event. This new virtual workspace works in autonomous thread, which is responsible to all communications with that specific user. When the MobiSurf API detects a client disconnection, it removes the workspace (i.e. disposed the client thread and resources associated with it) and raises the "ClientRemoved" event.

b) MobiSurf keeps tracking the pointer(s) and observes user's action on tabletop screen. Once it detects pointer manipulation, first, it identifies the user who performed the interaction and then raises the proper event. "PointerOver" event raises when the pointer device is moved over a UI elements. "PointerRotated" event raises when the user rotates the pointer over a UI element. When two or more pointers are closed to each other, the "PointerShare" event raises. This event is designed for sharing purposes. Two or more users can perform mobile device to mobile device sharing by putting their pointers close to each other.

c) MobiSurf creates proper action messages (Table 2) and sends them to client devices, based on the tabletop app requests.

d) MobiSurf translates all incoming messages from each client and raises the "MessageReceived" event. This event passes the message content along with user ID. The message content is a XML formatted text, which include the detail information about the user's action on mobile device. Various user's actions can be identified, such as, "ButtonClick"- when the user tapped a button UI element on mobile device. "ItemSelect"- when the user selects an item from a list box on mobile device. "TextEntered"- when the user input text to a text box on mobile device.

4.5. Client Mobile Application

Client application has two functionalities. a) It translates the received messages and performs proper action or renders the proper UI element on mobile device display based on the message content. b) It generates response messages based on user's action on mobile device and send them back to MobiSurf API.

5. INTERACTION SCHEMES

In respect to our design goals and other related works in this area [Sch12], we categorized user's actions to five main challenging issues on tabletop applications. We introduces interaction schemes to handle these user's actions using MobiSurf API.

5.1. Surface Exploration

To access and interact with UI elements on digital surface application, we need an effective and accurate exploration technique. Our propose method enables user to explore the surface application with a pointing object and receive relative feedbacks base on the pointer location on his/her mobile device. Feedbacks can be visual, Voice or vibration on the mobile device. Two samples application using this type of interaction are studied.

- *Tactile Feedback on UI Elements*- when user scrolls the pointing object over UI elements, which are clickable, his/her phone vibrates.
- *Voice Feedback on UI Elements*- when user scrolls pointing object over texts and twists the pointer the text will be read through his/her mobile phone.

5.2. Object Manipulation

User can interact with UI elements of the surface application through his/her mobile device. For example, user can click, double click or drag and drop a UI element.

- *Clicking* - user can click on any UI element by taping on his/her mobile display.
- *Drag & Drop* - user can select a UI element; put it in drag mode and drop it using his/her pointing object.

5.3. Data Entry

User can input data to surface application using his/her mobile device.

- *Text Input* - user can input text through his/her mobile phone and would be able to mark that text as private to prevent others to see the text on tabletop display. Text entry, date entry and list selection can be done using this interaction style.
- *List Selection* – User can select from a list of options on his/her mobile phone.

5.4. Data Store and Transfer

User can receive data from tabletop application and store it on his/her mobile device or can send stored data from his/her mobile device to tabletop application. For example, users can store their credit card information on the mobile and reuse them on a tabletop application when it is needed. In addition, user can personalize tabletop application (application must provide customization features) under his/her unique profile and store personalization data on his/her mobile device. System can restore user's custom settings in their future interactions. This technique can also enable tabletop application to customize the interface and activate accessibility features for disabled users.

- *Reusing Stored Data*- user can store personal information (credit card number, SSN, etc.) on his/her mobile phone and reuse them during interaction with tabletop application.
- *Storing Data on Mobile Phone*- user can receive data (address, phone number, application status, …) from tabletop application and store it on his/her mobile phone for future use.
- *Tabletop App. Personalization*- users can uniquely identify trough their mobile device unique IMEI[5] and this can help to customize the tabletop application for them based on their interests and requirements. For example in a hotel information desk

[5] International Mobile Station Equipment Identity

application, the system can customize provided information based on the users booking information.

- *Tabletop App. Accessibility*- Users can activate the accessibility option on their mobile client application. This lets the tabletop application to identify them and customize the interface based on their requirements. For example, once a blind user start interacting with tabletop application the system identifies him/her and activates accessibility features for blind users.

5.5. Content Sharing

Multi users who are interacting with tabletop device at the same time can share various types of information. Sharing action can be done between two or more users.

- *Share Data* - users can share content (images, text, etc.) with other users who are using the tabletop device by putting their pointing objects close to each other. A confirmation message appears on share source mobile device to prevent accidental sharing activation.

6. EVALUATION

We performed an empirical user study to compare the usability of the MobiSurf interaction style against the standard tabletop interface during the authentication and content sharing tasks.

6.1. Research Question and Hypotheses

Based on "The Goal Question Metric Approach" [Bas94] we obtained the following hypothesis for this study:

- **Hypothesis 1 (H1) –** Participants using the MobiSurf interface, do not spend significantly higher time to perform tasks, compare to standard tabletop interface.
- **Hypothesis 2 (H2) –** Participants rate the MobiSurf interface significantly better than standard tabletop interface, in term of security, effectiveness, comfort level and user satisfaction.
- **Hypothesis 3 (H3) -** There is no significant difference between the MobiSurf interface and standard tabletop interface in term of easiness of learning.

6.2. Participants

We recruited 45 participants from NDSU undergraduate students. None of the participants had previously used tabletop devices and 84% of them were smartphone users. Each participant had to perform two main tasks (i.e. User authentication and content sharing). Each one must be performed one time using the tabletop traditional interface and then using the MobiSurf interface. Tasks order and interfaces order was counterbalanced (discussed later) which led to four possible combinations of tasks and interfaces. Therefore, we decided to remove the last person in order to have 44 participants and 11 data point on each task/interface order.

6.3. Apparatus

Digital Surface- We used a Microsoft PixelSense version 2.0 tabletop device[6], Samsung SUR40, without any hardware modification. It is a commercial touch-screen tabletop device based on windows 7. Using PixelSense technology, it can responds to touch and real world objects. We selected this device because it is already used in various businesses[7] and some other related research [Kan11].

6.3.1. Mobile Device

We used two Android based mobile devices, a Nexus 4 (used by participants) and a Nexus 7 (used by experimenter for content sharing task). We developed a mobile application for MobiSurf and users would work just in our application. The application use mobile device as a touch screen device and does not use any specific feature from Android OS or device hardware such as sensors. Therefore, the hardware and OS of the smartphone do not affect the system usage. The same application can be developed for other smartphones such as IPhone and Windows phones.

6.3.2. Software

We developed two separate applications for Microsoft PixelSense using MobiSurf API in C#.Net. Each application provides a simple user interface to perform both tasks (i.e. user authentication and content sharing). One of the applications was designed for training purpose the other one was designed to conduct the user study.

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[6] www.microsoft.com/en-us/pixelsense/whatsnew.aspx

[7] www.microsoft.com/en-us/pixelsense/casestudies.aspx

6.4. Experiment Design

Figure 6 shows a graphical representation of the experiment design. Study began with a pre-study questionnaire and was followed by a session where, the subjects were trained on standard tabletop and MobiSurf interfaces. Next, the participants were asked to perform the two tasks using the tabletop interface, and the MobiSurf interface. Order of the tasks and interfaces are counterbalanced to reduce the learning effect. The experimenter records each tasks completion time in a spreadsheet Next, the participants fill out a questionnaire to provide feedback on their experiences with interfaces.

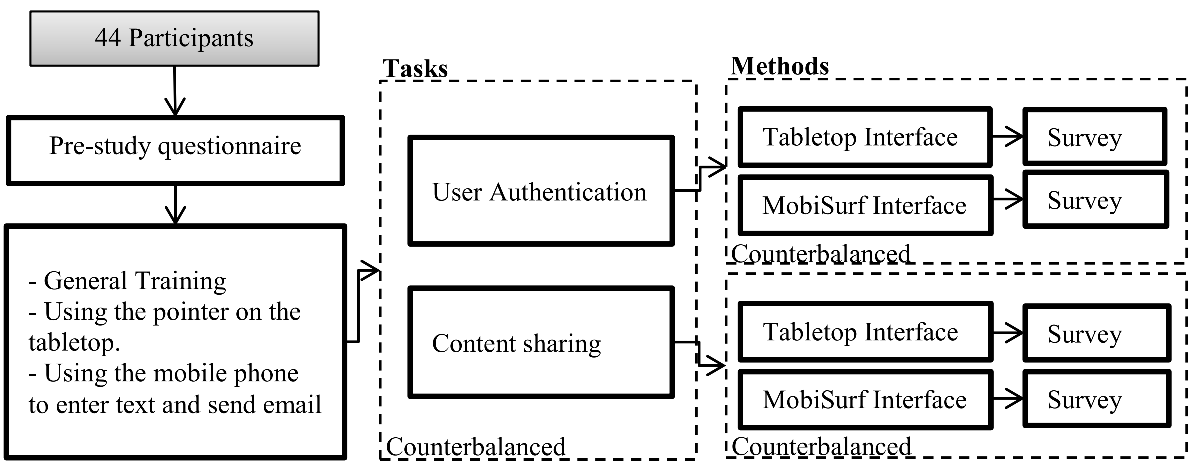

Figure 6 - Experiment Design

6.4.1. Step 1- Pre-Study Questionnaire

The first step was to collect the background information from the participating subjects regarding their reading comprehension skills, their prior knowledge of the touch screen interfaces, and their experience and comfort level with using mobile devices. The information during the pre-study was used to gain additional insights into the individual performance of subjects during the experiment.

6.4.2. Step 2- Training Session

Following the pre-study survey, the researcher trains the participant on each treatment method using the training application; this includes general description of the system, basic interaction trainings, tabletop exploration techniques, and mobile device interface exploration. During the training participant performs text entry task using the tabletop onscreen keyboard and MobiSurf interface as well as performing a simple content sharing task using both interfaces. Experimenter lets the participant to work with both devices until he/she fills comfortable with using both interfaces and ready to start the actual study.

6.4.3. Step 3- Performing Tasks

Previous researchers have tried to address the authentication and content sharing on the tabletop devices [Kim10, Mau08, Pat04, Pea09, Sch08]. These tasks represent most common type of interactions on tabletops and were selected to be able to compare the usability of the proposed interaction style in this study.

Each participant performed two separate tasks, *user authentication,* and *content sharing,* once using the standard tabletop interface and another time using the MobiSurf interface.

Task #1- User Authentication – MobiSurf provides secure method to do the user authentication. In this method, users can input their username and password on their mobile device instead of directly put down the sensitive information on public surface screen. Many applications such as shopping or hotel information desks need to identify the users through some sort of authentication process (i.e. username and password, social security). One of the main concerns in these applications on public digital surface interfaces is the user privacy. User's usually do not feel comfortable to enter their sensitive information (i.e. username, password, SSN, etc.) on public interfaces using touchscreen keyboard since. Some researchers focused on solving this issue by proposing alternative interfaces to enter sensitive information such as picture password [Kim10]. However, the main problem with these methods is that they usually violate the consistency of the user interface, which increases the learning effort.

For this task, we provide a simple standard login interface, which is commonly used in many of the standard applications to simulate the authentication process. Each participant performed the task two times. One time using the standard tabletop interface (i.e. on screen keyboard) and another time using the MobiSurf interface. Order of methods (i.e. on screen keyboard and MobiSurf interface) was counterbalanced. The experimenter measured the task completion time for each method.

Task #2- Content Sharing - The MobiSurf API provides a set of methods and gestures to store tabletop application content to user's mobile device as well as letting the users to edit and share the stored content with other users privately in the collaborative environments.

Many collaborative applications such as card games, brain storming and educational applications need the users to be able to share some content with other specific user(s). For example in an educational application instructor discusses a question on the tabletop screen and then ask the student to send him/her their suggested answers privately.

There are various methods such as SMS, Email, and IM applications available, which enable users to share content between devices. To perform this task using the existing methods, we decided to choose email because it is very popular, capable of sending various types of contents (i.e. text, image, and other digital contents) and required applications are available on mobile devices by default. We implemented a simple voting and brain storming application which let users to discuss about a content (in this case, a company mission statement) and each user could modify the content based on his/her opinion and send the modified content to the meeting coordinator. To simulate the private sharing using email, each participant was asked to email a text block (i.e. a company mission statement) to an email address. This email address was assigned to the participant's mobile phone and represents his/her own email address. Then, participant was asked to edit the content and forward it to another email address, which was the experimenter email address.

As an alternative to private sharing through email, we asked participants to use the MobiSurf interface. In this scenario, we used a gesture-based method to send a public content to user's mobile device which user could edit the content then send it privately to another user in collaborative interaction. Each participants was asked to move his/her pointer over a text block (i.e. a company mission statement) and rotate the pointer. Pointer rotate event was programed to send the text to user's mobile device. Then, participants were asked to edit the text and activate the sharing mode on the mobile application and then move their pointer close to experimenter pointer on digital surface device. By closing pointer to each other "PointerShare" event would raise and send the modified text to share target user (i.e. experimenter's mobile device).

Orders of methods (i.e. email and MobiSurf method) were counterbalanced and we measured the completion time for each method.

6.4.4. Step 4- Survey Questionnaire

At the end of each task using each interface, participants were asked to fill a computer based survey questionnaire to rank the overall system performance and provide feedback on their use of the system using a 5-point Likert-type scale (ranging from "*1=strongly disagree, 5=strongly agree*"). Each survey was consisted of 8 to 10 questions to rate difference characteristics (i.e. ease of learning, effectiveness, ease of use, user satisfaction, security and privacy, comfortability, overall satisfaction and training quality). Complete list of all survey questions are available in appendix A.

6.5. Data Collection

This section provides a brief description of qualitative and quantitative data collected during the study.

6.5.1. Quantitative Data

The quantitative data includes completion time (in seconds) for each of the four tasks (2 task per each interface - Figure 6). We collected twenty-two data points for each task. The researcher recorded the start time and the end time for each task.

6.5.2. Qualitative Data

We gathered subjective self-reported data during the pre-study and a set of four survey questionnaires (one per each task-interface) for each participant. Using a five point scale, the participating subjects rated their experience using each interface (i.e. Standard interface or MobiSurf interface), in terms of their ease of learning, effectiveness, ease of use, satisfaction, security, comfortability, overall performance, user satisfaction. Furthermore, we asked subjects to rate the usefulness of the training session provided to them on each interface and tasks at the beginning of the study.

6.6. Analysis and Results

This section provides an analysis of the data collected during the study. The results are organized around the three research hypotheses presented in Section 7.1. An alpha value of 0.05 was selected for judging the significance of the results.

6.6.1. H1 – Comparison of the Completion Time

We calculated the mean, average, and standard deviation of the task completion time for each task and interface (Table 4). For both tasks, the standard deviation values for both interfaces are small and indicate the consistency and the reliability of the collected data. We analyzed the interface efficiency by comparing the mean completion time (in seconds) of each task by subjects in each group using the MobiSurf and tabletop interface (Figure 7). Paired sample t-test was applied to judge the significance of the results as discussed below.

For the first Task (User authentication) although the mean values for the tabletop and the MobiSurf interface are very close, there is significantly difference between the two methods ($p<0.05$). The MobiSurf interface shows significantly higher completion time compare to tabletop interface. This result rejects our first hypothesis (H1) for the first task. For the second task (Content sharing) there is significant improvement in using the MobiSurf interface over the

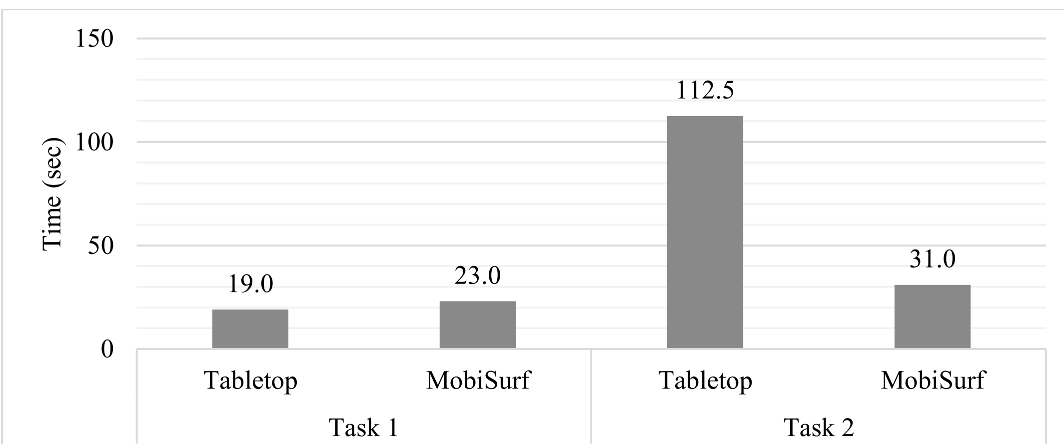

Figure 7 - Task Completion Time Median Values

Table 4 - Tasks Completion Time Results

	Task 1		Task 2	
	Tabletop	MobiSurf	Tabletop	MobiSurf
Standard Deviation	7.747	6.232	28.826	10.705
Mean	20.818	23.841	114.795	33.091
Median	19.0	23.0	112.5	31.0

tabletop interface (p=0.000). This result approve out first hypothesis (H1) for the second task. Based on the researcher observations during the user study, we think shifting between tabletop and mobile display caused higher time completion on task 1. However, for task 2, the MobiSurf interface offers a very straightforward interface for content sharing, compare to tabletop interface. Hence, the MobiSurf sharing method includes fewer steps compare to tabletop method and had much faster completion time.

6.6.2. H2 – Cooperation of the Usability Feedbacks on MobiSurf and Tabletop Interface

Participant evaluate relevant characteristics of each interface for each task using a five point likert-scale (1- strongly disagree to 5- strongly agree) questionnaire. We categorized the rating results in to two main categories, "Disagree" and "Agree"[8]. "Disagree" category included all rating values lower or equal to 3 and "Agree" category included rating values 4 and 5. Figure 8 show the percentage of ratings on each category for both tasks. Based on the categorized results (Figure 8) and a Wilcoxon singed-rank test we conducted on each pair of rating values for each characteristic, we noticed that the MobiSurf interface achieved significantly higher ratings in both tasks ($p<0.05$). However, there are some differences between the ratings on the two tasks which mostly caused by the nature of the tasks. For example, task 1 (user authentication) is more security concentrated compare to task 2 (content sharing), so, we can see a larger margin between the two interfaces on task 1 compare to task 2.

In order to make sure the majority of the ratings are in "Agree" category for each characteristic, we conducted a non-parametric one-sample Wilcoxon Signed Rank test on each characteristics to determine whether the mean values were significantly greater than the midpoint of the scale (test of median <= 3 versus median > 3). The results of this test show significantly

[8] Based on guidelines from www.likert.org/how-to-analyze-likert-scale-data

higher rate for the "Agree" category ($p<0.05$), which means most of the participants rated 4 or 5 on all characteristics for the MobiSurf interface.

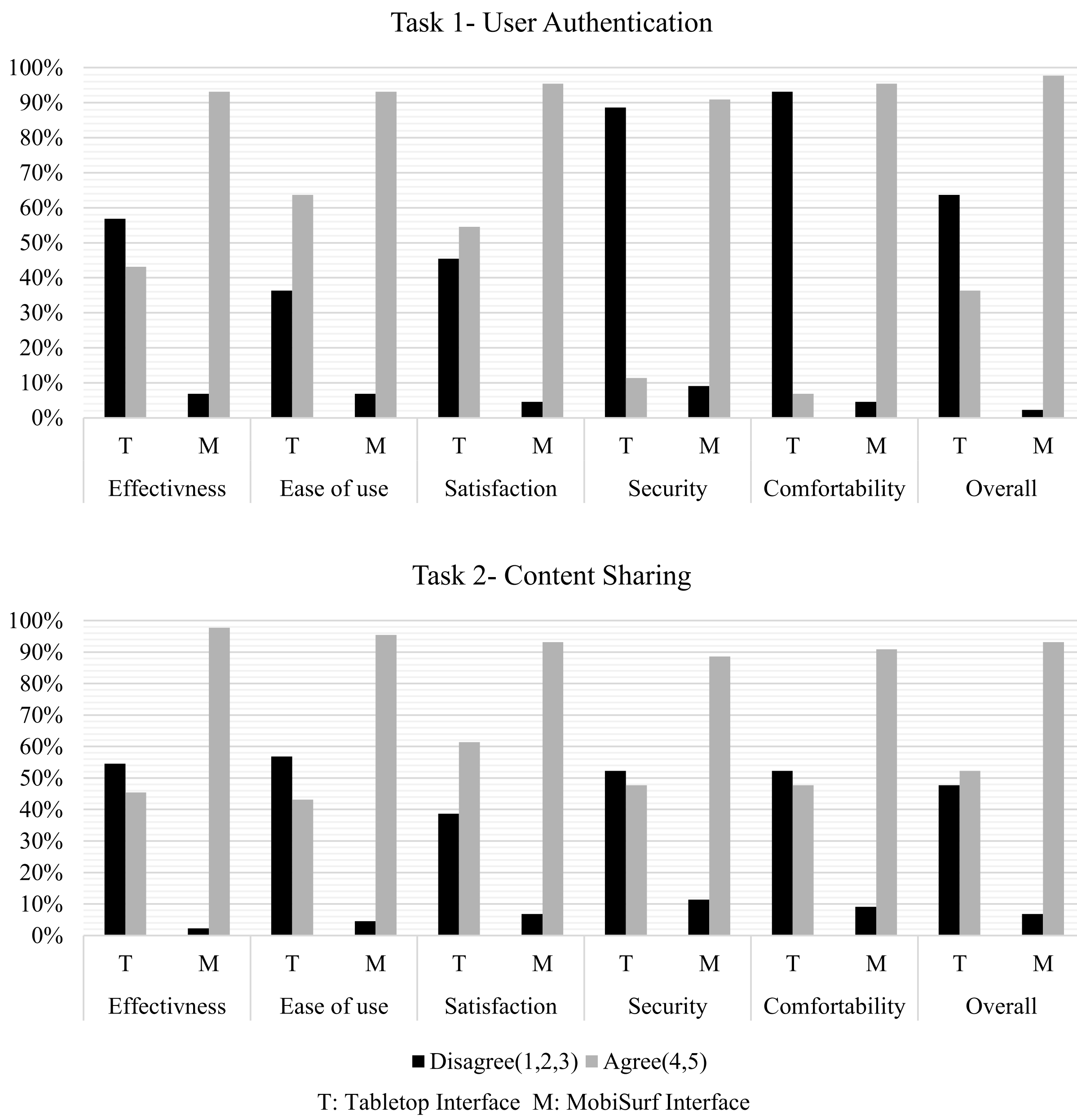

Figure 8 - Percentage of the Rating Results (Categorized)

6.6.3. H3 – Easiness of Learning on MobiSurf and Tabletop Interface

One of our main concerns during the design phase of this project was to develop an easy to use interface. Our target was an interface, which is as easy to use as the current tabletop interface. We included a question asking the participants to rate easiness of learning the MobiSurf interface and the tabletop interface in the surveys. Table 5 shows participant's feedbacks on easiness of learning each task. We applied a Wilcoxon singed-rank test on the results and calculated the p values for each task. For task1 (i.e. user authentication) the results show that the subject rated the easiness of learning on both interfaces in almost same range and we did not find significant difference ($p>0.05$). For task2 (i.e. data sharing) the participants rated the MobiSurf interface significantly easier to learn compare to tabletop interface ($p<0.05$). Therefore, the MobiSurf interface is as easy as, or in some cases much easier to learn compare to the standard tabletop interface.

Table 5 - Easiness of Learning

	Task 1		Task 2	
	Tabletop	MobiSurf	Tabletop	MobiSurf
Disagree(1,2,3)	6.82%	0.00%	29.55%	2.27%
Agree(4,5)	93.18%	100.00%	70.45%	97.73%

6.7. Threats to Validity

Here are some of the major threats to validity of the user study.

External Validity: There was low diversity in participants in term of age and education level, since, all participants were drawn from bachelor computer science students. However, the presented interface is likely to be used by anyone in public environments.

Internal Validity: We did not inform the participants about the study goals, in order to increase the validity of the study and remove any bias in provided data. We also asked the subjects to rate the training quality for each method (i.e. Tabletop and MobiSurf) and the results did not show meaningful difference. Due to privacy issues, we could not ask participants to use one of their real usernames, passwords for authentication task (task 1) and they were asked to input a fake username, and password, which may not, gave them the real feeling of inputting their own sensitive information on a public interface. Lack of classic control group could also be one of the threats to this study, which we plan to handle it in our future work.

7. DISCUSSION

Based on the evaluation results, the MobiSurf interface usability characteristics are significantly better than tabletop interface and the overall evaluation results approved usability characteristics of the MobiSurf interface. Our study shows that the presented interaction styles are easy to learn and easy to use. We also considered the users destruction during performing the tasks, and asked the participants to rate the level of destruction due to using mobile device as part of their interaction with tabletop device. More than 80% of the participants did not feel any destruction using two devices together. In some tasks, the MobiSurf interface was not as fast as the traditional methods of interaction, such as on screen keyboard. However, performance time is only one of the factors in overall user satisfaction and if we consider other factors such as system security and effectiveness then we can conclude that the MobiSurf interaction styles would significantly improve the tabletop interface. Based on the participants written and verbal feedbacks, we noticed that most of them feel more confident interacting with tabletop device using the pointers. Many of the subjects mentioned that the sharing gesture was very easy to use and natural.

We observed few limitations and problems in the system during the user study. Some of the problems were related to implementation, which we solved them later, but some of the issues were related to system design or the technologies that we have used which can be considered in future improvements on the system. For example, the presented approach is utilizing pointer objects to track users over the display, which is only applicable to horizontal displays such as tabletop devices, and we have to modify the pointers in order to be usable with vertical or wall mounted devices. Another serious limitation to our system is using infrared sensors to identify pointer's infrared tags, which limits the system to indoor environments. Therefore, we can consider an alternative solution to track pointers, which is usable for both indoor and outdoor environments.

The MobiSurf interface offers various interaction schemes as we discussed in section 6. Since, this was an initial investigation, just a few of the interaction styles have been evaluated in this user study. For example, we did not evaluate the drag & drop, data storing and data transfer features. We will investigate these features in future experiments.

8. APPLICATIONS

8.1. Accessible Public Interface

Tabletop devices are getting more and more popular as public interfaces. In recent years, we can see them in malls, hotels, or educational environments. However, there is very few accessibility features for blind users to access them. Although, there are some researches (e.g. [Kan08, Kan11, Gue08]) and commercial tools (e.g. Apple's Voice Over, Google's Eyes-Free) which can provide accessibility features to tabletop devices, mostly they have weaknesses makes them difficult to use in real world. There are common problems with all methods, which combine gesture input and speech output. Firstly, using voice output on a tabletop device in a public environment such as a mall is not feasible. In addition, using voice output or input (i.e. speech recognition) limits the public interface to single user interaction in most cases. Secondly, many of current approaches require highly modification even in device hardware or the software, which makes the device almost inaccessible for non-blind users. Many interaction techniques for blind users involve fundamental changes on user interface, which reduces the usability of the application for non-blind users. Tabletop devices mostly used in public environment and serve both blind and non-blind users. Thus, any accessibility feature must maintain the standard user interface and let all users to interact with the system.

Developers can use MobiSurf API to improve the tabletop application accessibility features. Using MobiSurf action messages (Vibrate and Speech), the application can give tactile and voice feedbacks to the vision impaired users. In addition, mobile devices special features can be used to improve the interaction. For example, user can input text or send command using voice recognition feature of his/her mobile device instead of typing on tabletop or mobile screen.

8.2. Information Desk Application

Digital surface devices as a public interface are a good option for information desks in malls, restaurants, hotels, and public commercial buildings. Few studies have been looked at the idea of using handheld devices and public interfaces to guide visitors within a building and providing them with relevant information [Bel12]. The MobiSurf API can facilitate the connection between user's personal mobile device and the public interface. Users can download various contents (text, images, videos, and maps) to their mobile devices and reuse them later. Developers can integrate various gestures using the MobiSurf UI events (i.e. PointerOver, PointerRotate) into their public interface applications. In addition, NFC tags can be used to upload required mobile application and configurations to user's mobile devices.

8.3. Brain Storming Application

Using digital surface devices can provide a dynamic collaborative interface for brain storming sessions. People can gather around the digital surface and interact with the system simultaneously. Using MobiSurf interaction techniques can improve various aspects of this collaboration. For example, the meeting coordinator can easily perform a private voting on particular idea and others can privately send their responds to the coordinator. Each individual can be identified through his/her pointer and interact with on screen contents using various gestures (i.e. "PointerOver" and "PointerRotate" events). Users can send private message to each other as well as share some contents from their mobile device on the digital surface screen.

8.4. Classroom Discussion Application

Applications running on tabletops and use their potentials to enable simultaneous interaction and face-to-face collaboration are beginning to be developed to enable the students to collaborate on variety of activities. Using tabletops for educational purposes have been the topic of many researches [Rik09, Ala10]. The MobiSurf interaction techniques can improve the collaborative interactions on these applications. For example, instructors can use public sharing to share a content from their personal tablet with the student and student can use the private sharing to send back their answers to the instructor. Developers can utilize “PointerOver” and “PointerRotate” events to implement new interactions with the UI elements. Voice feedback, vibration and other MobiSurf action messages can also be used to give each individual users the proper tactile and voice feedback.

9. CONCLUSION

In this paper, we proposed a set of inter-device bimanual gestures to improve interaction with tabletop devices. We developed a prototype and studied the usability factors of the proposed interaction style. We have shown that the presented interaction style is as usable as the traditional touch interactions while offers more diverse modality and increases the privacy features of the interface. These interaction styles can be extend for many other applications such as Hotel lobby information desk, public transportation maps or providing accessibility features for blind users who want to access public interfaces. We are planning to expand this research in our future work to cover more complex real-world application development using the presented interaction styles. Integrating these methods to applications in order to improve the accessibility feature of the tabletop interface would be one of the promising directions for our future works. In addition, we are planning to improve the user tracking system to be applicable not only to the horizontal touch displays, but also to the vertical mounted displays.

10. REFERENCES

[Ack12] C. J. Ackad, A. Clayphan, R. M. Maldonado and J. Kay, "Seamless and Continuous User Identification for Interactive Tabletops Using Personal Device Handshaking and Body Tracking," in CHI EA, NewYork, 2012.

[Ala10] I. Alagha, A. Hatch, L. Ma and L. Burd, "Towards a teacher-centric approach for multi-touch surfaces in classrooms," in *ITS*, NY, 2010.

[Ant09] A. N. Antle, N. Motamedi, K. Tanenbaum and Z. Xie, "The EventTable Technique: Distributed Fiducial Markers," in TEI, Cambridge, 2009.

[Bal05] R. Ballagas, M. Rohs, and J. Borchers, "Sweep and Point & Shoot: Phonecam-based interactions for large public displays," in CHI Ext. Abstracts, pp. 1200–1203, 2005.

[Bas94] V. R. Basili, G. Caldiera and H. D. Rombach, "The Goal Question Metric Approach," University of Maryland, 1994.

[Bel12] I. Belinky, J. Lanir and T. Kuflik, "Using Handheld Devices and Situated Displays for Collaborative Planning of a Museum Visit," in *PerDis*, Porto, Portugal, 2012.

[Bor10] S. Boring, D. Baur, A. Butz, S. Gustafson, and P. Baudisch, "Touch projector: Mobile interaction through video," in Proc. CHI, pp. 2287–2296, 2010.

[Dac09] R. Dachselt, R. Buchholz, "Natural throw and tilt interaction between mobile phones and distant displays," in Proceedings of the 27th international conference extended abstracts on Human factors in computing systems, 2009.

[Ech09] F. Echtler, S. Nestler, A. Dippon and G. Klinker, "Supporting casual interactions between board games on public tabletop displays and mobile devices," Personal and Ubiquitous Computing, vol. 13, no. 8, pp. 609 - 617, November 2009.

[Gre99] S. Greenberg, M. Boyle and J. Laberge, "PDAs and Shared Public Displays: Making Personal Information Public, and Public Information Personal," Pers. and Ubiq. Comp., vol. 3, p. 54–64, 1999.

[Gue08] T. Guerreiro, P. Lagoa, H. Nicolau, D. Gonalves and J. Jorge, "From tapping to touching: making touch screens accessible to blind users," *IEEE Multimedia,* vol. 15, no. 4, pp. 48-50, 2008.

[Har08] R. Hardy and E. Rukzio, "Touch & Interact: Touch-based interaction of mobile phones with displays," in Proc. MobileHCI, pp. 245–254, 2008.

[Hes10] T. Hesselmann, N. Henze and S. Boll, "FlashLight: Optical Communication between Mobile Phones and Interactive Tabletops," in ITS, Saarbrucken, Germany, 2010.

[Hut11] W. Hutama, P. Song, C. Fu and W. Goh, "Distinguishing Multiple Smart-Phone Interactions on a Multi-touch Wall Display using Tilt Correlation," in CHI, Vancouver, 2011.

[Kan08] S. Kane, J. Bigham and J. Wobbrock, "Slide Rule: making mobile touch screens accessible to blind people using multi-touch interaction techniques," in *ASSETS*, 2008.

[Kan11] S. Kane, M. Morris, A. Perkins, D. Wigdo, R. E. Ladne and J. Wobbrock, "Access Overlays: Improving Non-Visual Access to Large Touch Screens for Blind Users," in UIST, Santa Barbara, CA, USA, October 16–19, 2011.

[Kim10] D. Kim, P. Dunphy, P. Priggs, J. Hook, J. Nicholson, J. Nikolson and P. Olivier, "Multi-Touch Authentication on Tabletops," in CHI, Georgia, USA, 2010.

[Lee04] S. Lee and J. Eun Cho, "Evaluating Accessibility of Public Information Kiosks," in *ICCHP*, Paris, France, 2004.

[Luc08] A. De Luca and B. Frauendienst, "A privacy-respectful input method for public terminals," In Proc. NordiCHI, pp. 455–458, 2008.

[Mag04] C. Magerkurth, M. Memisoglu, T. Engelke and N. Streitz, "Towards the Next Generation of Tabletop Gaming Experiences," in Proceedings of Graphics Interface, 2004.

[Mag99] M. C. Maguire, "A Review of User-Interface Design Guidelines for Public Information Kiosk Systems," *International Journal of Human-Computer Studies,* vol. 50, no. 3, pp. 263-286, 1999.

[Mau08] A.J. Maunder, G. Marsden and R. Harper, “SnapAndGrab – Accessing and sharing contextual multi-media content using Bluetooth enabled cameraphones and large situated displays,” in CHI, 2008.

[Mca09] C. McAdam and S. Brewster, "Distal Tactile Feedback for Text Entry on Tabletop Computers," in BCS-HCI, Swinton, UK, 2009.

[Mca11] C. McAdam and S. Brewster, "Using Mobile Phones to Interact with Tabletop Computers," in ITS, Kobe, Japan, 2011.

[Mcg08] D. McGookin, E. Robertson and S. Brewster, "Clutching at Straws: Using Tangible Interaction to Provide Non-Visual Access to Graphs," in CHI, NewYork, 2010.

[Mcg11] D. McGookin and S. Brewster, "Investigating Phicon Feedback in Non-Visual Tangible User Interfaces," in CHI EA, NewYork, 2011.

[Miy04] K. Miyaoku, S. Higashino, and Y. Tonomura, “C-Blink: A hue-difference-based light signal marker for large screen interaction via any mobile terminal,” in Proc. UIST, pp. 147–156, 2004.

[Mye01] B. A. Myers, “Using handhelds and PCs together,” in Comm. ACM, 44:34–41, 2001.

[Nie94] J. Nielsen, "Enhancing the explanatory power of usability heuristics," in *CHI*, Boston, Massachusetts USA, 1994.

[Olw09] A. Olwal and S. Feiner, “Spatially aware handhelds for high-precision tangible interaction with large displays,” in Proc. TEI, pp. 181–188, 2009.

[Pat04] S. N. Patel, J. S. Pierce and G. D. Abowd, “A gesture-based authentication scheme for untrusted public terminals," in UIST, pp. 157-160, 2004.

[Pea09] N. Pears, D.G. Jackson, and P. Oliver, “Smart phone interactions with registered displays,” in IEEE Perv. Comp., 8:14–21, 2009.

[Rik09] J. Rick, A. Harris, P. Marshall, R. Fleck, N. Yuill and Y. Rogers, "Children designing together on a multi-touch tabletop: an analysis of spatial orientation and user interactions," in *IDC*, NY, 2009.

[San10] F. Sandnes, H. LI Jian, Y. Huang and Y. Huang, "User Interface Design for Public Kiosks: An Evaluation of the Taiwan High Speed Rail Ticket Vending Machine," *Journal of information science and engineering,* vol. 26, pp. 307-321, 2010.

[Sch08] J. Schöning, M. Rohs, A. Krüger, “Using Mobile Phones to Spontaneously Authenticate and Interact with Multi-Touch Surfaces,” in Workshop on designing multi-touch interaction techniques for coupled private and public displays, 2008.

[Sch10a] D. Schmidt, F. Chehimi, E. Rukzio and H. Gellersen, "PhoneTouch: A Technique for Direct Phone Interaction on Surfaces," in UIST, New York, 2010.

[Sch10b] D. Schmidt, M. Chong, and H. Gellersen, “HandsDown: Hand-contour-based user identification for interactive surfaces,” in Proc. NordiCHI, pp. 432–441, 2010.

[Sch12] D. Schmidt, J. Seifert, E. Rukzio and H. Gellersen, "A Cross-Device Interaction Style for Mobiles and Surfaces," in DIS, Newcastle, UK., 2012.

[Shi09] A. S. Shirazi, T. Döring, P. Parvahan, B. Ahrens and A. Schmidt, “Poker Surface: Combining a Multi-Touch Table and Mobile Phones in Interactive Card Games,” in Mobile HCI, 2009.

[Wie11] A. Wiethoff, R. Kowalski and A. Butz, "inTUIt – Simple Identification on Tangible User Interfaces," in TEI, Funchal, Portugal, 2011.

[Wil07] A. D. Wilson and R. Sarin, “BlueTable: Connecting wireless mobile devices on interactive surfaces using vision-based handshaking,” in Proc. GI, pp. 119–125, 2007.

APPENDIX A. QUESTIONNAIRE

A.1. Pre Study Questionnaire

General Background

1. What is your English-language background?

□Native speaker	□English is a second language

If English is a second language: What are your reading comprehension skills?

□Needs considerable improvement	□Needs improvement	□Moderate	□High	□Very High

2. What is your gender?

□ Male □ Female

Smartphone Experience

Experience with Browsing on Handheld Devices (e.g., PDA's, Mobiles, touch screen phones)

3. What type of cellphone do you own?

□Android Phone	□IPhone	□Windows Phone	□Other Smartphone	□Non-Smartphone

4. How often do you send email on your mobile phone?

□ everyday	□At least one time per week	□ At least one time per month	□Never

5. What is your experience on using multi touch tabletop devices?

1 None/rarely used	2	3	4	5 Very frequently used

A.2. User Authentication Using Tabletop Interface

Below are statements about your experience, working with tabletop device, using the tabletop interface. Please rate each statement based on your experience.

1. It is easy to learn how to use the tabletop interface to input sensitive information.

Strongly disagree				Strongly agree
1	2	3	4	5

2. It is effective to input a password on a tabletop.

Strongly disagree				Strongly agree
1	2	3	4	5

3. It is easy to use a tabletop interface to input sensitive information.

Strongly disagree				Strongly agree
1	2	3	4	5

4. It was a pleasant experience to use the tabletop interface to enter my username/password.

Strongly disagree				Strongly agree
1	2	3	4	5

5. I feel it is secure to input a password or other sensitive information in a public environment through Tabletop.

Strongly disagree				Strongly agree
1	2	3	4	5

6. I am comfortable to enter a password or other sensitive information in a public environment through tabletop.

Strongly disagree				Strongly agree
1	2	3	4	5

7. Overall, I am satisfied with the tabletop to input sensitive information.

Strongly disagree				Strongly agree
1	2	3	4	5

8. Training on the tabletop interface was sufficient and helpful for you.

Strongly disagree				Strongly agree
1	2	3	4	5

A.3. User Authentication Using MobiSurf Interface

Below are statements about your experience, working with tabletop device, using the MobiSurf interface. Please rate each statement based on your experience.

1. It is easy to learn how to use the MobiSurf interface to input sensitive information.

Strongly disagree				Strongly agree
1	2	3	4	5

2. It is effective to input a password on a tabletop using MobiSurf interface.

Strongly disagree				Strongly agree
1	2	3	4	5

3. It is easy to use a MobiSurf interface to input sensitive information.

Strongly disagree				Strongly agree
1	2	3	4	5

4. It was a pleasant experience to use the MobiSurf interface to enter my username/password.

Strongly disagree				Strongly agree
1	2	3	4	5

5. I feel it is secure to input a password or other sensitive information in a public environment through MobiSurf interface.

Strongly disagree				Strongly agree
1	2	3	4	5

6. I am comfortable to enter a password or other sensitive information in a public environment through MobiSurf interface.

Strongly disagree				Strongly agree
1	2	3	4	5

7. Overall, I am satisfied with the MobiSurf interface to input sensitive information.

Strongly disagree				Strongly agree
1	2	3	4	5

8. The combination of a mobile device and a tabletop does NOT distract my attention to complete the information sharing.

Strongly disagree				Strongly agree
1	2	3	4	5

9. Training on the MobiSurf interface was sufficient and helpful for you.

Strongly disagree				Strongly agree
1	2	3	4	5

10. Based on your experience with the usability of MobiSurf during this task, what specific changes would you suggest in the MobiSurf interface to make it more usable and efficient for entering sensitive information on tabletop devices?

………………………………………………………………………………………………
………………………………………………………………………………………………
………………………………...……………………………………………………………….

A.4. Data storing and Sharing Using Tabletop Interface

Below are statements about your experience, working with tabletop device, using the tabletop interface, please rate each statement based on your experience.

1. It is easy to learn how to use the tabletop interface to share private information.

Strongly disagree				Strongly agree
1	2	3	4	5

2. Tabletop interface provides an effective way to share private information on tabletop devices.

Strongly disagree				Strongly agree
1	2	3	4	5

3. It is easy to use tabletop to share private information in a public environment.

Strongly disagree				Strongly agree
1	2	3	4	5

4. It was a pleasant experience to use tabletop interface for sharing data.

Strongly disagree				Strongly agree
1	2	3	4	5

5. In a public environment, it is secure to share private information through tabletop interface.

Strongly disagree				Strongly agree
1	2	3	4	5

6. In a public environment, I am comfortable to share private information through tabletop interface.

Strongly disagree				Strongly agree
1	2	3	4	5

7. Overall, I am satisfied to use tabletop interface to share private information in a public environment.

Strongly disagree				Strongly agree
1	2	3	4	5

8. Training on the tabletop interface was sufficient and helpful for you.

Strongly disagree				Strongly agree
1	2	3	4	5

A.5. Data Storing and Sharing Using MobiSurf Interface

Below are statements about your experience, working with tabletop device, using the MobiSurf interface, please rate each statement based on your experience.

1. It is easy to learn how to use the MobiSurf interface to share private information.

Strongly disagree				Strongly agree
1	2	3	4	5

2. MobiSurf interface provides an effective way to share private information on tabletop devices.

Strongly disagree				Strongly agree
1	2	3	4	5

3. It is easy to use MobiSurf to share private information in a public environment.

Strongly disagree				Strongly agree
1	2	3	4	5

4. It was a pleasant experience to use MobiSurf interface for sharing data.

Strongly disagree				Strongly agree
1	2	3	4	5

5. In a public environment, it is secure to share private information through MobiSurf interface.

Strongly disagree				Strongly agree
1	2	3	4	5

6. In a public environment, I am comfortable to share private information through tabletop interface.

Strongly disagree				Strongly agree
1	2	3	4	5

7. Overall, I am satisfied to use MobiSurf interface to share private information in a public environment.

Strongly disagree				Strongly agree
1	2	3	4	5

8. The combination of a mobile device and a tabletop does NOT distract my attention to complete the information sharing.

Strongly disagree				Strongly agree
1	2	3	4	5

9. Training on the MobiSurf interface was sufficient and helpful for you.

Strongly disagree				Strongly agree
1	2	3	4	5

10. Based on your experience with the usability of MobiSurf during this task, what specific changes would you suggest in the MobiSurf interface to make it more usable and efficient for sharing sensitive information on tabletop devices?

…………………………………………………………………………………………
…………………………………………………………………………………………
……………………………...……………………………………………………………….

APPENDIX B. IRB APPROVAL

NDSU NORTH DAKOTA STATE UNIVERSITY

701.231.8995
Fax 701.231.8098

Federalwide Assurance #FWA00002439
Expires April 24, 2011

Institutional Review Board
Office of the Vice President for Research, Creative Activities and Technology Transfer
NDSU Dept. 4000
1735 NDSU Research Park Drive
Research 1, P.O. Box 6050
Fargo, ND 58108-6050

Monday, February 04, 2013

Jun Kong
Computer Science
IACC 258C

Re: IRB Certification of Exempt Human Subjects Research:
Protocol **#SM13146 , "Bimanual interaction with public touch interfaces using mobile device"**

Co-investigator(s) and research team: **Ali Roudaki**

Certification Date: 1/28/2013 Expiration Date: 1/27/2016
Study site(s): **NDSU**
Funding: **NSF**

The above referenced human subjects research project has been certified as exempt (category # 2) in accordance with federal regulations (Code of Federal Regulations, Title 45, Part 46, *Protection of Human Subjects*). This determination is based on protocol, recruitment and consent materials (received 1/24/2013).

Please also note the following:

- If you wish to continue the research after the expiration, submit a request for recertification several weeks prior to the expiration.
- Conduct the study as described in the approved protocol. If you wish to make changes, obtain approval from the IRB prior to initiating, unless the changes are necessary to eliminate an immediate hazard to subjects.
- Notify the IRB promptly of any adverse events, complaints, or unanticipated problems involving risks to subjects or others related to this project.
- Report any significant new findings that may affect the risks and benefits to the participants and the IRB.
- Research records may be subject to a random or directed audit at any time to verify compliance with IRB standard operating procedures.

Thank you for your cooperation with NDSU IRB procedures. Best wishes for a successful study.

Sincerely,

Kristy Shirley

Kristy Shirley, CIP, Research Compliance Administrator