TaPS Widgets: Tangible Control over Private Spaces on Interactive Tabletops

Max Möllers
RWTH Aachen University
moellers@cs.rwth-aachen.de

Ray Bohnenberger
RWTH Aachen University
ray.bohnenberger@rwth-aachen.de

Stephan Deininghaus
RWTH Aachen University
stephan.deininghaus@rwth-aachen.de

Patrick Zimmer
RWTH Aachen University
patrick.zimmer@rwth-aachen.de

Karin Herrmann
RWTH Aachen University
herrmann@humtec.rwth-aachen.de

Jan Borchers
RWTH Aachen University
borchers@cs.rwth-aachen.de

CHI 2011, May 7–12, 2011, Vancouver, BC, Canada.
ACM 978-1-4503-0268-5/11/05.

Abstract
Private areas are 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.

Keywords
Interactive tabletops, transparent widgets, shared spaces, private public, collaborative working

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

General Terms
Experimentation, human factors, security

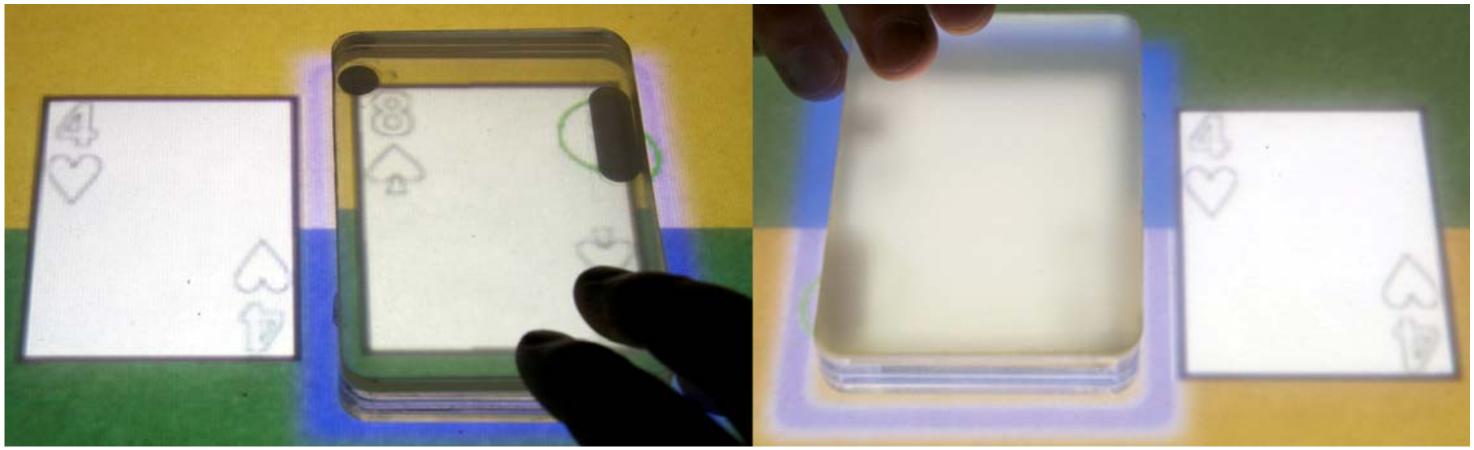

Figure 1. A TaPS widget seen from two sides of an interactive table. Left) The owner can see his card. Right) The other player cannot see it.

When multiple people interact with a multitouch table, they tend to divide table space into different territories: personal, group, and storage [21]. 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 that should not be revealed to the whole group. Most card games, for example, include private cards in a player's hands, and shared cards on the table. Another scenario is an exam in which the examiner has prepared a list of questions that she does not wish to reveal all at once.

A traditional table makes it 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. Projects like the Responsive Workbench [1] and the Studierstube [7] have addressed this challenge through wearable hardware such as head-mounted displays or special glasses. Other approaches, e.g., [17, 18, 23] use techniques that do not scale well with additional users, or that significantly reduce display resolution.

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.

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 a first look at using TaPS widgets as input devices. Thus, 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 via a tangible control widget that can be positioned anywhere on an interactive tabletop.

RELATED WORK

We aimed for a privacy technique that would still support walk-up use without any explanation. Each user should have tangible control over his documents, and should be able to move or orient private documents such that they are hard or impossible for others to read.

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.

More sophisticated methods have been proposed. Rekimoto et al. [19] 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. Other approaches use wearable devices for private information, such as head-mounted displays [7, 10, 24], shutter glasses with time-multiplexing [1, 22], or polarized glasses, avoiding the need for time-multiplexed displays [20]. However, as Gemperle [8] points out, humans 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 nonverbal 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 [17], 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.

The Lumisight Table [18] 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. Users standing on different sides of the table only see the image from their projector. This system was extended with tangible mini-screens on the table [14], transparent lenses [12], and displays above the surface [13]. 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. [23] use an LCD with a parallax barrier as used in some 3D displays to show different content to different users. Similar to IllusionHole, users' head positions need to be restricted or tracked. Additional users, i.e., viewing angles, reduce resolution significantly: "we were unable to display text clearly for more than four persons" [23].

Both [18] and [23] exhibit a fundamental usability problem: users may attempt to 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, to keep them from using them. We follow the approaches of Fitzmaurice [5] and Ishii [11] who propose using tangibles to control digital content on tabletops.

Design Requirements

The above discussion reinforces the requirements that introducing a privacy technology on tabletops should not hamper social interactions through blinds or wearable technology, that scalability in the number of users is crucial, that it should avoid conflicting interactions, and that tangibles may represent a promising solution. Our TaPS widgets provide such tangible control over private documents using gestures known from the real world. The TaPS approach can be used with various display technologies, scales well with additional users, and provides sufficient privacy without walling off from collaborators.

IMPLEMENTATION

TaPS widgets consist of a scattering foil on top of an acrylic spacer. The foil (Lumisty MFY15551[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

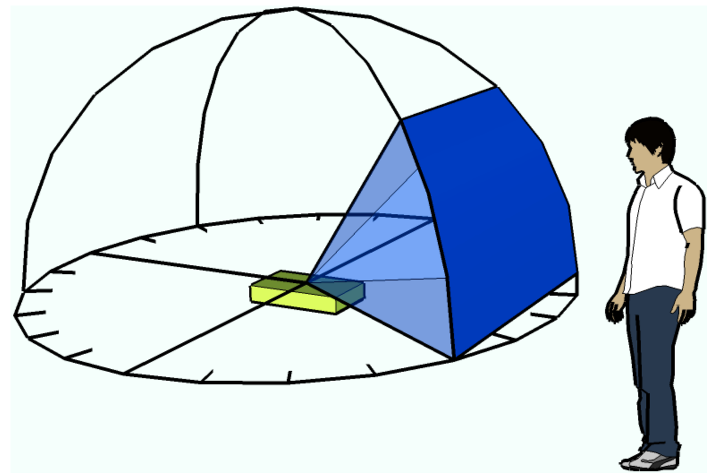

Figure 2. Visibility for a single Lumisty foil on an acrylic spacer. The person on the right will only see blurred content. Any person outside the dark 90 degree cone has a clear view on the content. We use several rotated layers of the foil to widen the cone of invisibility.

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 × 45° = 270°, so only viewers within a 90° cone from each widget can see the information beneath it. As a result, 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).

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

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

solutions for two technologies: LCD displays for high dpi resolutions, and rear projection for large, collaborative tabletops.

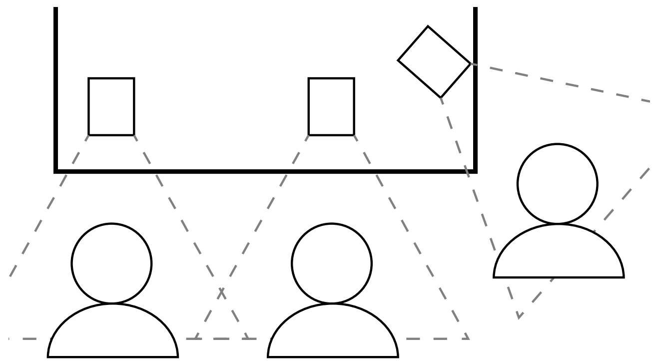

Figure 3. Three TaPS widgets on an interactive tabletop. Each user can only see the content of his widget. The number of widgets can be increased further without compromising privacy.

On our rear projection system, we use FTIR [9] for multitouch sensing; Diffuse Illumination is used to track markers beneath the TaPS widget, following the approach used by the SLAP widget system [25].

On our LCD system, we track the widget using a camera above the screen. LCD screens emit polarized light, and putting another polarization filter in front of the tracking 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. This is tracked using standard computer vision. We use image convolution to determine pixel-wise gradients, and create a histogram of gradient directions [6]. 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. To track more than one widget, we preprocess the data using k-means clustering [15].

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 contents outside the 90° cone. 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.

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 that 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 [11]. When used

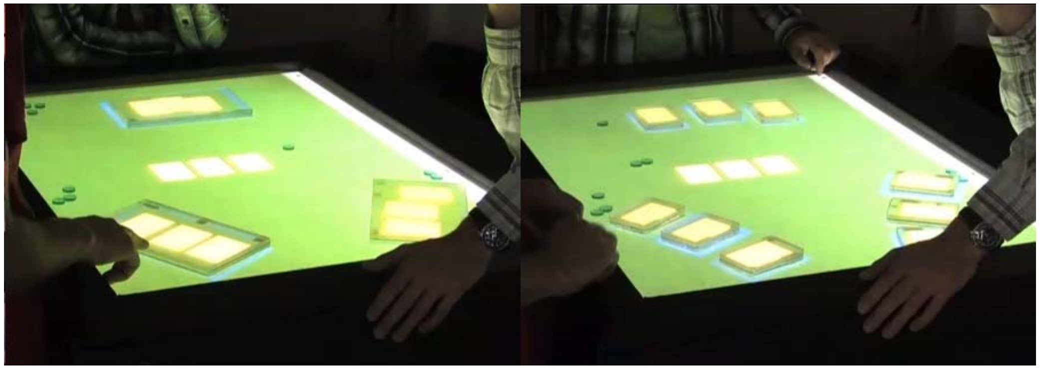

Figure 4. Two different study setups. Left) 1 ft x 1/2 ft-sized widgets serving as magical lenses. Right) card-sized widgets acting as tangible bits.

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., 1ft×1ft, 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 magical lens, users were interested in interacting with widget contents directly by touching on the widget surface, which was not possible in this version. 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. We will address a possible technical solution to this problem in the future work section. However, one could also use indirect manipulation techniques where a specific area next to the widget can be used to manipulate content beneath it. Overall, users felt the system was trustworthy for the designated use-case but were not sure whether they would use it for highly sensitive data.

FUTURE WORK

Supported by early user feedback, we wanted to enable TaPS widgets to receive user input. We used FTIR [9] by attaching a stripe of IR LEDs to the side of the widget. Touching on the surface yields very bright spots on the infrared camera image. Preliminary testing suggests that Diffuse Illumination could also be used for touch detection. This would remove the need for batteries or cables to power the LEDs. Such a touch-active TaPS widget could be used for private input such as PIN entry. Randomizing the layout of a number pad on the TaPS widget would make it impossible for eavesdroppers to guess the PIN code. We will explore this promising direction further, and compare it to existing privacy techniques for multitouch such as [16].

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, and explained how to include these into a variety of existing interactive tabletop systems. TaPS widgets scale well with additional users, require only low-cost hardware, and do not suffer from concurrent access conflicts.

ACKNOWLEDGEMENTS

We thank all the participants of our user studies. This work was funded in part by the German B-IT Foundation and by the German Government through its HumTec Human Technology Center at RWTH Aachen University.

REFERENCES

[1] M. Agrawala, A. Beers, I. McDowall, B. Fröhlich, M. Bolas, and P. Hanrahan. The two-user responsive workbench: support for collaboration through individual views of a shared space. *Proc. SIGGRAPH'97*, 332–388.

[2] M. Bekker, J. Olson, and G. Olson. Analysis of gestures in face-to-face design teams provides guidance for how to use groupware in design. *Proc. DIS'95*, 157–166.

[3] E. Bier, M. Stone, K. Pier, W. Buxton, and T. DeRose. Toolglass and magic lenses: the see-through interface. *Proc. SIGGRAPH'93*, 73–80.

[4] L. Chan, T. Hu, J. Lin, Y. Hung, and J. Hsu. On top of tabletop: A virtual touch panel display. *Proc. TABLETOP'08*, 169–176.

[5] G. Fitzmaurice, H. Ishii, and W. Buxton. Bricks: laying the foundations for graspable user interfaces. *Proc. CHI'95*, 442–449.

[6] D. A. Forsyth and J. Ponce. Computer Vision: A Modern Approach. *Prentice Hall Professional Technical Reference*, 2002. ISBN 0130851981.

[7] A. Fuhrmann, H. Lo ffelmann, and D. Schmalstieg. Collaborative augmented reality: exploring dynamical systems. *Proc. Visualizations'97*, 459–462.

[8] F. Gemperle, C. Kasabach, J. Stivoric, M. Bauer, and R. Martin. Design for wearability. *Proc. Wearable Computers'98*, 116–123.

[9] J. Han. Low-cost multi-touch sensing through frustrated total internal reflection. *Proc. UIST'05*, 115–118.

[10] H. Hua, L. Brown, C. Gao, and N. Ahuja. A new collaborative infrastructure: Scape. *Proc. Virtual Reality'03*, 171–179.

[11] H. Ishii and B. Ullmer. Tangible bits: towards seamless interfaces between people, bits and atoms. *Proc. SIGGRAPH'97*, 234–241.

[12] Y. Kakehi, T. Hosomi, M. Iida, T. Naemura, and M. Matsushita. Transparent tabletop interface for multiple users on lumisight table. *Proc. TABLETOP'06*, 143–150.

[13] Y. Kakehi and T. Naemura. Ulteriorscape: Interactive optical superimposition on a view-dependent tabletop display. *Proc. TABLETOP'08*, 189–192.

[14] Y. Kakehi, T. Naemura, and M. Matsushita. Tablescape plus: Interactive small-sized vertical displays on a horizontal tabletop display. *Proc. TABLETOP'07*, 155–162.

[15] T. Kanungo, D. Mount, N. Netanyahu, C. Piatko, R. Silverman, and A. Wu. An efficient k-means clustering algorithm: Analysis and implementation. *Transactions PAMI'02*, 24(7):881–892.

[16] D. Kim, P. Dunphy, P. Briggs, J. Hook, J. Nicholson, J. Nicholson, and P. Olivier. Multi-touch authentication on tabletops. *Proc. CHI'10*, 1093–1102.

[17] Y. Kitamura, T. Konishi, S. Yamamoto, and F. Kishino. Interactive stereoscopic display for three or more users. *Proc. SIGGRAPH'01*, 231–240.

[18] M. Matsushita, M. Iida, and T. Ohguro. Lumisight table: a face-to-face collaboration support system that optimizes direction of projected information to each stakeholder. *Proc. CSCW'04*, 274–283.

[19] J. Rekimoto and M. Saitoh. Augmented surfaces: a spatially continuous work space for hybrid computing environments. *Proc. CHI'99*, 378–385.

[20] S. Sakurai, Y. Kitamura, S. Subramanian, and F. Kishino. Visibility control using revolving polarizer. *Proc. TABLETOP'08*, 161–168.

[21] S. Scott, M. Sheelagh, T. Carpendale, and K. Inkpen. Territoriality in collaborative tabletop workspaces. *Proc. CSCW'04*, 294–303.

[22] G. Shoemaker and K. Inkpen. Single display privacyware: augmenting public displays with private information. *Proc. CHI'01*, 522–529.

[23] R. Smith and W. Piekarski. Public and private workspaces on tabletop displays. *Proc. AUIC'08*, 51–54.

[24] Z. Szalava ŕi, E. Eckstein, and M. Gervautz. Collaborative gaming in augmented reality. *Proc. VRST'98*, 195–204.

[25] M. Weiss, J. Wagner, Y. Jansen, R. Jennings, R. Khoshabeh, J. Hollan, and J. Borchers. SLAP widgets: bridging the gap between virtual and physical controls on tabletops. *Proc. CHI'09, 481–490.*