Towards Transparent Handheld See-Through Devices

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Abstract
See-through has been simulated for handheld devices to enable back-of-device interaction and for augmented reality applications. Researchers explored a wide range of applications for such devices and technologies to realize them. In this paper we revise previous work on simulated and real see-through handheld devices and their applications. Based on previous work and our own experience with see-through devices, we argue that using pseudo-transparency has inherent drawbacks. We discuss that usable transparent handheld devices require adaptive transparency, consideration of binocular disparity, and new ways to capture content. Furthermore, we indicate approaches to address these factors.

Author Keywords
3D display, touch input, back-of-device interaction, mobile HCI

ACM Classification Keywords
H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces. - Graphical user interfaces.

Introduction
Devices that enable the user to see through them allow to directly interact with items located behind the devices, which are usually occluded. Interaction concepts for

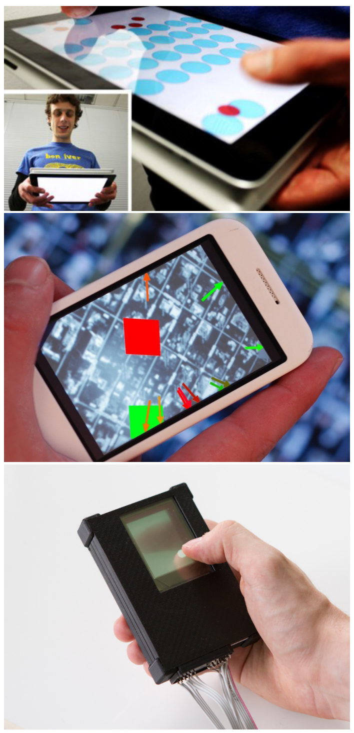

Figure 1: Back-of-device interaction using touch-sensitive back side [21] (top), camera-based handheld augmented reality [4] (center), and back-of-device interaction using transparent displays [1] (bottom).

see-through devices have been explored for augmented reality and for back-of-device interaction. In augmented reality applications, the scene behind the device is visible on the display and is augmented with additional information, for example, a city view is displayed and the buildings are labeled for augmenting the city view with additional information. To enable back-of-device interaction, the position where the fingers touch the back of the device are displayed on the screen. These back-of-device touches can for instance be used for target selection, which solves the problem of display occlusion when using touchscreens.

As transparent displays have not been available, see-through technology has been simulated as so called pseudo-see-through using embedded [16] and external [19] video cameras. Furthermore, external sensors were used to track the device position [3, 12] and embedded sensors such as touchpads [20] on the back of the device were used to track the position of the hand and fingers.

Pseudo transparent displays have some shortcomings such as delay and information loss. This paper is motivated by the believe that see-through displays using real device transparency would remedy the shortcomings current pseudo see-through technologies have. In this paper, we revise previous work on see-through technologies in the domain of handheld devices. Based on the discussed use cases, we derive challenges that developers have to face if building transparent see-through devices.

Related Work

Back-of-Device Interaction

One of the main drawbacks of interacting with touch screens is the fact that the finger used for input is covering parts of the user interface. While interacting with the back of the device, the finger does not cover the interface. Thus, the size of the fingers at the backside of a handheld device doesn't matter with regards to covering interface parts and more precise interactions are possible [19]. This can be either achieved by capturing the backside or by using true transparency. Wolf and Henze, for example, compared different target selection techniques on the front and on the back by just highlighting the fingers' position on the back of the device on the display [20]. To further investigate front and back touch Bader et al. developed a layered 3D screen that enables touch input on both display sides [1]. Thereby, they show that back-of-device interaction is improved if the user can actually see the finger on the back through the transparent display.

Far-Field Augmented Reality

Early work in the handheld AR domain used external sensors to track the position of the mobile device [3, 12]. With the increasing computing power that became available in tablets and smartphones it became possible to implement marker-based AR on mobile devices. Wagner et al. developed a system that realizes handheld AR by recognizing and tracking visual markers on a PDA with up to 3.5 fps [16]. Similarly Möhring et al. presented the design and implementation of marker-based handheld AR using even less powerful mobile phones [10]. With increasing processing power and refined algorithms, pose tracking from natural features [15] and detection and tracking of multiple natural targets [18] became feasible on mobile phones. Despite the technical advancements that are expected to continue in the future [17] Billinghurst et al. stated that "much of the research in the field has been focused on the technology for providing the AR experience (such as tracking and display devices), rather than methods for allowing users to better interact with the virtual content being shown." [2].

Near-Field Augmented Reality
AR with transparent displays is particularly interesting because a virtual layer can directly be placed over the real world. Common use cases explored by researchers are the augmentation of paper maps [4, 11]. The video from the device's camera is shown on the screen and maps recognized from the video are augmented with additional information. At very close range or in direct contact of a virtual layer with a real surface, numerous additional applications arise. Some use cases were presented by *tPad* [5, 6] or *Glassified* [14]. Overlay interactions like tracing or scribbling require no capturing of the surface below the display. Interactive applications instead need surface monitoring with markers or image capturing and cause difficulties through the occlusion of the device itself.

Summary
In the mobile HCI domain, see-through technologies have been used for back-of-device interaction, far-field AR, and near-field AR. Different approaches to enable users to see-through the device have been used. As several different research projects show, back-of-device interaction as well as AR applications benefit from using see through displays.

The vast majority of previous work simulated see-through capabilities of handheld devices using cameras and other sensors. In contrast to true transparency, this poses inherent limitations. In particular, a certain latency cannot be avoided. Touch sensors, for example, typically have a latency of 75ms-150ms [8] and the refresh rate of consumer cameras results in similar latency. Latency, however, clearly affects the users' performance (cf., [7]). Furthermore, using camera-based AR the camera image shown on the display is not in line with the rest of the world the user sees which even alters the interaction strategy [13]. Finally, showing information from cameras and other sensors instead of the real world results in a loss of information. Using a touch sensor, for example, reduces the shape, orientation, position, size, and color of the user's finger to a single X/Y value.

Challenges of See-through Technologies
See-through of handheld devices has been simulated to enable different interaction techniques and applications. Real see-through transparent displays can overcome limitations that arise through the simulation. In the following we discuss three main challenges we are currently facing.

Adaptive Transparency
The overlap of content and background on transparent displays not only impedes reading but all kinds of content that have to be clearly differentiate from the background. Non-augmented content that will be disturbed by transparency benefits from an adaptive visibility of the background. Transparent LC-displays are able to control their opacity pixel by pixel, but can not illuminate without a diffuse background light. Transparent OLED displays instead illuminate individual pixels, but do not have the ability to darken it. Combining the advantages of additive and subtractive color spaces and the pixel-precise control of transparency and luminosity open a new kind of displays without compromising the appearance of ordinary contents like text or images. Without having to forgo the advantages of see-through displays like seeing the fingers while back-sided inputs, adaptive transparent displays lead to a new generation of handheld devices and augmented applications.

Binocular Disparity
The Binocular Disparity describes the difference of view angles seen by the left and right eye resulting from their spatial separation. By focusing the eyes on an object the brain is able to extract the spatial depth, but also produces two overlapping images of other objects with different distances. During focusing on elements on a see-through display, the brain extract depth information from the eyes' images but produce a duplicated and overlapping image of the background due to different depth levels. This overlap also occurs with UI elements or a finger on a see-through display by focusing objects behind the device and causes problems in particular using augmented reality applications. Lee and Bea suggest a Binocular Cursor [9] to handle the problem for selection and pointing tasks on transparent displays by tracking the eye's position. However, future works of augmented applications with full screen content have to find auto-stereoscopic solutions to deal with this challenge. Using transparent auto-stereoscopic displays, for example, which show each eye a correct displacement of display content can solve this problem on the digital layer and open up many new possibilities for augmented and 3D applications on portable see-through devices. A holistic solution that will work for both the digital and the real world represent a further challenge.

Tracking and Capturing
For all applications discussed in the related work it is necessary that the device can sense what is behind the display. For back-of-device interaction this can easily be realized using widely available transparent touch sensors. Similarly, existing camera-based approaches can be used for far-field AR. For near-field AR, however, the device can be too close to the augmented object to get an image using common cameras. Recent contact-based AR approaches therefore use an external camera above the device to capture content from the surface, for example, from a paper sheet as presented by *tPad* [5, 6] or *Glassified* [14]. However, viable mobile devices must have a technology to perceive the appearance of the occluded surface. This could be realized by an array of infrared emitters and detectors similar to the technology used by Microsoft's PixelSense that is only monochrome. The challenge realizing such a back detector will be to design a transparent array of such infrared reflectors, since they would cover the entire back surface of the display to augment the underlying surface precisely.

Conclusion
In this paper we revised previous work on handheld see-through devices. We argue that pseudo-transparency has inherent limitations compared to real transparency. To develop usable transparent handheld devices it is necessary to realize adaptive transparency for example by combining LCD and OLED displays in a single device. Furthermore, binocular disparity has to be considered for augmented reality applications by using auto-stereoscopic displays. Finally, new approaches to recognize and track content are needed for near-field AR. While we believe that these three aspects pose major challenges for future work, overcoming them would result in a new class of handheld mobile devices as well as applications.

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