MobiSurf: Improving Co-located Collaboration through Integrating Mobile Devices and Interactive Surfaces

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Figure 1. MobiSurf supports co-located decision making through integrating personal devices and a shared surface. a) Users discuss their goals. b) They can decide to work on the surface or their personal device. c) Information can be shared easily for discussion on the surface.

ABSTRACT

One of the most popular scenarios for advertising interactive surfaces in the home is their support for solving co-located collaborative tasks. Examples include joint planning of events (e.g., holidays) or deciding on a shared purchase (e.g., a present for a common friend). However, this usually implies that all interactions with information happen on the common display. This is in contrast to the current practices to use personal devices and further, most people's behavior to constantly switch between individual and group phases because people have differing search strategies, preferences, etc. We therefore investigated how the combination of personal devices and a simple way of exchanging information between these devices and an interactive surface changes the way people solve collaborative tasks compared to an existing approach of using personal devices. Our study results clearly indicate that the combination of personal and a shared device allows users to fluently switch between individual and group work phases and users take advantage of both device classes.

Author Keywords

Interactive surfaces, co-located collaboration, smart phones.

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ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI).

General Terms

Experimentation, Human Factors.

INTRODUCTION

It is envisioned that the tables in our domestic environments will turn into interactive surfaces once the price per square meter is in the region of a few hundred Euro. One of the key reasons for buying and using them is the natural support for co-located collaboration, such as information visualization and retrieval or joint planning and decision making [2].

So far it has been widely assumed that users in such a setting will focus almost exclusively on the interaction with the interactive surface. However, this neglects the number of existing personal devices people currently have in use at home such as laptops, tablets, or smart phones and use them for co-located collaboration tasks. Our novel *MobiSurf* concept establishes a seamless integration of personal mobile devices and an additional shared interactive surfaces for co-located collaboration (Figure 1) extending existing interaction concepts and technologies.

The following scenario illustrates how MobiSurf supports collaboration: *Kim and John want to buy a new camera. After an initial discussion and joint web search on the interactive surface, they know what they want and what their needs are (Figure 1a). Then they start searching for offers individually using their personal devices (Figure 1b) as they would like to* *use different web sites, have differing ways of searching, want to check personal discounts, etc. As soon as they find interesting offers, they share them by dropping the web page on the common surface (Figure 1c). Now they can jointly view and discuss their options or go back to individual browsing.*

Using this approach, the mobile devices facilitate interaction in private while the interactive surface constitutes a shared space that is equally accessible to everyone (e.g., for placing information). This also turns mobile and personal devices at home into tools that support collaboration although they are primarily designed for a single user and usually relegate people nearby to mere observers.

The main contributions of the presented research are the results from a study which compared MobiSurf with the current practice of using laptops for co-located collaboration at home. When using MobiSurf, the participants interacted with the mobile devices twice as long as with the interactive surface itself. Furthermore, none of the groups in our study exclusively used the interactive surface or the mobile devices. This shows that the suggested combination of devices provides distinct advantages to the user which has not been exploited in existing systems. Furthermore, participants exchanged two to three times more web pages using MobiSurf than with the laptop-based approach further supporting the value of our approach.

RELATED WORK

MobiSurf mostly builds on work in co-located search in general as well as the combination of personal and shared displays and the way information is transferred between them.

Co-located Search

Collaboration in information seeking is very common. A recent web survey found that 97% of 204 respondents had already engaged in a collaborative web search activity [12]. Further, 88% of those who searched the web collaboratively reported doing so in a co-located setting. Similarly, in a diary study with 20 participants, Amershi and Morris observed 38 co-located collaborative web search sessions within one single week of which 45% occurred at home [2].

This motivates why there has been considerable research on supporting small-group co-located collaboration. Most of this has focused on the use of a single large interactive display. We basically follow this as it has been shown to support teamwork activities [25] and improve collaboration in general [3]. While Schneider et al. summarize advantages of using multi-touch tables for collaboration with respect to other systems [19], the successful integration of tabletop systems in the home has been frequently demonstrated (e.g., [24]).

Morris et al. have extensively studied tabletops for collaborative browsing and provide an overview of several projects using Microsoft Surface for collaborative search tasks, discussing the design space and challenges [13]. For instance, WeSearch has been designed for collaborative web search to leverage the benefits of tabletop displays for face-to-face collaboration [15]. A user study showed that tabletop displays facilitate collaborative web search. Furthermore, it revealed that they enhance the awareness of group members' actions and artifacts such as search criteria and allow fluent transitions between tightly- and loosely-coupled work styles.

A few studies have been conducted comparing collaboration when each user has a personal device to using a tabletop system only. Heilig et al. in [7], e.g., found that, with respect to a setting with synchronized laptops, their tabletop version fostered more simultaneous interactions, people were more likely to interrupt and engage in other users' actions, and they needed less short interruptions to notice and interpret "non-verbal expressions of the other group members". Yet, their study focused on a special tangible, physical token as an additional UI element on the tabletop and also did not incorporate cross-device sharing.

In the last years, some projects have begun to extend collaborative systems with several devices, especially multi display environments. These systems, however, usually involve high cost for acquisition, setup, and maintenance. They are thus mostly targeted at specific groups at a professional level and not suitable for home use (e.g., combining large vertical displays with a multi-touch tabletop to support scientific exploration of large data sets in teams [27]).

Personal and Shared Displays

A major theme in combining mobile and shared devices is that a personal screen can keep private documents or data such as passwords invisible and unreachable to other users. For example, Döring et al. used a tabletop as digital poker table while the cards of each users show up only "in their hands" on the mobile phone [5]. Other projects have shown additional promising uses of mobile displays in combination with large displays, e.g. the ability to present additional information [21, 27], enhance mobility of the overall system [9], improve control and security (e.g., for authentication [16]), leverage group discussions [22], and share information across different classes of displays [17].

Wallace et al. provide a comprehensive overview of projects that integrate heterogeneous devices [25]. Other research working with a combination of devices mostly focused on systems limited in some sense or concentrated on a specific issue. For example, the CoSearch system employs mobile devices mostly for cursor control and download of material [1]. Twidale also integrated phones into his system to upload images onto a shared display [24]. However, no further sharing or synchronization functionality has been envisioned.

Mobile Data Sharing Interaction

With respect to how data can be shared between a mobile device and an interactive surface, many approaches have been proposed: placing the phone on the table [28], using the phone's camera to detect its location with respect to a tabletop [4], or detecting dragging gestures across displays [8]. Also, gesture-based systems for moving data between screens have been implemented (e.g., [10]). In order to provide an easy to understand, quick interaction style for transferring data from a mobile device to the surface and back that requires little effort, we chose to employ *PhoneTouch* which is based on direct touch interaction between mobile and surface [18]. In order to transfer data using this technique, users simply touch the surface with their phone and selected data items are transferred and appear at the touch location on the surface. The technique allows users to transfer data from the surface to their phone (*picking them up*) through touching the corresponding item with their phone.

CONCEPT

The MobiSurf concept has been developed along the lines of various guidelines retrieved from related systems and projects: Amershi and Morris conducted a set of interviews leading to seven limitations of current co-located collaborative web search practices [1]; the last three (*Referential Difficulties*, *Single-Track Strategies*, and *Information Loss*) have also been stressed in the context of remote collaboration [14]. Besides these, Scott et al. identified three more guidelines for co-located collaborative tabletop systems [20] and Twidale et al. empirically derived guidelines for media surfaces in domestic environments [24]. Yuill and Rogers created a mechanism framework of factors for collaboration including *Awareness, Control,* and *Availability* [29]. Finally, studies with their WebSurface system lead Tuddenham et al. to a set of design goals for a tabletop-based co-located collaborative systems [23].

We summarized most of those issues and guidelines into five groups G1-G5. The following listing shows how the MobiSurf concept is built on top of them:

G1 The issues of *Difficulties Contributing* and *Pacing Problems* [1] as well as the feature *Independent Work* [23] are implemented by **giving each user a personal device**

G2 The issues of *Referential Difficulties* [1] and *Lack of Awareness* [1, 14, 23, 29] as well as features *Designing Activity Centers* and *Coordinate Displays* [24] are implemented by **using a shared device for all users**

G3 The issue of *Information Loss* [1, 14] is implemented by **using a tabletop as storage device for (intermediate) results**

G4 The features *Single-Track Strategies* [1, 14], *Flexible User Arrangements* [20], *Combining and Linking Heterogeneous Devices* [24], and *Transitions between Working Independently and Closely Together* [23] are implemented by allowing **easy switching between personal and shared device**

G5 The features *Natural Interpersonal Interaction* [20] and *Seamless Sharing of Results* [23] are implemented by an **easy to use cross device information sharing technique**

Thus, MobiSurf is based on the observation that collaborative searching and planning tasks often consist of individual and shared phases. People need to be able to follow their own strategies (**G1**) while at the same time be able to easily share their results with each other (**G2**). Accordingly, the concept includes one large, shared interactive surface (**G3**) and personal mobile devices for each user. For a seamless integration and supporting shifting between individual and joint work (**G4**), it is important, especially for ad-hoc meetings that often happen in the home, that information can be easily transferred from one device to another through a simple interaction technique (**G5**). This is provided by using a simple touch-based interface.

MobiSurf Application Design

From the user's perspective, the system consists of two main components: a web browser application running on the shared surface (Figure 2) and a web browser application running on the personal mobile device.

Figure 2. Two users jointly viewing and interacting with information on the shared surface.

The web browser application on the interactive surface allows users to open any number of browser windows on the surface which can be arranged freely using a corresponding handle at the top of the window (Figure 3). Browser windows support touch-based interaction with the web page content and controls (e.g., links, buttons, or scrolling) and a virtual keyboard is available for text input. Users can control the zoom level using corresponding buttons on the left of each browser window.

Figure 3. The shared browser application on the interactive surface.

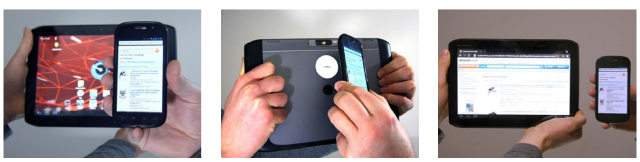
The web browser application on the mobile devices (implemented for Android devices) allows the exchange of web pages with the interactive surface and other mobile devices through transferring URLs of the respective web pages (this implementation is limited to websites that encode session information in the URL). For instance, when a user wishes to transfer a web page from the mobile device browser (Figure 4) to the surface to share it with other users, the user simply touches the surface with the mobile device at the desired location (Figure 4(b)). The touch event gets detected, the URL of the page is transmitted in the background via WiFi, and the web page is loaded and displayed on the surface (Figure 4(c)). For picking up web pages from the surface in order to further review them on the personal device, the user just touches a displayed browser window on the surface with their phone.

After the touch event is detected, the page URL is transmitted, and the web page is loaded and displayed on the mobile device.

(a) (b) (c)

Figure 4. Transferring data from a mobile device to the surface. The web page shown in the mobile browser (a) is transferred to the surface using PhoneTouch [18], causing the system to create a new browser window (b). The received webpage is then immediately loaded (c).

In addition, users can exchange web pages directly between mobile devices. In order to do so, the *sending* device needs to display the web page which is to be shared (Figure 5(a)). The *receiving* device displays the home screen. As the users hold both device close to each other (Figure 5(b)), the web page is transferred and displayed on the receiving device (Figure 5(c)). For MobiSurf, we used Near Field Communication (NFC) to implement this functionality.



(a) (b) (c)

Figure 5. Transferring data between mobile devices. (a) The phone displays a web page (sender); the tablet shows the home screen (receiver). (b) Users hold their devices together for reading the NFC tag information. (c) The page is transferred from phone to tablet.

COMPARATIVE STUDY DESIGN

We designed and conducted a user study in order to gain in depth insights of how users interact with MobiSurf in comparison with current practice. The general aim of the study was to investigate to what extent MobiSurf facilitates collaboration. In doing so, we are particularly interested in its abilities to seamlessly integrate personal mobile devices and a shared large interactive surface to support varying collaboration styles. Also, how and to what extend are users taking advantage of different classes of devices offered simultaneously. We are further interested in how the provided shared space supports information sharing and discussion as basis for joint decision making

Current Practice

To guide the design of a the system which reflects current usage realistically we conducted a web-based survey about current practices and reasons for collaboration when performing planning or shopping tasks on the web. We advertised the questionnaire via a department email list (ca. 250 recipients) and posted it on a departmental discussion board. As incentive, participants could win one of five gift vouchers for 10 € each. In total, 54 persons (13 female), aged between 19 and 34 (M=24) completed the questionnaire. The majority of participants reported to *always* (18.5%) or *often* (40.7%) collaborate with others for online shopping. When planning holiday trips 35.2% reported to collaborate *always*, 24.1% *often*, and 31.5% *sometimes*. In general, 83.3% reported to be co-located with their collaborators. Laptop computers were most often used (90.7%) followed by desktop computers (57.4%), smart phones (46.3%), and tablet computers (11.1%). In response to the question whether they would share a single device with others during collaborative tasks, 13% stated *never*, 25.9% *rarely*, and the majority (42.6%) *sometimes*. Based on these results as well as on related settings reported in the literature (e.g., [1, 12]), we choose to compare MobiSurf with participants working side by side at a table using their individual laptop computers and allow for message exchange via instant messenger.

Practical Tasks

To familiarize participants with the systems, we arranged training tasks before working on the collaborative tasks. These tasks were system specific and covered all features that were available for performing the tasks. In case of MobiSurf, we asked participants to "Use the surface browser to look up your current location (use Google Maps)", "Use the mobile device and search your favorite movie DVD on Amazon. Then, share the results on the surface", and "Share a URL with the other participant using the 'beam' feature". Participants were told that they were allowed to move around the interactive surface. Further, the investigator pointed out that they were free to use the surface or the mobile devices. Participants were also told that they could switch their personal devices if they want to do so.

In case of the laptop-based approach, the training tasks included "Look up your favorite music album and share the link with the other participant by instant messaging". Participants were told that they are allowed to talk, to move and to share their laptop screens as they would like to do.

We designed two simple tasks, yet typical for domestic environments, that allow people to easily relate to in order to investigate co-located collaboration with both systems. Inspired by Morris who found travel planning and shopping to be the most common tasks for collaborative web browsing [12], we also chose these categories for our study.

The first task (T1) required participants to plan a weekend trip to London. Participants had to find options for flights, hotels, and museums they wanted to visit. In addition, participants were told that they had a budget of 700 €. The task was finished when they found a configuration they agreed on. The second task (T2) was to find a birthday present for a friend, which should cost not more than 40 €. Additional information about the friend was given (playing volleyball and badminton). In this task, participants were asked to make suggestions for presents, collect corresponding offers, and come to a final decision on how to spend the money.

In both cases, participants were free to decide by themselves when they were finished with the task. No goals were defined such as short completion time or money they spend. Accordingly, no quality criterion for the outcome of the group collaboration was defined.

Session Structure

We recruited eight pairs of volunteers (i.e. 16 participants in total; seven female) for our repeated measures design. Participants received 10 € as compensation for participation. In each study session two participants worked together. We omitted to include additional group sizes (e.g., triads or small groups) to avoid increasing the study complexity. The session was organized in three parts: 1) introduction, 2) tasks with the MobiSurf and laptop-based approach, and 3) post-hoc questionnaires.

Initially the participants were introduced to the study and gave their consent that recorded data may be analyzed and published. In the second phase, participants were asked to perform two tasks. One task using MobiSurf and another task using the laptop approach, preceded by training tasks with both systems. While working with the laptop approach, participants were sitting at a table and were free to change their position. During the MobiSurf condition, however, participants were standing at the interactive surface device as this makes it easier to reach for distance items on the surface. The order in which participants used the two systems was counterbalanced as well as the task assignment. All task instructions were read by the investigator. After giving the instructions, participants had the opportunity to clarify open questions with the investigator. Participants were allowed 10 min per task after which the investigator asked them to finish their discussion (which was not necessary in any case).

Apparatus

The hardware of the MobiSurf implementation consists of a custom-built interactive multi-touch surface able to support an arbitrary number of connected mobile devices. As mobile devices we used a Samsung Nexus S and a Motorola Xoom tablet. The former has a 4 inches screen with a resolution of 480×800 pixels. The latter has a 10.1 inches screen with a resolution of 1280×800 pixels. The interactive surface is based on frustrated total internal reflection (FTIR) technology using a rear-projected screen (1280×800 pixels on 65×105 cm). The whole system is controlled by a PC (Windows 7 (64), Xeon dual core 2.4 GHz, 4 GB RAM) that runs both the multitouch server and the browser application.

Communication between the interactive surface and the mobile devices was implemented based on the PhoneTouch technique [18]. Mobile devices and the interactive surface are connected via (wireless) network to a central server receiving events. Based on time correlation, the server matches accelerometer events from the mobile devices and corresponding visual events from the surface. Matching pairs of events are considered as *phone touch*. Depending on where the mobile device touches the surface a *picking up* (touch on open browser window on the surface) or *dropping* (touch free area on surface) action is performed. In this implementation of MobiSurf only URLs of webpages are transferred which are loaded on the receiving devices. Accordingly, only websites that encode session information in the URL are supported.

The touch-based transfer of web-pages between two mobile devices was implemented using NFC, whereas one device needs to be equipped with an NFC reader and the other device is equipped with an NFC tag on its back (see Figure 5(b)). For communication between the mobile devices the surface server is used to transfer webpage URLs.

The compared laptop-based approach consisted of two laptop computers (IBM ThinkPad, 15", 1400×1050 pixels) running Windows. As a web browser we installed Mozilla Firefox. To allow users to share information (e.g., a URL) not only verbally, Skype was installed and configured with a corresponding account to allow sharing via instant messaging.

Data Collection

We took notes during the study sessions and recorded videos for a post-hoc multi-pass analysis. We used *ChronoViz* for coding and annotation [26]. Repeated analysis passes allowed us to identify both high-level trends as well as subtleties of ongoing interactions between participants and with devices.

After performing the practical tasks with each system, participants answered questions concerning the systems' ability to support collaborative task performance and selected questions from the NASA TLX questionnaire [6]. As the last part of the user study, participants had to fill out a questionnaire about the two systems and their experiences with them. Participants were also asked to compare the two systems and to share any thoughts and observations they made.

STUDY RESULTS

The 16 participants were aged between 21 and 26 years (M=24). Three of the pairs were couples. Participants of two pairs were sharing an apartment while the remaining pairs were friends. Three were graduate students and the others were undergraduate students. The kind of relation between participants of each pair did not have any significant effects and no correlations to aspects such as verbal communication or sharing of information could be found.

All participants reported that they had prior experiences in collaborative tasks for which computers were used together with other users to achieve the common goals. Reasons for collaboration were ranging from gaming to working on course assignments together with other students. All participants had experiences with planning a trip or buying a product together with others. Each study session lasted for about one hour including the introduction, the tasks, and the completion of the questionnaires.

User Feedback

Initial Semi-Structured Interview

Concerning previously applied practices of the participants for collaborative shopping two themes were reoccurring: Eight participants reported that they used one personal computer together with others (sharing mouse, keyboard, and a single screen). Four participants pointed out that only one person is controlling the computer while the others are sitting nearby and participate in the discussion. In another approach that was described by six participants each user controls their individual device (e.g., the laptop) for searching offers online and discussing their search results with the others simultaneously.

One participant emphasized that using one computer that is shared with the others is quite comfortable because one can point at particular items in a web page. Another participant reported that he experienced the planning of a trip with friends where they set up a projector so that all could see comfortably the web browser while one person was controlling the computer.

Quantitative Feedback

After completing the two tasks with both systems, participants answered questions from a post-hoc questionnaire. The first part focused on aspects of collaboration support. Participants answered the questions on a five points Likert scale (1=very poor; 5= very good; Figure 6). Differences were tested for significance using the Wilcoxon signed ranked test.

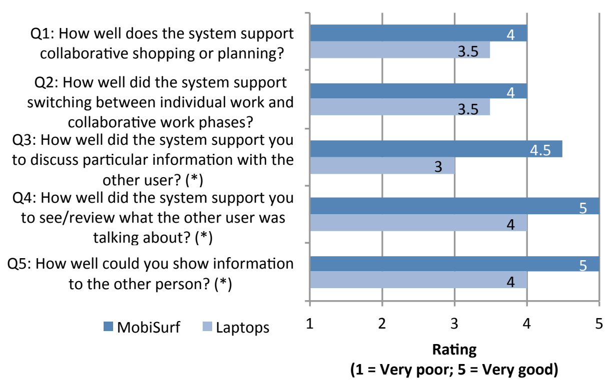


Figure 6. Results of the participants rating the tested systems regarding collaboration support ((*) indicate significant differences).

Answers to (Q1) “How well does the system support collaborative shopping or planning?” and Q2 “How well did the system support switching between individual and collaborative work phases?” indicate both a preference towards the MobiSurf (Mdn=4.0) over the laptop-based approach (Mdn=3.5). Yet, differences are not statistically significant. Question Q3 (“How well did the system support you to discuss particular information with the other user?”) resulted in a significantly higher rating (z=-2.37; p=0.018; r=-0.53) in favor of MobiSurf (Mdn=4.5) compared to the laptop-based approach representing current practice (Mdn=3.0). Also Q4 (“How well did the system support you to see what the other user was talking about?”) resulted in significant higher ratings for MobiSurf (Mdn_{MS}=5.0; Mdn_{Laptop}=4.0) (z=-2.83; p=0.005; r=-0.63). Accordingly, users rated MobiSurf significantly higher (Mdn_{MS}=5.0) in Q5 (“How well could you show information to the other person?”) than the (Mdn_{Laptop}=4.0) (z=-2.7; p=0.007; r=-0.60). The large effect sizes (r) for Q3, Q4, and Q5 were expected considering that MobiSurf provides a shared display for shared reviewing of information.

Participants rated both systems using selected questions from the NASA task load index (TLX) questionnaire [6]. The results for one question show significant differences: ratings of “How physically demanding was the task using this system?” show that participants perceived MobiSurf as physically more demanding (Mdn=2.0) than the laptop-based approach (Mdn=1.0) (z=-2.109; p=0.035; r=-0.52). One probable reason for this different rating is while using MobiSurf, many participants held the mobile device in one hand and did the typing with other one. In particular, participants who used the tablet computer often placed their device on the rim of the surface partially due to the weight of the device. Also, direct touch interaction between mobile devices and interactive surface could be perceived as physically demanding as most users were very careful not to hit the surface too hard with the mobile device. Anther factor that influenced this rating is that users were standing while using MobiSurf and sitting during the laptop-based condition. However, we believe that this factor is rather small as none of the participants gave feedback indicating that standing while using MobiSurf was straining. In fact, standing while interacting with MobiSurf is of advantage as it is easier to reach for distant items on the surface.

Results of the remaining TLX questions do not show significant differences: on average the mental demand was rated to be equally moderate low (both systems with Mdn=2.0). Also the level of effort for accomplishing the level of performance was rated for both systems low (Mdn=2.0) and the success of accomplishing the tasks was rated equally for both systems (Mdn=4.0). The latter aspect indicates that MobiSurf allows participants to reach the collaboration task in to a satisfying level, event though participants were not familiar to use it,

Finally, we asked the participants to compare the two approaches they were using in the study with each other directly. 12 participants answered that in general they would prefer to use MobiSurf. 13 participants answered that MobiSurf allowed them to have a more active conversation and discussion with the other user. In addition, 15 decided that MobiSurf was more fun to use.

Qualitative feedback

To complement the quantitative data we collected qualitative feedback from the study participants, thereby drawing a more detailed picture of the user experience.

Seven participants emphasized that they liked the shared large display as one could show some information to the other user. For instance, P12 pointed out that “you could easily point at specific items on a website”. Another aspect that was perceived as positive by three participants was how the system is supporting the discussion and conversation of the collaborators. For instance, P10 stated “the discussion is very direct”, and “both had the same information available”. Further, four participants identified as a positive aspect that users can start searching individually using the personal mobile device and collect valuable information on the shared screen. One participant highlighted that it was very easy to transfer information between different devices.

Concerning the laptop approach, seven participants indicated that they liked it because they were already familiar with it and have used it before. Four highlighted that exchanging links to webpages containing relevant information was something they liked. For instance, P1 emphasized that "one could share information by turning the screen towards the other person or simply send the link" via instant messaging. However, six participants expressed that the discussion support is not sufficient using individual laptops. For instance, P12 stated that "you cannot show what you are talking about, so one has to turn the screen and point to that piece of information". Also, three participants indicated that sharing of information using instant messaging did not suit their needs. For instance P9 expressed: "I did not know which link I should open and what the other one was talking about."

Video Analysis

Table 1 exhibits the results of our video analysis which are described in detail in the following.

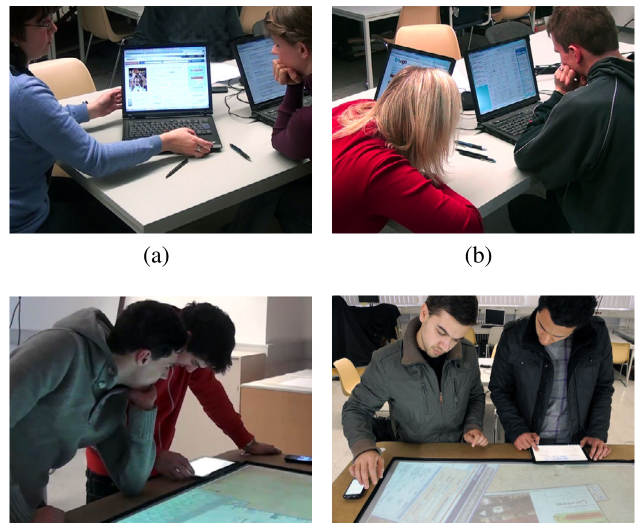
Total duration	**MobiSurf**: 8:11		**Laptop Approach**: 8:49	
Conversation	27.6%	2:15 (1:26)	29.2%	2:34 (0:41)
Joint viewing	28.5%	2:20 (1:28)	5.45%	0:29 (0:30)
Mobile interaction	51.3%	4:12 (3:08)		
Surface interaction	26.1%	2:08 (0:41)		
Pointing		2.5 (2.0)		0.9 (1.4)
Dropping		5.4 (2.7)		
Picking up		0.8 (2.1)		
Instant messaging				1.0 (1.5)

Table 1. Video analysis results (times in minutes, SD in parenthesis): Device interaction, communication, and information exchange in both conditions.

Device Interaction

To complete the tasks, participants took on average 8:11 min with the MobiSurf, and 8:49 min with the system representing current practice. The number of average interaction phases we observed was similar with the mobile device (M=3.6 phases/session) and with the surface (M=3.7 phases/session). Interaction phases included all kinds of touch interactions (e.g., typing, scrolling) interrupted by reading information performed on one device. When a participant changed focus, the phase was considered to be ended. We observed, users interacted about twice as long with their mobile devices (4:12 min, or 51.3% of the average session length) compared to interactions with the surface (2:08 min, or 26.1%) in the MobiSurf condition. In the remaining time (1:51 min, or 22.6%) when participants did not actively interact with one of the two device classes, users mostly discussed with and observed the other participant's interaction. Moreover, participants frequently switched between mobile and surface interaction.

This difference in interaction time of the personal mobile and the shared device results from diverse reasons. First, in all study sessions, participants divided the task and decided to search for offers in parallel. Most participants started searching using the personal mobile device. Two participants decided right from the beginning to use the surface. The main reason appeared to be that the participants preferred to use the larger keyboard on the surface application. As they found satisfying offers they shared and collected them on the surface. When they had collected a set of selected web pages on the surface, the discussion about which option to chose was much shorter as all information were at hand and no time consuming typing was necessary. Second, during the discussion often only one participant interacted with the contents presented on the shared surface, while the other one followed the actions on the surface.



(a) (b)

(c) (d)

Figure 7. Using the mobile and surface system and using the laptop approach, users reviewed information together. (a) Participant actively sharing the laptop screen. (b) Participant leaning over to get a view on the screen of the other participant's laptop. (c) Participant looking at the screen of the mobile device used by the other participant. (d) Two participants reviewing a web page together on the surface.

Using MobiSurf, we observed that participants spent 2:20 min or 28.5% of a session to *jointly* view and interact with shared information on the surface. In contrast, joint information viewing accounted for 0:29 min or 5.45% in the laptop-based condition. This required either actively sharing the screen by turning the laptop towards the other participant (six instances, Figure 7(a)), or leaning over to get a view on the other screen (12 instances, Figure 7(b)).

(a) (b)

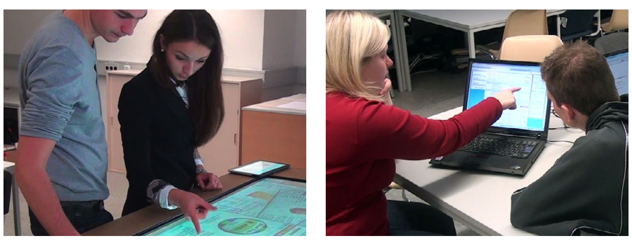
Figure 8. Users often put their mobile devices aside: (a) for typing with both hands and (b) for interacting with the surface.

Regarding mobile device usage, we observed in total 11 occurrences of participants depositing their devices on the surface rim (Figure 8) to free both hands for typing on the tablet

(Figure 8(a)) or interacting with the surface (Figure 8(b)), for example. Two times, both users deposited their mobile devices simultaneously while discussing their search results. In 9 cases, the time period of depositing the mobile device was less than a minute and succeeded by further interaction using the mobile device. In two cases, participants decided not to use the mobile device as they felt more comfortable using the surface application. Therefore, they placed their mobile devices on the surface rim after a short interaction period and continued to interact with the surface application.

Communication

Each participant spent on average 2:15 min for conversation using MobiSurf and 2:34 min in the laptop-based condition. This corresponds to roughly the same amount when compared to the mean session lengths, namely 27.6% (MobiSurf) and 29.2% (laptops). In both systems, the verbal communication was dominated by dialogs between users. Participants frequently articulated information they were looking at or commented on their current actions. For example, one participant stated "I found one [offer] for only 25.99" (MobiSurf). Another said "I just sent you a link", before actually doing so (laptop approach). We also observed an instance of reading out loud the entire text of an offer in the laptop-based condition for comparison with the other participant.



(a) (b)

Figure 9. For discussing information, users point to them on the surface (a), and while using laptop computers (b).

In addition, participants repeatedly used their hands to point out information in both conditions (Figure 9). This happened more frequently using MobiSurf than using the laptop computers, which required screen sharing or leaning over as discussed above.

Information Exchange

Both systems supported directly exchanging web links either by touching the surface with a mobile (MobiSurf) or by sending instant messages (laptop-based). In total, participants dropped 43 web pages (on average 2.7 per participant) but picked up only six with MobiSurf. Turning to the laptop-based approach, a total of 16 instant messages were exchanged (on average 1.0 per participant).

Analyzing the other participants' reaction to a drop interaction, we found that in 18 cases (41.9%) they were already focused on the surface. Another 10 drops (23.2%) interrupted the other participant's ongoing interaction with the mobile and drew their attention towards the surface. We could not observe any reaction for 14 cases (32.5%).

A percentage of 81.3% of sent instant messages resulted in immediately opening the included link on the other side. Two pairs of participants did not use instant messaging at all. Sharing links using instant messaging was accompanied by different actions. For instance, P6 sent a link to P7 to then lean over and discuss the content of the shared web page. In another case, sharing multiple links caused confusion since the receiver was uncertain as to what link the sender referred to in a subsequent conversation.

DISCUSSION

Our study results derived from user feedback and observations indicate that MobiSurf improves on a comparable laptop-based approach which represents current practice and which was identified in a preceding online survey.

MobiSurf successfully supported interleaving individual and group work as participants used both mobile devices (roughly 50% of the time) and interactive surface (roughly 25% of the time) to complete the tasks. Mobile devices were mainly used for individual searching while the surface was predominantly used for the shred discussion which was less time-consuming. They also made frequent use of the possibility to switch between those devices, strongly supporting our design decision **G5**. Especially notable here is that the usage of the mobile devices has been considerable thus confirming **G1** and marking the importance of the differences of MobiSurf to other systems. This is in line with the observation by Marshall et al. that collaborators often start with individual work phases and shift to shared work phases [11].

In particular, participants exchanged digital information more frequently in the MobiSurf condition (43 dropped and 6 picked up webpages) compared to using instant messages in the laptop-based approach (16 exchanged links) which confirms **G4**. Dropping information frequently caused the other participant to interrupt ongoing individual interaction on their mobile and switch the focus to the shared surface, leading to a better understanding of what the other user was engaged with. These findings suggest that users interacting with MobiSurf have a higher awareness of the current state of the workspace compared to the using individual laptops which is what **G2** asked for.

MobiSurf's interactive table proved indeed to be an effective area for shared storage and interaction (see **G3**). In particular, participants jointly looked at the surface for about one fourth of the overall task completion time. They were also substantially more likely to accompany their words with pointing gestures when using MobiSurf. Consequently, the *awareness* (c.f., [29]) of the other user's actions on the shared surface and presentation of information changes the quality of how users collaborate. Transitions between individual work phases and shared work phases are supported through the awareness of the shared surface as users can quickly decide whether they continue with their individual work or join the other user. While participants spent about the same time with verbal communication in both conditions, the majority felt that MobiSurf facilitated more active conversations and provided better support for discussions. This may be attributed to the availability of a common basis for discussion, as provided by the content shown on the shared surface. Further, the shared device creates a higher degree of *control* (c.f., [29]) compared to using individual laptops. As both users have access to displayed information and optionally picking them up with their mobile device allows them to interact with the corresponding web pages individually.

Participants rated MobiSurf to be more physically demanding compared to the laptop condition. The main factor appears to be holding the mobile device with one hand while typing with the other one. Also the direct touch interaction of dropping or picking up information from the surface seemed to be physically straining. Further, participants were standing while using the MobiSurf system as this allowed reaching for distant items more easily. We did not get feedback that indicated that users perceived the standing as unpleasant or tiring, yet, we cannot fully rule out that this as a factor, which we assume to be rather small.

Another interesting finding is that none of the participants used the device-to-device information sharing feature even though all participants were introduced to it during the training phase. It seems that the shared surface already provided an adequate place for sharing information without the direct and quite intrusive and especially interruptive means of pushing content to the other person's mobile device.

Although MobiSurf and particularly its integration of mobile devices with an interactive surface is novel and thus unfamiliar, participants were able to effectively use its features after a brief introduction. A few participants highlighted that they liked the laptop-based approach due to its familiarity, but MobiSurf was still rated as easy to learn and use with low mental demand required. This is also reflected in the similar average completion times and the throughout effortless interaction that we observed. As we allowed users to freely decide when they were finished with a task, we could not apply objective measures for the collaboration outcome. However, participants rated their successes of accomplishing their task when using MobiSurf equally high as in the laptop condition. When asked to state a preference, most participants favored MobiSurf and consistently rated it superior to the laptop-based approach with respect to information exchange and shared viewing.

CONCLUSION AND FUTURE WORK

As technology matures and prices fall, interactive surfaces are expected to become more pervasive in people's homes. In this paper we introduced MobiSurf which integrates an interactive surface into the interaction with people's own personal and mobile devices using existing interaction technologies and techniques.

In our study, we observed that even though participants used the mobile devices twice as long as the shared surface (e.g. for searching), the shared surface proved to be an integral part of the overall interaction. Using MobiSurf, participants shared more links and spend more time jointly viewing web pages compared to the laptop-based alternative. This shows that the mobile devices become central interaction devices and that the interactive surface is primarily used to share information for common discussions or later use.

This observation is very much in line with current situations at home when people discuss based on paper (e.g. holiday planning using various holiday catalogs or brochures) at a table in the kitchen or living room. People are used to take the material in their own hands to read it, show it to others by turning it towards them, place it on the table for discussion, and arrange it on the table to organize previously discussed aspects. People have different strategies and preferences when working in such a way. Some, for example, may prefer to read while holding a paper in their hands while others might prefer placing it on the table to read it. These types of familiar behavior have been taken into account during the design of MobiSurf and the results of our study confirm the need for adding and integrating shared interactive surfaces into interaction with personal mobile devices. Hence MobiSurf provides an environment allowing a user to seamlessly switch between individual and group work and easily share information between devices. As we have shown, these features made users more engaged in the task and helped them to have a better understanding of the current situation.

Our study design featured two specific tasks in a scenario of domestic environments. Although not investigated as yet, we envision MobiSurf to also facilitate co-located collaboration in office or educational situations (e.g., to support collaborative problem solving tasks in schools or planning meetings at work). In addition, surfaces in semi-public settings can serve as walk-up platforms for ad-hoc collaboration. For example, to schedule a meeting, the mobile devices can contribute personal appointments while the surface displays a joint calendar, hence facilitating finding a joint time slot. Besides using mobile devices for separate and private input, they also serve as source for personal data (e.g., documents or photos) that can readily be brought into the shared space.

In future work we will explore how to respond to some of the limitations that emerged during the post-hoc questionnaire in which users expressed the desire of having more discussion support at the feature-level of the system (e.g., organizing information or adding support for more than two concurrent users). Further, we are planning to investigate how MobiSurf can be used by triads and small groups for co-located collaboration.

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