
When Mobile Phones Expand Into Handheld Tabletops

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Abstract

Future mobile devices that feature a rollout display will be able to act as a relatively large interactive surface on-the-go. This will allow for novel collaborative usages in mobile settings. In this paper, we explore several dimensions of the design space of such “handheld tabletop” devices. We will illustrate our thoughts by means of a first prototype. Early evaluation results indicate that it effectively supports mobile social encounters.

Author Keywords

Mobile phone; flexible display; rollable display; CSCW; collaboration; meeting; tablet; tabletop; proxemics

ACM Classification Keywords

H.5.2. [Information interfaces and presentation]: User interfaces – *Input devices and strategies*

General Terms

Design, Human Factors

Introduction

It is only a matter of time when many mobile devices will feature rollout displays. Ongoing advances in flexible display technology [10] will allow for smart phones and tablets with a compact form factor, which



Figure 1. A mobile device with a rollout display can act as a large interactive surface on-the-go. The surface can be dynamically resized to adapt to the demands of different collaborative settings.

can be rolled out, slid out or unfolded to feature a large display surface. Promising first prototypes show that the market breakthrough can be expected in the near future [13].

Prior research [11,8,9] has explored interaction techniques for personal use of resizable mobile devices. How resizable mobile devices can foster co-located collaboration has not been studied. Mobility in collaboration is subject of many studies [12]. It is known from the literature that people do share their mobile devices in co-located settings; however most often only by handing them over [6], not by jointly interacting with the device, since the display of most current devices is too small for collaborative usage.

In this paper, we explore how a mobile device with a resizable display can be used as a shared surface during mobile face-to-face encounters. By enlarging the display, the mobile phone or tablet becomes a handheld interactive tabletop (see Fig. 1). This novel device class generates many open questions, in particular related to how people interact with a mobile device which they jointly hold. The aim of this paper is to explore several dimensions of the design space, in order to guide future research and design.

We start by identifying promising usage scenarios for such “handheld tabletops” and then explore their design space following three themes: 1) What are promising functions of jointly held devices? 2) How can users ensure a comfortable proxemic distance while they hold the device? 3) How can several people jointly hold the device? We will illustrate our thoughts by means of a first prototype and conclude with results of an early user study.

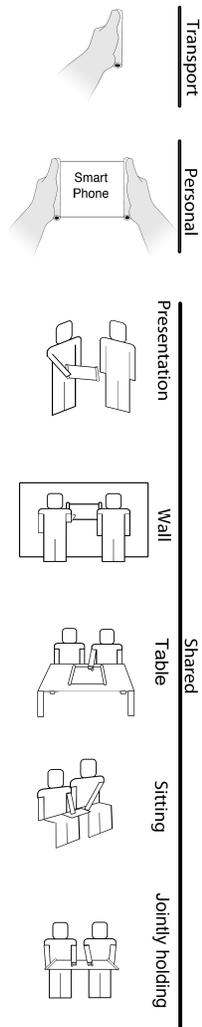
Device Concept

Consider the following example scenarios, which show how short (unplanned or planned) meetings in a mobile setting can benefit from a shared interactive surface:

At the bus stop, Sally and Julie meet casually. They are close friends. They start talking about their recent vacations. Sally decides to show some photos from her Facebook profile. She opens the photo stream on her mobile phone and pulls the display out, such that Julie can see the photos in larger size. Once sitting inside the bus, they put the device on their laps, so both can point to the photos and switch between photos. Finally, Julie also opens her Facebook profile on the device and they exchange some of their photos. Some minutes later, Sally has to get off the bus. She takes the device, rolls it in, and puts it into the pocket of her coat.

At the construction site, Brad, an architect, meets with Jim, the construction manager, to check the construction progress. By pulling out his mobile phone, he unfolds a digital floor plan of the building. Jim grasps the second handle of the device. Both look at the large plan, discuss about it and annotate it with handmade sketches.

In the hallway, Bill runs into his manager. Bill’s task is to prepare a slide presentation for a meeting with customers. One issue is unclear. Bill takes the opportunity to check back with his manager. He expands his mobile device and holds it out to his manager, showing the slide in question. When he has explained the issue, the manager makes a suggestion how the slide could be improved. He grasps one of the handles, expands the display further and directly



modifies the slide. Both together continue improving the slide until they are satisfied with the result.

At the airport, Adam, employee of a car rental agency waits for a customer. He holds his mobile device like a signboard, displaying the name of the customer. Once the customer has approached him, he holds the display horizontally, similar to a tray. The display shows various available cars. The client can flick through photos and additional information about the cars. After he has selected a car, Adam closes the device and asks the client to follow him to the car.

These examples have shown collaborative situations, which benefit from a shared interactive surface. With today's mobile devices, it is difficult or even impossible to create a large interactive surface on-the-go. The display of a single device is typically too small for effective collaboration. Sticking multiple devices together on-the-fly [4,15] creates a shared display, which is sufficiently large for some activities, like comparing or exchanging resources between devices. However, the display size cannot be continuously adapted and is limited to the combined size of the devices. Moreover, it is difficult in mobile settings to maintain several physically unconnected devices in a position which creates a continuous display surface, and even if perfectly aligned, the surface is divided by bezels. Mobile projectors (e.g. [17]) are able to provide a seamless display surface, which can be dynamically resized. However, they require that an adequate and sufficiently large projection surface be available. Moreover, privacy issues arise when projecting personal contents in public.

As an alternative solution, we propose to leverage flexible rollout displays. This allows for constructing a very small mobile device, which, on demand, can be continuously resized to various display widths (see Fig. 2). A small to medium width affords individual work, encompassing for the functions of current smart phones and tablets. Larger widths afford co-located collaboration while people are on-the-go.

A large mobile display is held differently than small to medium sized devices, since it cannot be conveniently held in one hand. Figure 2 shows several configurations: The display can be placed on a table, e.g. in a café, or attached to a vertical surface, e.g. to a wall or to the backside of the front seat in the bus. As an alternative, two or more persons who are sitting side by side can place it on their thighs. However, in many mobile settings, there is no furniture available and people are standing. In this case, two users can jointly hold the device, each with one hand. This leaves the other hand free for gesturing and for performing touch input anywhere on the display within the arm's reach. If more than two persons use the device, the remaining persons do not hold the device and can use both hands for touching. In this paper, we restrict our discussion to cases with only two users.

The former configurations are quite similar to known uses of tabletops and wall displays. In contrast, the latter configuration – a jointly held interactive surface – was, to our knowledge, not considered in previous work. In the remainder of this paper, we focus on the specifics of this novel configuration. In the following sections, we will explore three dimensions of the design space.

Figure 2. Physical design space of handheld resizable tabletops. Other device sizes (e.g. Tablet size) are possible.

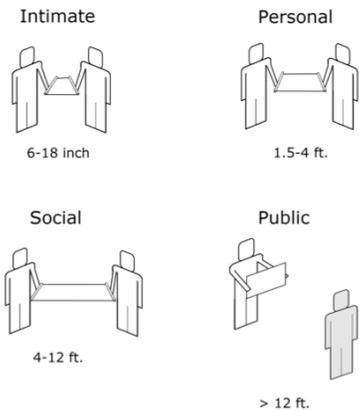


Figure 3. The device concept allows users to adapt their interpersonal distance dynamically. We illustrate this aspect using Hall's four zones of proxemic distance.

Functions of Jointly Holding A Device

Unlike we hold personal mobile devices, a large display cannot be easily held with one hand. It requires that two persons physically coordinate themselves and jointly hold it. At first sight, joint holding could be considered a necessary evil of using a large interactive surface on-the-go. However, we argue that – despite obvious ergonomic challenges – joint holding also has characteristics which can be beneficial for collaboration.

Guiard [2] has shown how physical tasks can benefit from the coordinated use of both hands of one single person. We are not aware of a theory of how *several* persons make coordinated use of their hands. However, a look into real-world practice shows that it is common that several persons hold together a physical object or jointly manipulate it. People have high skills at the coordinated use of their hands.

We identified examples from a variety of real-world practices and derived function classes. Amongst others, people jointly hold or manipulate a physical object because:

1. it is too large or too heavy to be held by one person, e.g. a large unfolded map [1] or a heavy bag.
2. it requires more simultaneous operations than one person can perform with two hands, e.g. folding a bed linen, navigating a sailing ship, or four-handed piano play.
3. it creates a physical connection between people, e.g. lovers jointly hold the photo album they are viewing; lovers jointly hold their bag of popcorn at the cinema; psychotherapists hold a ribbon with

their patients to physically support the interpersonal connection while talking [14].

4. it allows to play games, e.g. collaborative jump roping or competitive Tug of War.
5. it requires a lot of manual labor, which can be speeded up by several persons doing it concurrently, e.g. tilting a quilt, making a hand knotted rug.

Inspired from this practice, we argue that jointly holding a mobile device can have similar functions. Obviously, it allows to more easily hold the large display (function 1 above). However, it has also the potential to create a strong physical connection between the collaborators (3), it allows several persons to temporarily work separately on the same device (2, 5), and it is also well-suited for different forms of gaming (4).

Interpersonal Distance

By jointly holding the interactive surface, the collaborators engage in a physical connection that ties them to one another. The jointly held shared surface also requires that they coordinate the movements of their upper bodies, arms, and hands, because each movement of one person is likely to affect the physical state of the shared surface. It is obvious that this generates a stronger sense of togetherness than if each person holds a separate mobile device.

However, as a matter of course, the physical connection can become too strong. Users might feel “trapped” within a conversation; the connecting ribbon might become a tie. They might also feel awkward, being too close, too intimate to their collaborator.

The design of user interfaces for jointly held mobile devices must account for this balance between a close, but not too close connection. This includes support for flexible transitioning between individual use and shared holds. Second, also *while* several persons jointly hold the device, they should be enabled to flexibly adapt the degree of their proximity.

We propose E.T. Hall's theory of Proxemics [3] as the conceptual framework for modeling proximity between collaborators who jointly hold the device. Hall argues that physical distance between people correlates with their social distance and varies significantly in different situational contexts. He distinguishes four distance zones (intimate, private, social, and public) that each suggest different types of interpersonal interaction. This concept has been successfully applied in a number of ubicomp systems [5,16].

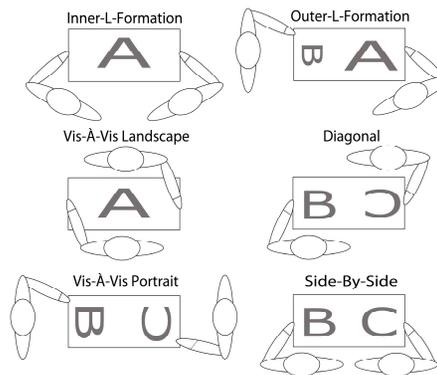


Figure 4. Spatial arrangements of two users. ("A" denotes shared content, while "B" and "C" denote personal contents. For the ease of understanding, the illustration shows the most common hold for each arrangement.)

The continuously adaptable width of the device ensures that users can space themselves in a distance they feel comfortable with while they hold the device. This stands in contrast to jointly holding fix-size mobile devices, where people are forced to position themselves in a distance which is predefined by the form factor of the device. With a rollout display, users can space themselves in an intimate, personal, or social distance (see Fig. 3): If the device is very small, users are in an *intimate* distance and engage in a highly shared activity. For instance, this configuration can be used for discussing about confidential resources that other persons should not see. It is also appropriate for very close friends to create a feeling of intimacy. If the device is larger, users situate themselves in *personal* or *social* distances. These zones allow for a range of contact, from rather intimate to relatively formal ones.

Due to the increased interpersonal distance combined with the quite large screen, not only shared activities, but also personal activities are well supported (see next section). In *public distance*, users cannot jointly hold the device, since they are too distant. For instance, this distance is suitable for presentations to larger audiences or when the rollable device is used as a public information display.

Also during an ongoing conversation, interpersonal distances are changing. For instance, while the distance is typically larger at the beginning of a conversation, distance is usually smaller when people collaborate intensely on the shared surface. When people engage in personal activities (for instance looking up some personal information as input for the conversation), distance tends to increase to ensure privacy.

Put into the context of prior work on rollout displays, this discussion allows us to identify an additional function of display resizing. Prior work [9] has identified two functions: 1) increasing/decreasing display real estate and 2) resizing gestures as explicit tangible input. We add a third, collaborative, function: 3) managing interpersonal distance between collaborators.

Collaborative Holds

Having discussed functions and proxemics of joint holding, we now explore how actually two users jointly hold the device. We argue that different holds each provide adequate support for different communicative situations. By switching between holds, users can flexibly choose and dynamically transition between a variety of working modes.

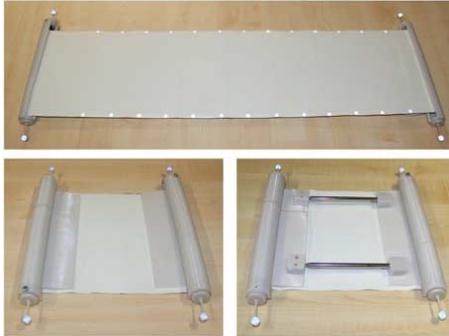


Figure 5. The physical prototypes. The display is 8.7" high and can be resized to widths between 3" and 32". One display is fully flexible (weight: 360 grams). The display of the other prototype is stiff, ensuring that it remains stable even if it is held only at one side (weight: 440 grams). For this aim it contains two telescope poles at its backside.

We propose F-formations [7] as the conceptual lens on collaborative holds. F-formations, introduced by Adam Kendon, is a promising theoretical framework for the analysis of interpersonal orientations in co-present interaction. It identifies a variety of arrangements and describes how these create functional spaces. Kendon shows that the way how people orient themselves in relation to one another directly reflects how they may be involved with one another.

Our taxonomy refines Kendon's formations to take into account the use of a shared artifact. We propose six arrangements, which are depicted in Fig. 4. Similarly to how Kendon maps formations to specific communicative situations, we provide mappings of collaborative holds to collaborative uses of the device:

The *inner L-formation* well supports intense collaboration on a shared artifact. The artifact is displayed in the center of the display and equally visible and reachable by both users. Also the *vis-à-vis landscape formation* creates a shared area in the center of the display. However, shared content is differently oriented to both users, affording different roles (e.g. a mobile counter with a sales clerk and a customer).

A number of other formations afford temporarily leaving the close collaboration in favor of individual work. In the *outer L-formation*, one user disorients himself from the shared area. This affords individual work, e.g., shortly leaving the shared area for entering a password or for looking up relevant information in the personal mailbox. If both users move outwards to the *vis-à-vis portrait formation*, both users have different orientations and are quite distant from each other. While it is not realistic that users of a shared mobile

device engage in extensive separate work on the same device, there are short phases in which the collaboration is interrupted in favor of individual work. As one example, both users in parallel selects photos from their personal Facebook pages before they move back to the inner-L formation to collaboratively review their photos. Also the *side-by-side formation* affords separate work, since the users are oriented to separate areas of the display. Nevertheless, both users are close by; this provides some awareness about the display area of the other user. Finally, the *diagonal formation* is a variant of side-by-side in which the users position themselves at the opposite sides of the device, providing less mutual awareness.

A detailed discussion of the ergonomic aspects of collaborative holds is beyond the scope of this exploration paper. Obviously, jointly holding a device is not well-suited for extended periods of time. In such cases, the device would rather be put on a table, a wall, or laid on the users' laps. In contrast, for shorter periods (which we aim at with our device concept), traditional practice shows that it is perfectly acceptable to jointly hold a lightweight artifact, such as a paper map. We assume that it is even more comfortable to jointly hold a resizable display than if one user held out a fix-size mobile device to the other user. The resizable display allows the users to keep their arms close to their bodies, which is a less strenuous posture.

One further issue is the ergonomics of touch input. In all holds, the free hand can be used for touch input and for gesturing. However, two of the collaborative holds (inner L and side-by-side formation) require that one person uses his left hand while the other person uses her right hand for holding the device. If both persons



Figure 6. Presenting information to a user who is not holding the device.

have the same handedness, this means that one of them must use her non-dominant hand for touch input. Future work should study in detail these ergonomic challenges.

Putting It All Together: A First Prototype

To illustrate our theoretical considerations, we constructed a hardware prototype and designed an exemplary interface.

Despite recent advances in thin-film rollable displays currently available technology does not yet allow us to produce a device with a rollable active display. Similar to [9,11], we therefore opted for a passive display approach. Our physical prototypes are depicted in Fig. 5. An optical motion capture system tracks the position, orientation, and width of the physical prototype in 3D space. Display contents are projected by two full HD projectors and warped onto the display surface. The display update rate is 60 fps; the average resolution on the display approximates 42 dpi. Multi-touch input and the position of users around the device are also tracked by the motion capture system. Our software framework runs native multi-touch applications developed for Microsoft Surface 2.0.

We envision that future devices feature a rollable OLED display, which will increase resolution and make motion capturing obsolete. The arrangement of users will be captured by tiny cameras built into the handles.

To explore collaboration with different device configurations (display size, interpersonal distance, collaborative holds), we developed an exemplary user interface. It supports mobile short-term meetings. Users can display one document or juxtapose several

documents at a time, and browse through the documents using direct touch input. Our prototype supports XPS documents, as a representative for PDFs, photos, and web pages.

Our design makes use of the implicit input that the users convey about the current state of their conversation. By switching between holds and by regulating proxemic distance, users can easily transition between a variety of working modes. Our prototype supports the following modes:

Presenting information: Held by only one user in the L-formation, the device serves for presenting information to a collaborator (Fig. 6 top). If the device is held vertically in a vis-à-vis landscape formation, it can act as a public information display (Fig. 6 middle). In contrast, holding it horizontally invites to the other user to interact with the device (Fig. 6 bottom). For instance, this is useful for a mobile information booth or a sales counter.

Discussing a document: Intense collaborative work is well supported by the inner L-formation (see Fig. 7), which allows both users to interact with the document(s). In this mode, shared documents are displayed in full-screen size. To open documents from the cloud, each user can access a file picker at a personal tray, which is displayed next to his or her handle. By resizing the device, both collaborators flexibly regulate their interpersonal distance to a distance they feel comfortable with. Contents on the display remain centered and automatically fit to the new size.

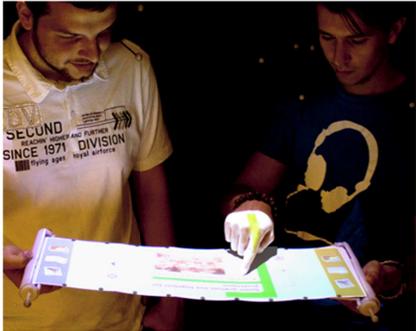


Figure 7. Discussing a shared document in an inner L-formation.

Accessing personal information: Both users can display and access personal information in their personal tray next to their respective handle. Usage examples comprise quickly looking up some information from the personal mailbox or entering a password. When the user turns away from the collaborator to an outer L-formation, personal information rotates to the user's new position and increases in size (see Fig. 8). Since the personal tray always sticks to the handle, privacy can be further increased by increasing interpersonal distance (aka expanding the display).

Temporarily splitting up into sub-activities: A common activity in meetings is to temporarily work in separation (e.g. each user looks up some information) and combine the results later on. This mode is automatically triggered when users enter the vis-à-vis portrait, side-by-side or diagonal formation (see Fig. 9). Then, each personal tray extends until it covers half of the screen. The shared area temporarily disappears. Also here, users can flexibly regulate their interpersonal distance by resizing the device. Users can quickly switch back to the normal shared mode by moving to an L-formation or to a vis-à-vis landscape formation.

We opted for these different modes, which support frequent activities in meetings, to showcase the versatility of the device. It flexibly adapts to various modes of an ongoing collaborative encounter, taking into account variations of collaborative holds and of interpersonal distance.

First User Feedback

We conducted a preliminary user study to gather early user feedback. In particular, we were interested in how users perceive holding a mobile device collaboratively.



Figure 8. Accessing personal information. The user can turn away from his collaborator into an outer L formation. This automatically rotates artifacts in the personal area to the new location of the user and disorients them from the other.

Methodology

Eight volunteer participants participated in pairs of two. Their task was to conduct a short meeting (e.g. a briefing, a document review or a creative discussion) which they would have done anyway. While we did not prescribe what the participants should do during the meeting, it turned out that all four activities introduced above naturally occurred during all of the meetings. Two pairs were close peers: a couple, both professional designers (f, 30y and m, 27y), brainstormed about a joint project; two PhD students who closely work together (m, 29y and 32y) compared their research statements. Two pairs were asymmetric in hierarchy: an undergrad research assistant (m, 28y) and his supervisor (m, 54y) talked about the assistant's job options; a PhD student (m, 29y) and his supervising senior researcher (m, 31y) discussed a presentation.

Each participant could send us documents beforehand (in text, PPT, PDF or XPS format), which we converted and made available on the device. The meetings had an average duration of 22 minutes (SD=8). After the meeting, we conducted a semi-structured group interview. Each entire session lasted about 1 hour. Our qualitative analysis is based on video recordings of the sessions and field notes.

Physical Connection between Collaborators

We were particularly interested in how participants perceived jointly holding a device with their collaborator. Without exception, all participants stated that they really appreciated jointly holding the device, even though many of them had not expected this to be the case: "Frankly, I found it much better than I had expected (...) also because the device is extremely lightweight" (P8). Many participants stated that the



Figure 9. Splitting-up into sub-activities by moving to the vis-à-vis portrait or side-by-side formation. The display is automatically split into separate personal zones.

device creates a close connection to the collaborator. P5: “This brings you closer to one another because you have such a connection... a really physical connection. (...) There wasn’t anything that was between us, like a table, but something that connected us.” This was seen as an advantage for joint work: “We were more focused; we paid attention to what the other person was doing” (P8). “It allows you to really work together on something. It is much better than if each person had a separate device” (P6).

However, P1 was concerned that there might be cases in which the other person is too imposing, in particular with strangers or persons she does not like. In such cases, she could not simply go away because this would be impolite. She would be caught in the conversation.

Collaborative Holds and Interpersonal Distance

During the meetings, we observed frequent and dynamic transitions between collaborative holds and adaptations in interpersonal distance. In line with our observations and statements from other participants, P5 commented: “Except for one single case, I have never thought about how I was standing. I intuitively changed my positions.”

The most frequent mode of all pairs was the inner L-formation. This was used to look at and interact with shared resources, but also in situations where the conversation became more important than looking at the documents. Four participants (P1,2,3,4) often slightly inclined the display towards them, similarly to how we read from paper documents. Moreover, two participants (P1, P2) varied the height in which they held the device. By lowering the device, they increased

their distance to the contents in order to get a better overview of contents.

As expected, participants moved to an outer L-formation before they accessed personal information. P2 and P3 additionally enlarged the device before opening the document to increase privacy. A finding we did not expect was that by courtesy, three participants (P1, P4, P5) also rotated to the outer side while their collaborator accessed a personal document. However, no participant handed the device fully over to the person who was accessing personal documents. This might be different in cases when the device is owned by one of the collaborators.

The display was frequently resized for adapting the screen real estate to the contents. For instance, all participants enlarged the device when a second document was opened, and collapsed it when a document was closed. While all participants commented positively on the large display size, P8 desired an even larger maximum width to allow for displaying a large number of document pages side by side.

Conclusion

In this paper, we explored the new device class of handheld tabletops. Based on an analysis of existing real-world practice and on the theories of Proxemics and F-formations, we discussed three dimensions of the design space and took these considerations as the conceptual basis for a first prototype. This prototype supports a variety of collaborative activities in mobile meetings, by making consistent use of collaborative holds and proxemic distance between users. Early study results indicate that jointly holding a resizable mobile device is promising for collaboration on-the-go,

since it creates a strong connection between users while retaining flexible physical arrangements and flexible spacing of users.

Introducing a novel device class creates a large number of challenges. Many of them are beyond the scope of this paper. Future work should investigate the following aspects: 1) *More advanced hardware prototypes*: Once active rollable displays will be available, fully mobile prototypes can be implemented. While we focused on rollout displays as the most pure solution of continuously resizable display, also foldable and sliding displays deserve attention. 2) *Detailed user studies*: Future work should study more deeply the ergonomic characteristics of a jointly held device as well as interaction with more than two users. 3) *Interaction techniques*: Our considerations can be the basis of novel interaction techniques in a variety of collaborative settings, including collaborative and adversative games.

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