ReflectoSlates: Personal Overlays for Tabletops Combining Camera-projector Systems and Retroreflective Materials

Diego Martinez
University of Bristol
diego.martinez-plasencia@bristol.ac.uk

Jarrod Knibbe
University of Bristol
jarrod.knibbe@bristol.ac.uk

Andy Haslam
University of Bristol
ah0744@my.bristol.ac.uk

Eddie Latimer
University of Bristol
el0545@my.bristol.ac.uk

Barney Dennis
University of Bristol
bd0906@my.bristol.ac.uk

Gareth Lewis
University of Bristol
gl0262@my.bristol.ac.uk

Matthew Whiteley
University of Bristol
mw0829@my.bristol.ac.uk

David Coyle
University of Bristol
david.coyle@bristol.ac.uk

CHI 2014, Apr 26 - May 01 2014, Toronto, ON, Canada
ACM 978-1-4503-2474-8/14/04.
http://dx.doi.org/10.1145/2559206.2581269

Abstract

Tabletop systems are great platforms for collaborative work and social interaction. However, many fail to also accommodate contents visible only to some users, or they do so by reducing the surface visible to the rest of the users. We present ReflectoSlates, which combines a chest mounted camera-projector system connected to the user’s mobile device and retroreflective sheets (ReflectoSlates). When placed on the tabletop, ReflectoSlates allow users to see their private contents while other users continue to see the tabletop. They can be lifted and moved while still displaying each user's individual content. Users can also interact with them using mid-air gestures detected by the camera-projector system. This way they do not interfere with other users when their contents are in the tabletop, or they can continue to interact with them, when they lift the ReflectoSlate or walk away from the tabletop.

Author Keywords

Tabletop; Retroreflective Surface; Camera-projector System; Personalized contents; Multi-User.

ACM Classification Keywords

H.5.3 Information interfaces and presentation (e.g., HCI): Group and Organization Interfaces

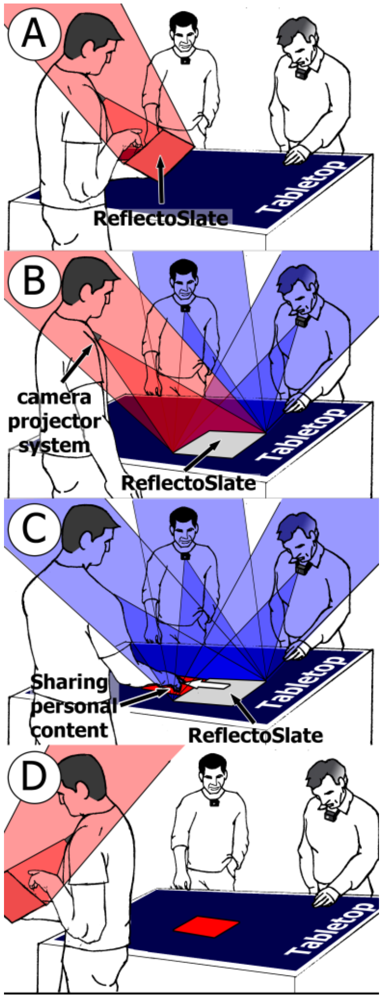

Figure 1. (a) Users can join in, bringing their personal contents.(b) These are not visible to others, until the owner shares them (c). (d) Users can leave, while interacting with content in their ReflectoSlate.

Introduction

Tabletop systems are often used to support information sharing and collaborating, but they also encourage social interaction and discussion among the users around them. However, while the always-visible shared surface of a tabletop encourages this collaboration, it can also limit the opportunities for customized or private views for each user.

Recognizing this limitation, researchers have proposed systems that combine tabletops with tablets or other personal devices for the presentation of customized content. This encourages spontaneous collaboration among users, who can simply approach the tabletop, share content and collaborate [14]. These solutions are especially powerful as they adapt well to the current ubiquity of mobile devices and expected increase in availability of tabletop surfaces. However, accessing personal content causes user's attention to be deviated from the tabletop, potentially making them lose track of other users' actions. When placed on the tabletop, these devices occlude parts of the display and can interfere with other users' actions (interference).

Recent additions to the capabilities of mobile devices could solve these limitations. Particularly, the reduction in size and power consumption of pico-projectors (e.g. 3M MM200 weights a few grams and draws as little as a watt of power) allows mobile devices to be extended with wearable camera-projector devices. In light of this, the research community has begun to explore the potential of these systems [13].

In this paper we explore a combination of such a wearable camera-projector system with sheets of retroreflective material (ReflectoSlate) to extend tabletop interaction. The resulting system provides unique possibilities: when a ReflectoSlate is on the tabletop, a user can see personal/private contents on it, while other users still see the tabletop (no interference). ReflectoSlates also serve as a bridge, allowing seamless transitions among personal tasks in the user's mobile device and shared tasks on the tabletop.

We describe the design and vision behind ReflectoSlates and provide a proof of concept implementation. We describe a map application that allows different users to visualize different levels of detail of the map and use it to explore the interaction opportunities that such a system raises, such as direct interaction, mid-air and shadows-based interaction. We conclude with a discussion on the potential of our approach, identifying types of systems where they can be applied and future lines of research.

Related Work

View-enhanced tabletops allow personalized information to be presented to each user. *Lenses* [17] provide local changes to views in selected regions of the tabletop allowing a user to inspect new information locally. However, these changes are visible to all users of the tabletop and can potentially occlude shared content causing interference to other users.

Several tabletop systems have been proposed that provide personalised information either using personal overlays or enabling transitions with personal devices. Systems like UbiTable [14], Carretta [16], WeSpace [3], LUMAR [12] or E-conic [11] include multiple displays to alleviate interference. However, since it is not possible to see through these displays they are often pushed to the periphery of the interaction space, like in WeSpace [3]. This usually leads to a loss in the

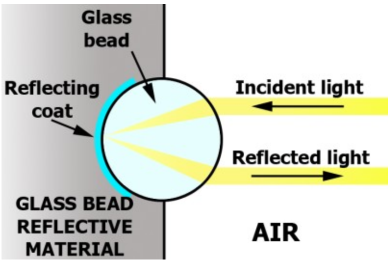

Figure 2. ReflectoSlates use glass bead based reflective materials, which reflect most of the light in the direction of incoming light.

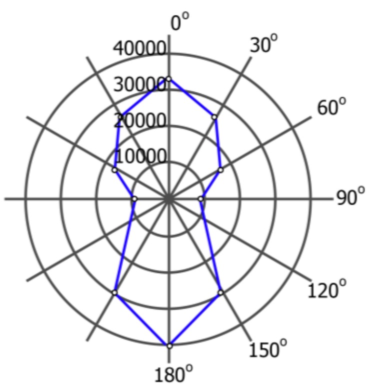

Figure 3. Model of light intensity for each angle for a glass bead based retroreflective material.

awareness of other users' actions, and various forms of cursor and hand embodiments become necessary [11].

Ulteriorscape [5], TaPS [10] and PiVOT [6] overlay tabletop surfaces with diffusion control materials to create regions within the surface which are only visible from specific positions. In all these solutions, overlays are constrained to the surface of the tabletop. SecondLight [4] and *tangible views [15]* allow overlays that can be lifted and moved, but the contents projected are visible to anyone. ReflectoSlates can be lifted while still remaining private. In contrast to these prior systems, the ReflectoSlate illustrated below does not constrain the location of the user. It is possible for two users to stand side by side or even to move away from the tabletop, as the camera-projector system is carried by the user. ReflectoSlates also can be lifted while still remaining private.

Some prior systems combine pico-projectors and retroreflective materials to provide user-specific projections. CastAR [1] focuses on creating Augmented Reality applications, showing 3D contents on a tabletop. REFLCT [8] uses retroreflective surfaces in different places of a training ground with military training purposes. However, unlike ReflectoSlates, both are focused on head mounted approaches and do not attempt to extend the functionality of a tabletop system or leverage the potential and ubiquity of mobile devices to create a fluid interaction between the users' personal personal devices and the shared tabletop.

Design of ReflectoSlates

By combining a chest-mounted camera-projector systems and overlays of retroreflective material, each user to only sees on the ReflectoSlates the contents from their camera-projector system. Figure 1 shows This enables unique possibilities, as shown in Figure 1. First, ReflectoSlates provide personal/private contents on a tabletop. Contents presented on the ReflectoSlates are visible for some users, but they simply show the tabletop (as if the ReflectoSlate was not there) to the rest. This ensures the tabletop will only display contents relevant for the user viewing it (Figure 1.b).

Secondly, ReflectoSlates are portable and interactive (Figure 1.a). The chest-mounted system is used to detect mid-air gestures and interactions. As a result, besides interacting on the tabletop, users can lift the ReflectoSlate to interact with it while standing or even while walking away from the tabletop (Figure 1.d).

Thirdly, ReflectoSlates serve as seamless proxies for the user's personal device, both to interact and to share/retrieve contents from the tabletop. Users can drag contents from the tabletop to their ReflectoSlates (i.e. making it visible only to them, but also automatically copying them to the user's device) or viceversa (sharing personal contents, as in Figure 1.c). Our vision is to provide seamless transitions, where users can contribute contents to the tabletop, take them and interact with them as they walk away.

Projection on Retroreflective Materials

Retroreflective materials return most of the incoming light back along the same incoming direction (Figure 2). An ideal material, returning all the light in the incoming direction, would be unpractical, as the observer should be located exactly in the same position than the source of light. Real materials spread the light in all directions, but the intensity of light decays greatly as the angle between the incoming light and the observer (observation angle) increases. Figure 3 shows the attenuation of the coefficient of luminous intensity (CIL)

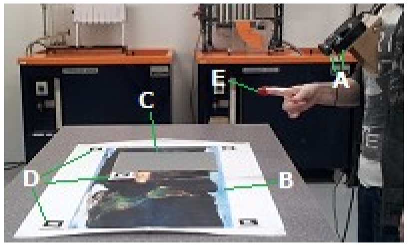

Figure 4. Main elements of the system: camera-projector system (A), shared surface (B), ReflectoSlate (C), AR and fingertip marker (D, E).

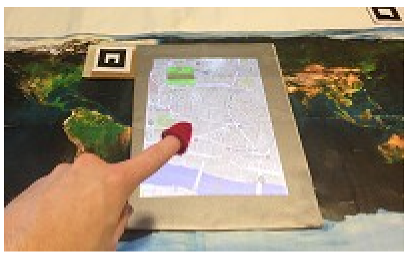

Figure 5. Users can see personal contents from the camera-projector system mounted on their chests.

Figure 6. Users not allowed to see the contents, will see the ReflectoSlate overlaid with the original tabletop image.

for a glass beads based retroreflective material like the one used in our prototype and according to the model presented in [9]. This property allows the implementation of personal overlays. The observer angle between each user and the projector is kept small, to assure a high perceived brightness from the projected contents. At the same time, the observation angle to other users' projected images is much higher, resulting in a lower brightness. As a result, users only see contents from their own camera projection system.

Retroreflectors allow us to use low power projectors, given their higher efficiency. When using a traditional diffuser (e.g. a screen or wall) light is scattered in all directions, and only a small amount reaches every observer. With retroreflectors, most light is redirected in the direction of incoming light, towards the observer. Low power projectors can be used, which is especially appropriate for mobile devices. Actually, light intensity needs to be carefully limited to prevent glaring.

Location of the Camera-Projector System

In order to provide a high brightness, the projector needs to be located close to the user's eyes. Mounting the camera-projector system as a head mounted device (like REFLCT or CastAR) would be the most direct choice. However, head mounted devices are intrusive and occlude facial expressions, interfering social interactions around the tabletop. Besides, a projector near the user's eyes could cause glaring when users' look into each other's eyes.

In our prototype, we place the camera-projector system in the top part of the users' chest, facing downwards 45 degrees. This covers the tabletop, and the region in front of the chest where users are more likely to place a mobile device (e.g. to read or browse the internet [18]). Finally, this offers increased stability and is also the most comfortable position for wearable projectors according to [13]. The resulting arrangement results in a projector to eye distance of 10-16 cm, 10-15 degrees observer angle.

Implementation of ReflectoSlates

We built a proof of concept implementation in order to explore the possibilities of our system (Figure 4). We used a 60x40cm poster of a world map, as a replacement for the tabletop system and 3M 8910 sheets as the retroreflective material. The camera-projector system uses a conventional webcam and a pico-projector. Several ARToolkit markers (i.e. on each ReflectoSlate and each corner of the surface) are used for registration. A glove fingertip is worn to facilitate finger tracking. The ReflectoSlates act as a *magic lens* [17], showing a detailed map of selected cities (Figure 5). These views are private (Figure 6), and the remaining users only see the tabletop image projected on the ReflectoSlate.

Tracking and Projection

We use the AR marker on the ReflectoSlates to identify them and determine their 3D position and orientation relative to the camera. Knowing the intrinsic and extrinsic features of the camera-projector system allows us to present perspective corrected contents on the ReflectoSlates. The four markers in the surface's corners are necessary to determine the position of the ReflectoSlate relative to the tabletop. This allows us to determine the parts of the tabletop's contents (world map) that the overlay is occluding.

Mid air interactions and Fingertip Tracking

ReflectoSlates allow users to interact with well established tabletop techniques, such as gestures and

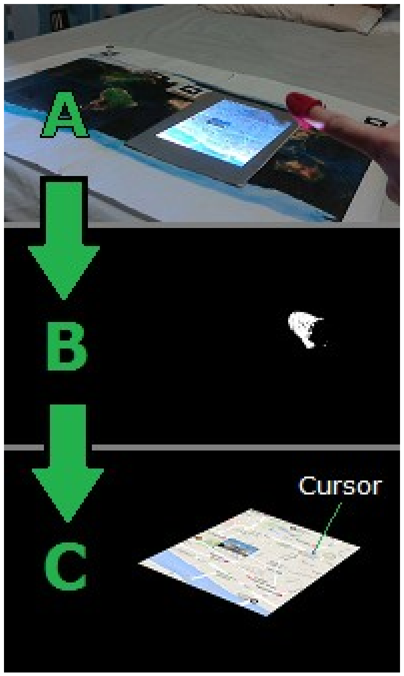

Figure 7. Images are retrieved from the camera in RGB (A), converted to HSV and thresholded (B) to detect the finger and update the cursor (C).

finger touches. While diffuse IR or FTIR techniques are not viable through the retroreflective sheets, techniques based on cameras above the tabletop, such as dSensingNI [7], could be used.

Our preliminary tests indicated that mid-air interaction was also desirable. ReflectoSlates allow contents to be only visible to certain users, alleviating interference to the rest of them. However, users still caused interference when touching the overlays. Besides, images projected by each user's projector became visible to everyone on the user's hands where he/she occluded the retroreflective material. The possibility to walk away from the tabletop, interacting with the contents in a ReflectoSlate also encourages adding interaction techniques independent from the tabletop.

We use OpenCV to track users' fingertips. Red glove fingertips worn by users are added to facilitate the implementation. As a first approach, we used the 2D finger coordinates to control a pointer on the overlay. However, when users reached their arm forward, a shadow was cast on the overlay. Most users did not notice the presence of the pointer and assumed this shadow determined the point of interaction. We implemented a second technique using the shadow to determine the point of interaction.

Conclusion

We have proposed ReflectoSlates, an improvement for tabletop systems, leveraging on the current availability of mobile devices and the possibility to extend them with camera-projector systems and retroreflective overlays. Such an arrangement offers interesting opportunities, like support for personalized contents (visible only to certain users) with reduced interference to other users. ReflectoSlates can be placed on the tabletop, or lifted and carried away, making it easy to break in and out shared tasks and encouraging spontaneous collaboration. The paper identifies relevant issues related to projection on retroreflective materials and ergonomic considerations, and proposes a feasible design allowing for a reduced power consumption. Our design has been investigated through a proof of concept implementation. While this implementation has not explored all the opportunities offered by ReflectoSlates, it does demonstrate the key feature that allows our concept to work, the possibility to have personal contents, visible only to one user, while other users only see the background tabletop image.

Future work will focus on several issues. First, we aim to characterise the properties of the retroreflective material experimentally. These properties could be used to compensate image brightness according to the observer angle of each pixel, producing homogeneous brightness across the overlays. Matching the brightness of the overlay with that of the tabletop would allow for a less perceivable interference. Secondly, user studies are necessary both to evaluate the opportunities our system offers thoroughly (mixed-focus collaboration, spontaneous group formations and walk-up-and-use, combinations of shared and personal tasks), but also its limitations. For instance, personal contents disappear if the user rotates his chest away from the ReflectoSlates and the tabletop, which could be confusing. A trade-off must be found between a field of view covering a wide region in front of the user, and the accompanying loss in resolution.

Finally, ReflectoSlates can also be adapted to a range of application and interaction contexts. For example educational or entertainment contexts (e.g. strategy games or board games). Using non planar

ReflectoSlates can be another interesting possibility. A tangible object covered in retroreflective material would allow for augmentations common in Spatial Augmented Reality [2], but these augmentations could be tailored for each user.

References

[1] Ellsworth, J., et al. *Technical Ilusions: CastAR*. 2013; Available from: http://www.kickstarter.com/projects/technicalillusions/castar-the-most-versatile-ar-and-vr-system.

[2] Grossman, T., et al., *Going Deeper: a Taxonomy of 3D on the Tabletop*, in *IEEE TABLETOP*. 2007. p. 137-144.

[3] Hao, J., et al., *System design for the WeSpace: Linking personal devices to a table-centered multi-user, multi-surface environment*, in *IEEE TABLETOP*. 2008. p. 97-104.

[4] Izadi, S., et al., *Going beyond the display: a surface technology with an electronically switchable diffuser*, in *Proceedings of the 21st annual ACM symposium on User interface software and technology*. 2008, ACM: Monterey, CA, USA. p. 269-278.

[5] Kakehi, Y., et al., *UlteriorScape: Interactive optical superimposition on a view-dependent tabletop display*, in *IEEE TABLETOP*. 2008. p. 189-192.

[6] Karnik, A., et al., *PiVOT: personalized view-overlays for tabletops*, in *ACM UIST*. 2012, ACM Press: Cambridge, Massachusetts, USA. p. 271-280.

[7] Klompmaker, F., et al., *dSensingNI: a framework for advanced tangible interaction using a depth camera*, in *ACM TEI*. 2012, ACM Press: Kingston, Ontario, Canada. p. 217-224.

[8] Krum, D.M., et al., *Augmented reality using personal projection and retroreflection.* Personal Ubiquitous Comput., 2012. **16**(1): p. 17-26.

[9] Kuesters, C., *Designer software for retroreflective garments*. 2005, Google Patents.

[10] Mollers, M., et al., *TaPS widgets: interacting with tangible private spaces*, in *ACM ITS*. 2011, ACM Press: Kobe, Japan. p. 75-78.

[11] Nacenta, M.A., et al., *E-conic: a perspective-aware interface for multi-display environments*, in *ACM UIST*. 2007, ACM Press: Newport, Rhode Island, USA. p. 279-288.

[12] Olwal, A., et al., *LUMAR: A Hybrid Spatial Display System for 2D and 3D Handheld Augmented Reality*, in *Artificial Reality and Telexistence*. 2007, IEEE Computer Society. p. 63-70.

[13] Ota, S., et al., *A Method for Wearable Projector Selection that Considers the Viewability of Projected Images.* Comput. Entertain., 2010. **8**(3): p. 1-16.

[14] Shen, C., et al., *UbiTable: Impromptu Face-to-Face Collaboration on Horizontal Interactive Surfaces*, in *UbiComp 2003: Ubiquitous Computing*, A. Dey, et al., Editors. 2003, Springer Berlin Heidelberg. p. 281-288.

[15] Spindler, M., et al., *Tangible views for information visualization*, in *ACM International Conference on Interactive Tabletops and Surfaces*. 2010, ACM: Saarbrücken, Germany. p. 157-166.

[16] Sugimoto, M., et al., *Caretta: a system for supporting face-to-face collaboration by integrating personal and shared spaces*, in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 2004, ACM: Vienna, Austria. p. 41-48.

[17] Tang, A., et al., *Collaborative coupling over tabletop displays*, in *ACM CHI*. 2006, ACM Press: Montreal, Quebec, Canada. p. 1181-1190.

[18] Young, J.G., et al., *Touch-screen tablet user configurations and case-supported tilt affect head and neck flexion angles.* Work, 2012. **41**(1): p. 81-91.