Tracs: Transparency Control for See-through Displays

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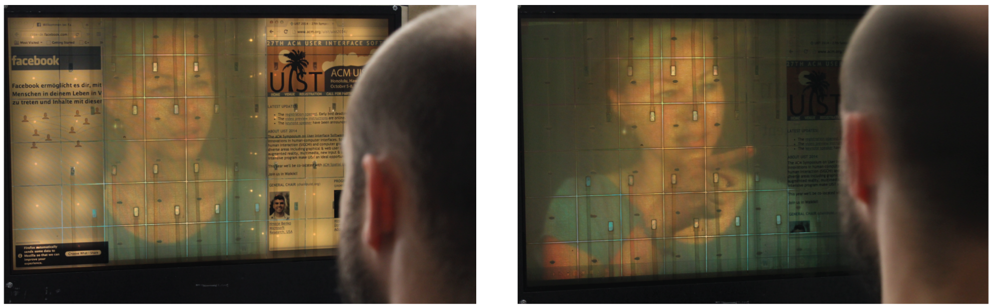

Figure 1. Tracs is a dual-sided transparency-controlled see-through display system to avoid visual interference on transparent displays and to support fast switching between personal work and collaboration. Users can control the transparency of specific parts of the display (*left*) or overall (*right*).

ABSTRACT

We present Tracs, a dual-sided see-through display system with controllable transparency. Traditional displays are a constant visual and communication barrier, hindering fast and efficient collaboration of spatially close or facing co-workers. Transparent displays could potentially remove these barriers, but introduce new issues of personal privacy, screen content privacy and visual interference. We therefore propose a solution with controllable transparency to overcome these problems. Tracs consists of two see-through displays, with a transparency-control layer, a backlight layer and a polarization adjustment layer in-between. The transparency-control layer is built as a grid of individually addressable transparency-controlled patches, allowing users to control the transparency overall or just locally. Additionally, the locally switchable backlight layer improves the contrast of LCD screen content. Tracs allows users to switch between personal and collaborative work fast and easily and gives them full control of transparent regions on their display.

Author Keywords

Transparent display; transparency-controlled display;

ACM Classification Keywords

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

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INTRODUCTION

Traditional displays are dominating our office environments. They provide crystal-clear images on the one side, but block the view on the environment behind the display. Consequently, these displays are a constant visual barrier and thus also a communication barrier. Additionally, they do not allow for face-to-face communication while seeing screen content, one of the main affordances of transparent displays [18].

Transparent displays offer the ability to see screen content as well as the environment behind the display. They have been explored for co-located collaboration [10, 18, 19, 21, 22], exposing beneficial features like workspace awareness. However, traditional (non-transparent) displays still are ubiquitous. We believe this is because transparent displays lack basic features of traditional displays such as shielding from visual disturbances from the environment behind the display. In order to make see-through display devices more usable, we believe it is important to allow users to change the transparency of their display on-demand. This way, visual interference can be decreased and users can regain privacy by turning the display opaque.

In this paper, we present Tracs (TRAnsparency Controlled Screens), a dual-sided transparency-controlled display system. With Tracs, users can control the transparency of individual areas of their display (see Figure 1). It consists of two see-through displays enclosing a transparency-control layer, a backlight layer, and a polarization adjustment layer.

The transparency-control layer is a grid of transparency-controllable patches and is created from a single piece of PDLC (Polymer Dispersed Liquid Crystal) switchable diffuser with additional pieces of transparent ITO (Indium Tin Oxide) film for controlling the individual patches.

The transparency of the PDLC diffuser is controlled by adjusting the voltage supplied to it. Tracs' backlight layer, a LED matrix mounted on transparent ITO, improves the contrast of the see-through display. The polarization adjustment layer is added to enable users to see through the LCDs.

RELATED WORK

Transparent Displays

Using transparent displays for co-located collaboration and using their features like face-to-face communication and gaze-awareness has been proposed by Tang and Minnemann with VideoDraw [21] and VideoWhiteboard [22] as well as by Ishii and Kobayashi with Clearboard-0 [10]. They emphasized the importance of integrating content directly into the communication channel to allow users to switch focus and task smoothly. Hirakawa et al. [8] used a see-through display as collaborative working environment in combination with augmented reality. Olwal et al. [19] used an interactive dual-sided FogScreen for multi-user face-to-face collaboration, giving users the ability to collaborate closely while being able to see and interact with screen content. With MUSTARD [12] and PiVOT [13], Karnik et al. explored the possiblity to target contents at specific users, giving them the ability to see contents collaboratively or exclusively. HoloDesk [7] and SpaceTop [17] use an optical see-through display for 2D and 3D spatial interactions behind the display. In Transwall, Heo et al. [6] display equal content on both sides of a transparent display for facilitating interpersonal communication, mostly through gaming. Li et al. [18] used a dual-sided projected transparent display for collaborative work. They discuss the affordances and possibility of such setups, with enhancements in workspace awareness being fundamental advantages of transparent displays over traditional displays.

With Tracs, we focus on controlling the transparency and the ability to see or hide the environment behind the display. Prior systems could control transparency only by overlaying the environment behind the display with screen content. Tracs' transparency-control layer offers the unique ability to control transparency independent of screen content, thus allowing users to avoid visual interference and to switch seamlessly between personal (opaque) and collaborative (transparent) usage on demand.

Transparency and Visual Interference

Insights from research on interface transparency evaluations (e.g., [1, 3, 4]) show decreased performance of task execution (e.g., selection or menu interaction) with transparent user interfaces. For transparent displays, Laramee and Ware [16] showed that visual rivalry between screen content and background leads to decreased performance and readability. With Tracs, users control the transparency of our see-through displays and can therefore avoid potential visual rivalry.

Switchable diffuser in HCI

For our transparency-control matrix, we used PDLC switchable diffuser, a material normally employed in architecture (e.g., meeting rooms, trains) that has also been used in HCI before. Prior systems mostly used switchable diffuser for camera see-through systems (e.g., [2, 14]) or for projecting through surfaces [11]. For Squama, Rekimoto [20] used a large-scale grid of switchable diffusers as programmable physical architecture and for dynamic shadow creation. He focused on making use of the interplay between transparency and opacity, also by conveying information with the diffuser themselves, without additional devices or displays (except camera tracking). In contrast to this, our work focuses on creating a dual-sided see-through display system which uses the property of adjustable transparency. Tracs should enhance the user experience when working with transparent displays.

TRACS

Tracs gives users the ability to toggle the transparency of individual areas on the display through its transparency-control layer (see Figure 1). These areas support more fine-grained adjustments for users and to cover a broader range of use-cases and applications, e.g., to allow users to create collaborative (transparent) and personal (opaque) regions on their display simultaneously (see Figure 8). Additionally, this enables users to block visual interference locally without having to turn the whole display opaque.

Hardware Components

Tracs consists of a stack of five hardware components (see Figure 2). We use two transparent 22" LCDs (Samsung LTI220MT02[1]) as a basis for displaying content. In-between the two displays, Tracs includes a transparency-control layer which allows users to manually control the transparency of the displays. Furthermore, we included a backlight layer to increase the contrast of the LCDs and a polarisation adjustment layer to improve the transparency of the displays.

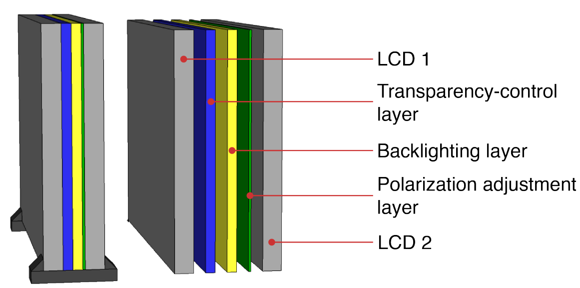

Figure 2. Schematic of the dual-sided screen system, consisting of two transparent LCDs, a transparency-control layer, a transparent backlight and a half-wave retardation film for adjusting polarization.

Transparent displays

Transparent LCDs rely on ambient light for displaying screen content. They are transparent when turned off or displaying non-black content. Since they do not emit light, contrast is limited compared to e.g., transparent OLEDs (not commercially available yet). We chose displays over projection to make Tracs self-contained and to cover a broad range of co-located collaborative use cases (e.g., office context with workers facing each other). Since we used transparent LCDs in our setup, we equipped Tracs with an additional backlight and polarisation adjustment layer.

[1]Each display offers a transparency of about 15% according to the specification.

Transparency-control layer

Our current prototype consists of a 9×6 matrix of individually controllable patches, each with a size of 5 cm $\times$ 5 cm. We constructed the matrix from a single piece of PDLC switchable diffuser (see Figure 3). This material is composed of two layers of ITO and one layer of polymer dispersed liquid crystals. The conductive sides of the ITO layers are facing each other, with the crystals in between. When no voltage is applied, the material is diffuse (60% VLT[2], 90% haze), and becomes clear (80% VLT, 10% haze) when voltage is applied (60 volts). One ITO layer serves as anode (*layer A*), the other as cathode (*layer C*). Our transparency-control matrix is a passive matrix layout with a common anode.

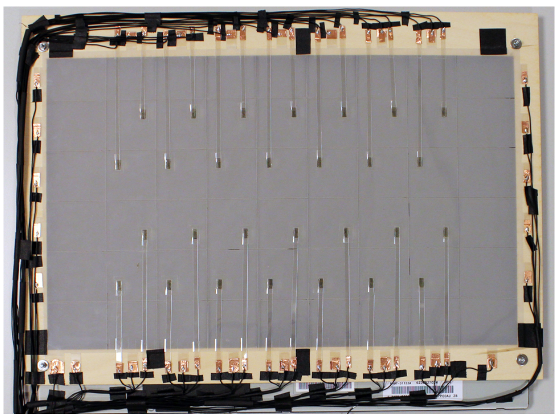

Figure 3. Our current 22" prototype of the transparency-control matrix. Each of the 54 patches can be controlled individually.

We first laser engrave *layer C* of ITO in a grid-like manner to create the individual patches (see Figure 4, cuts are dashed red lines *right*, resulting patches *left*). Note that in order to disconnect the individual patches from each other, each line consists of two cuts (distance 1 mm). The ITO between the two cuts is removed manually to avoid current from flowing. The cuts only go through *layer C*, *layer A* is left intact (see Figure 4, *center*). Damaging the conductive coating of *layer A* side would not allow us to use it as a common anode.

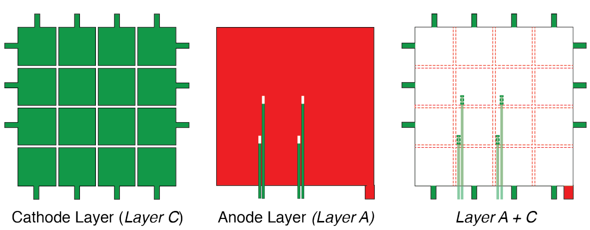

Figure 4. Schematic of a 4×4 transparency-control matrix: cathode layer (*layer C*, *left*) with individual patches, common anode layer (*layer A*, *center*) and *A* and *C* combined (*right*). Both layers have connectors for the wiring (areas outside of grid). We added additional strips of ITO on top of the anode layer (*center*, light green) to connect inner patches.

For controlling the patches in *layer C* individually, we connect them to the cables running at the outside. Therefore, we laser engrave 5 mm $\times$ 10 mm holes into *layer A* (see Figure 4, *right*). Subsequently, we applied thin separate strips of ITO from the outside to the holes and connect the strips with the holes, *layer C* respectively[3]. Patches at the edges are connected with small additional areas on the outside to avoid cutting holes. These transparent ITO connections in combination with the common anode from *layer A* allow us to control the transparency of each patch individually. The patches are controlled with 8 Texas Instruments TPIC6B595 high voltage 8-Bit shift registers, which can handle load up to 60 volts, connected to a microcontroller.

Backlight layer

We constructed the Tracs backlight matrix by mounting LEDs on top of a piece of ITO (80% VLT, 2% haze) using wire glue. In order to being able to control the LEDs individually, we used a passive matrix addressing scheme, with individually addressable rows and columns. All lines for anodes and cathodes were engraved into ITO (Figure 5, red lines) to construct the matrix from a single layer of transparent material.

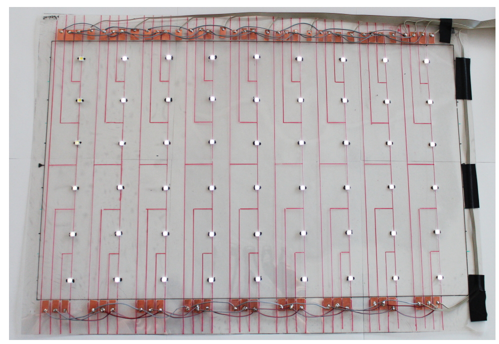

Figure 5. Tracs' backlight matrix is composed of LEDs mounted on ITO and controlled via a passive matrix addressing scheme. The red lines highlight the engraving in the ITO and are not visible for users.

Polarization adjustment layer

Each LCD used for Tracs has a linear polarizer film (orientation 45°) applied to their front- and backside in order for them to work. Since the two LCDs are polarized orthogonally once positioned back-to-back, the displays would be completely opaque. In order to overcome this issue, we included an additional layer of transparent half-wave retardation film[4] (see Figure 6) in-between the two displays. The film acts as a polarization rotator by shifting the phase of the input light by π, rotating the incoming linearly polarized light by 90°, respectively, cf. Figure 2 [5].

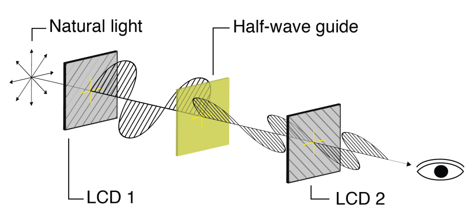

Figure 6. The polarization is adjusted using a half-wave retardation film positioned between the screens. Without the film, users could not see through the display, since the displays are polarized orthogonally.

[2] VLT = visible light transmission

[3] We used 3M™ Z-Axis Electrically Conductive Tape 9703 for connecting the two layers of ITO.

[4] We used an American Polarizers APHW92-003-PC-280NM half wave retardation film (92% VLT)

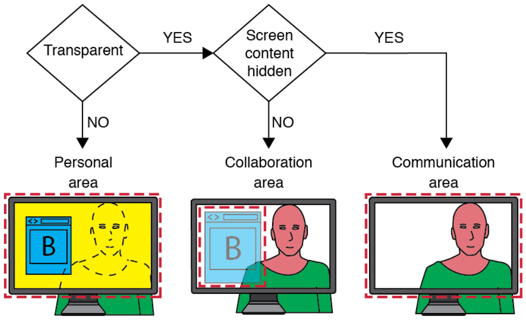

Figure 7. Tracs' three states: personal (opaque, *left*), collaboration (transparent, screen content visible, *center*), and communication (transparent, screen content hidden, *left*).

USAGE AND APPLICATIONS

Tracs offers users with three basic usage states, which are (1) personal, (2) collaboration and (3) communication (see Figure 7). Each state is possible on either the full display or on a specific area (see Figure 8). In personal state, Tracs acts like a regular display, preventing visual interference and privacy. During collaboration, the display is transparent and the screen content visible. This way, users can relate to items visible on the screen just by looking at them and establish a shared focus. During the communication state, the display is transparent and no screen content visible, allowing users to communicate freely. Tracs' custom control software allows users to implicitly select the different states through controlling the transparency of patches and screen content.

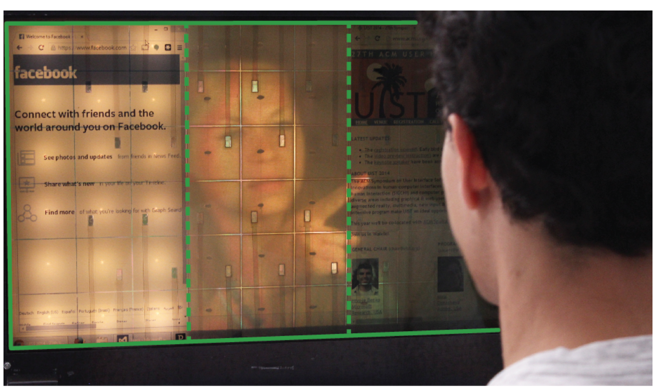

Figure 8. Tracs' states combined on a single display, personal (*left*), communication (*center*), collaboration (*right*).

DISCUSSION

We believe that by being able to control transparency, thus privacy, and visual interference, those limitations of see-through displays can be overcome and new ways of collaboration be opened. Transparent displays could bring together benefits from shoulder-to-shoulder collaboration (shared perspective on screen content) and face-to-face collaboration (eye-contact) [9, 18]. Like reducing spatial distance can increase collaboration [15], we believe that removing the barrier introduced by traditional displays can make collaboration more instant and effective. However, we believe users need to be able to choose between transparent and opaque to increase to usability and acceptance of transparent displays.

Quality and Transparency

Currently, Tracs uses transparent LCDs, which require additional environmental light to provide a good view through the display. Otherwise transparency would be limited. Transparent OLED displays do not suffer from such limitations, but their commercial availability is limited. Tracs is designed in a way to work with many types of see-through displays because of its flexible layering. The transparency-control layer can applied to an OLED to equip it with controllable transparency. The most influential factor for the Tracs' transparency are the LCDs, which give it a approximate overall transparency of 10%. This is a limiting factor for potential deployment and needs to be resolved.

Our current backlight emits light only at one side, and, while PDLC diffusely reflects the backlight also to the same side, there is a decrease in brightness and some minor reflections. To improve contrast from both sides, a second backlight layer could be added or a transparent electroluminescence display emitting light at both sides could serve as backlight.

Currently, the LCDs are 5 cm apart, so the LEDs illuminate the correct area and the switchable diffuser is not directly on the display, which results in a parallax effects. While in our experience this does not decrease Tracs' practical usability (e.g., when pointing), showing overlapping contents on both displays is currently not supported. In terms of ergonomics, our displays have to be positioned in a way that users are able to see through them without having any edges within their view. Feedback we received also addressed the possibility to tilt the display for a more comfortable viewing angle. Both points are important for transparent displays in general and need to be taken into account.

Switching and Symmetry

While Tracs gives users the possibility to switch between transparent and opaque states, it is yet unclear, which one users prefer. Users might only switch to transparent mode in case of actual collaboration and not during daily work, therefore decreasing workspace awareness. However, we believe that by making switching effortlessly, users would be encouraged to collaborate more frequently. Since users can switch to transparent state all the time, these switches could occur in moments not wanted for one of the users. Switching is currently negotiated verbally by users. Being able to prevent unwanted switches, especially to transparent mode, is important for systems like Tracs.

FUTURE WORK

For future work, we plan to increase the efficiency and resolution of the transparency-control matrix design to support more fine grained control over the transparency. Additionally, working with components of higher transparency, e.g., transparent OLEDs, would give us the opportunity for evolving our setup. Furthermore, applying our concept of transparency-control to more device class (e.g., smartphones, tablet) is an interesting point for future research. Finally, the negotiation process between collaborators, whether or when to change transparency, introduces an interesting challenge, which we will look into.

CONCLUSION

In this paper, we presented Tracs, a transparency-controlled see-through display system. With Tracs, users can control the transparency of individual areas of a display. Tracs includes a locally switchable backlight, increasing the contrast of transparent LCDs. We proposed using transparency-controlled see-through displays for fostering on-demand collaboration while retaining a personal space, which is not possible with conventional see-through displays. We believe that this mechanism is substantial for improving the usability of see-through displays and that it allows us to resolve issues regarding personal privacy, screen content privacy, and visual interference.

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