TaPS Widgets: Interacting with Tangible Private Spaces

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ABSTRACT
Interacting with private data is important in multi-user tabletop systems, but hard to implement with current technology. Existing approaches usually involve wearable devices such as shutter glasses or head-mounted displays that are cumbersome to wear. We present TaPS, lightweight transparent widgets that only pass light coming from a particular direction to shield the content beneath them from other users, creating **Ta**ngible **P**rivate **S**paces. TaPS widgets use low-cost hardware to provide tangible privacy controls to interactive tabletops. Informal studies indicate that TaPS widgets enable users to successfully move documents between public and private tabletop spaces without compromising privacy and allow for secret data entry.

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General terms: Security, Human Factors

Keywords: interactive tabletops, transparent widgets, shared spaces, private/public, collaborative working

Introduction

When multiple people interact with a multitouch table, they tend to divide the table space into different territories: *personal*, *group*, and *storage* [20]. Objects in the *group* space are often public and the focus of group discussion, while those in the *personal* space usually belong to one person and often contain private information. Most card games, for example, include private cards in a player's hands, and shared cards on the table. Other scenarios additionally require input or manipulation of private information.

On a traditional table it is easy to veil printed information from others by holding the sheet upwards, but this is difficult to achieve with digital documents on an interactive tabletop. As the display space usually also is the input space, entering private data is difficult as well. Projects like the Responsive Workbench [1] and the Studierstube [6] have addressed this challenge through wearable hardware such as head-mounted displays or special glasses. These hide the visual output from others and make it hard to guess user input from interactions with the void. Other approaches, e.g., [15, 16, 22] use techniques that do not scale well with additional users, or that significantly reduce display resolution. There are dedicated authentication solutions for interactive tabletops, e.g., [14] but they do not help in visualizing general information.

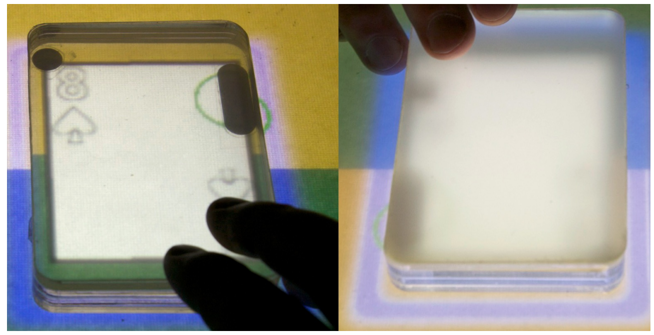

Figure 1: A TaPS widget seen from two sides of an interactive table. Only the card owner (left) can see his card below the widget; his opponent (right) cannot.

TaPS widgets are lightweight, transparent, tangible widgets that reveal the information below them only in one direction, blurring the content for everybody except the owner. While providing hints as to the user's actions, they protect private data beneath them, simplifying collaboration as well as veiling the user's input. In the remainder of this paper, we review related work, explain how TaPS widgets work, and show how they can be used easily with existing interactive tabletops. We conclude with the use of TaPS widgets as input devices. The key contribution of this work is a simple, low-cost solution to make areas on an interactive screen surface readable only for certain users. We do not use wearable hardware but a tangible control widget that can be positioned anywhere on an interactive tabletop.

Related Work

The most established privacy technique is to use your own hand (or a piece of cardboard) as a blind. However, hiding content behind your own hand can result in a physically uncomfortable posture. Blinds also not only hide a private space from others but also block the view onto the shared space from the user herself. Finally, they create a hard border that does not allow others to even get a gist of what the other person is doing. This makes the technique less attractive for collaborative scenarios such as brainstorming or sketching.

Our review of more sophisticated methods focus on systems that are capable of private output, but not necessarily private input. For an overview of private input methods, see [14].

A number of approaches use wearable devices for private information, such as head-mounted displays [6, 9], shutter glasses with time-multiplexing [1, 21], or polarized glasses, avoiding the need for time-multiplexed displays [19]. However, as Gemperle et al. [7] point out, people prefer devices that are familiar, unobtrusive, and do not hinder them in their tasks. This is also supported by Bekker et al. [2] who found that non-verbal communication such as gestures, eye contact, and deictic references are an essential part of collaborative work. Thus, restricting this non-verbal communication by introducing wearable hardware is undesirable.

The first system not requiring wearable devices is the IllusionHole [15], although it does use glasses for stereoscopic vision. It uses a mask with a hole in its center mounted above a standard tabletop display. Users standing on different sides of the table see different areas of the display through the mask, providing them with their own private areas. Head tracking is used to present the correct viewport for each user. The system does not provide means to interact with it, e.g., via touch or a dedicated device.

Rekimoto et al. [18] use a PDA to display personal information with an interactive table for shared media. Similarly to using blinds, however, this separates group interactions and private interactions from each other, hampering cooperation.

The Lumisight Table [16] is a rear projection tabletop that emits different images in different directions. Four projectors, one for each user, project the images through a special foil. The foil works as a diffusor when looked at from the right direction. Users standing on different sides of the table only see the image from their projector. In contrast, our system uses the foil as a blurring filter. This system was extended with tangible mini-screens on the table [13], transparent lenses [11], and displays above the surface [12]. The idea of displaying information on dedicated mini-displays was also implemented by Chan [4] who additionally made the mini-displays reactive to touch. However, both systems are hard to extend to more than four users. Smith et al. [22] use an LCD with a parallax barrier as used in some 3D displays to show different content to different users. Similar to IllusionHole, the head position of the user needs to be restricted or tracked. Additional users, i.e., viewing angles, reduce the resolution significantly: "we were unable to display text clearly for more than four persons" [22]. Both Matsushita et al. [16] and Smith et al. [22] have the problem that users may interact with the same area simultaneously. Where one person sees a text document, the other may see a button, and interacting with either will lead to conflicts. This makes it crucial for a collaborative system to indicate areas under private control to others. We follow the approaches of Fitzmaurice [5] and Ishii [10] who propose using tangibles to control digital content on tabletops. Part of our approach for output was presented in the non-archival alt.chi session at CHI 2011 [17].

Design Requirements

Introducing a privacy technology on tabletops should not hamper social interactions through blinds or wearable technology, scalability in the number of users is crucial, it should avoid conflicting interactions, and tangibles may represent a promising solution. Our TaPS widgets provide such tangible control over private documents using gestures known from the real world. TaPS can be used with various display technologies, scales well with additional users, and provides sufficient privacy without walling off from collaborators. It also can be used for private input by randomizing the UI layout.

Implementation

TaPS widgets consist of a scattering foil on top of an acrylic spacer. The foil (Lumisty MFY1555[1]) scatters the light coming from beneath it depending on the viewing angle. A single foil blurs vision from one side ($90°$) of the widget (Fig. 2). However, just putting this foil directly on a tabletop is not sufficient. The blur is not strong enough, leaving some data readable. Adding the acrylic spacer beneath it increases the blur effect. To restrict vision from a wider area, we use a stack of five foils rotated by $45°$ each. This covers $90° + 4 \times 45° = 270°$, so only viewers within a $90°$ cone from each widget can see the information beneath it. Using more or less foils changes the viewing angle. As the cone of the visibility is centered around the widget (and not the center of the table as in [16]), more than four widgets can be used on the same table without compromising privacy, even with several users on one side of the table (Fig. 3). However, the number of simultaneous widgets is limited by the overall table space.

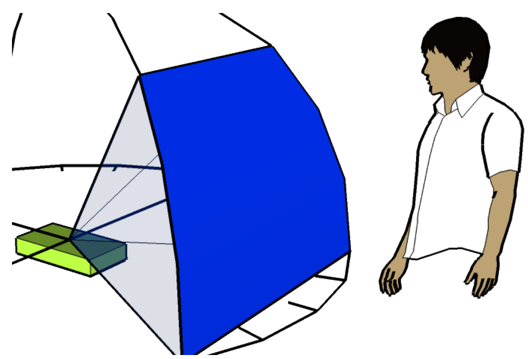

Figure 2: Visibility on an acrylic spacer with a single Lumisty foil. The person on the right will only see blurred content. Any person outside the dark $90°$ cone has a clear view on the content. We use several rotated layers of the foil to widen the cone of invisibility.

Widget Tracking

To display information beneath a widget, its position on the table needs to be tracked. The choice of tracking method depends on the display technology. We include solutions for two technologies: LCD displays for high dpi resolutions, and rear projection for large, collaborative tabletops.

On our rear projection system, we use FTIR [8] for multi-touch sensing; Diffuse Illumination is used to track markers beneath the TaPS widget, following the approach used by the SLAP widget system [23].

On our LCD system, we track the widget using a camera above the screen. LCD screens emit polarized light, and

[1] http://www.sumitomo-chem.co.jp/english/research/develop_basic.html

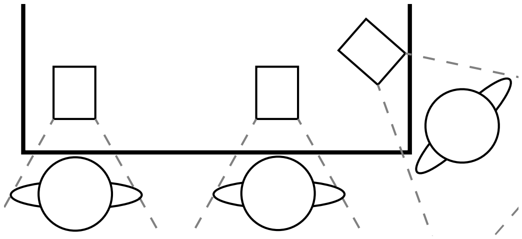

Figure 3: Three TaPS widgets on an interactive tabletop. Each user can only see the content of his widget. The number of widgets can be increased without compromising privacy, yet is limited by positioning of the widgets.

putting another polarization filter in front of the camera blackens the camera image. However, an acrylic widget on the LCD destroys its straight polarization, especially around the widget edges. Thus, the camera sees a black background with a bright white area in the shape of the widget. To track a single widget, we use image convolution to determine pixel-wise gradients, and create a histogram of gradient directions. The four major spikes in this histogram represent the directions of the detected edges. By fitting a linear best-fit curve to each cluster of points, weighted by their gradient magnitude, we obtain a functional representation of the widget shape with sub-pixel accuracy. Image segmentation allows us to track more than one widget.

Readability

Display technology, contrast, brightness, and ambient lighting conditions influence how readable a TaPS widget is, for both its owner and an eavesdropper, making it difficult to provide universal TaPS widget design specifications. We found that in our setting, with 30 pt black text on white background using a 100 dpi Apple Cinema Display, a .6" acrylic spacer increased blurring enough to make any content unreadable outside the 90° cone. When contrast of the content was reduced by using dark gray (150/255) text on light gray (100/255) background, the blurred image became even more uniform, allowing us to decrease the acrylic spacer to .3" while still protecting the content. Using a 24 pt font had a similar effect, allowing for a .4" spacer. None of these variations reduced readability significantly for the widget owner. If the content is colored or printed in bold fonts, we recommend to switch to a smaller font and gray tones as soon as a TaPS widget is put above the content.

Exploring the Design Space

TaPS widgets can easily be created in various shapes and sizes to serve different uses and application domains. These fall into three categories which we call *bit, lens,* and *space*.

If the widget is similar in shape and size to a single digital artifact it covers, it becomes a direct physical counterpart of that digital object, or *tangible bit*, as suggested by Fitzmaurice [5] and Ishii [10]. When used this way, the widget is tied to a particular object or class of objects, and the digital object should not be resized, to maintain coherence.

The TaPS widget can also be made in a default size and be used as a privacy *lens* [3] that will make any content private that it is placed upon.

Finally, an even larger TaPS widget, e.g., $1\text{ft}\times\frac{1}{2}\text{ft}$, can represent the private interaction *space* of a user. Such a widget would usually be used in a more stationary way, and typically directly in front of the user.

To explore the effects of these different sizes, we developed a tabletop version of the card game *Thirty-One*, in which three players exchange their cards with a public, shared stack of cards. We evaluated two form factors with ten test users: (i) card-sized tangible bits for each of their cards, and (ii) a privacy lens large enough to cover all cards of one user at once, while software would blank out those cards that were not covered by their widget.

Our testers overall preferred the tangible bit condition to organize and exchange private items. In the case of the privacy lens, users were interested in interacting with widget contents directly by touching on the widget surface, which was not possible during this test. We saw two strategies to cope with that problem: some users moved the lens away to expose the cards, manipulated the cards, and then slid the widget back. Others arranged their cards along the widget's edges so that a portion of each card protruded from under the widget and served as a handle. One approach to offer input would be to provide a specific area next to a widget that users can interact with to indirectly manipulate the contents beneath the widget. However, we will present a direct-manipulation solution below. Overall, users felt the system was trustworthy for the designated use-case but were not sure whether they would use it for sensitive data.

Private Input

Figure 4: A TaPS Widget covering a PIN entry component. The randomized layout makes it impossible for others to guess the entry from the finger movement.

Motivated by the above findings, we enhanced the widget to receive user input. We used FTIR [8] by attaching a strip of IR LEDs to the side of the widget. In a study with 18 participants, users were asked to enter data and observe each other taking turns. The widget was placed on a 5×3ft table over a randomized PIN entry (Figure 4) directly in front of user A, who was standing on the short side of the table. The first independent variable was the position of user B: middle of the long side of the table or on the opposing side. The second variable was how we randomized the layout of the keypad: after each full 4-digit PIN input (1-shuffle) or after each finger tap (n-shuffle). Users switched roles after two PIN entries.

The PIN entries were only guessed right three times. Using 1-shuffle or n-shuffle had no impact on the security, but all users felt more secure using n-shuffle. Acceptance of randomizing the layout was mixed: "I remember PINs as shapes, shuffling is unacceptable" versus "n-shuffle is not a problem for four digits". Extending the shuffle concept to TaPS-based keyboards or other UI components should preserve its security, but users will not be able to apply existing knowledge such as input shape or ten finger typing.

Conclusion

In this paper, we demonstrated a simple way to make varying areas on an interactive tabletop readable only for certain users. We proposed TaPS widgets, tangible controls for such private spaces, explained how to include these into a variety of existing interactive tabletop systems, and how to use them for secure data entry. TaPS widgets do not need wearable hardware, scale well with additional users, require only low-cost hardware, and do not suffer from concurrent access conflicts.

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