WatchThru: Expanding Smartwatch Displays with Mid-air Visuals and Wrist-worn Augmented Reality

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ABSTRACT

We introduce WatchThru, an interactive method for extended wrist-worn display on commercially-available smartwatches. To address the limited visual and interaction space, WatchThru expands the device into 3D through a transparent display. This enables novel interactions that leverage and extend smartwatch glanceability. We describe three novel interaction techniques, *Pop-up Visuals*, *Second Perspective* and *Peek-through*, and discuss how they can complement interaction on current devices. We also describe two types of prototypes that helped us to explore standalone interactions, as well as, proof-of-concept AR interfaces using our platform.

ACM Classification Keywords

H.5.1 Multimedia Information Systems: Artificial, augmented, and virtual realities; H.5.2 User Interfaces: Graphical user interfaces, Input devices and strategies; I.3.6 Methodology and Techniques: Interaction techniques

Author Keywords

Smartwatches; Micro-Interaction; Wearable Devices

INTRODUCTION

Smartwatches are designed to support micro-interactions. Their small screens enable compact form factors, but result in a limited visual and interaction space. While most work on addressing these limitations explores additional input techniques or modalities, this work focuses on the output challenges that arise from small screen sizes of currently 1.5–1.8″ (10–25% the size of typical 5″ smartphone screens).

WatchThru extends the output capabilities of current smartwatches into 3D with an additional 1.8″ transparent screen that complements the main touchscreen with graphics that can be displayed floating in mid-air (see Figure 1). WatchThru can show different information on the two screens, based on the user's viewing direction. Additionally, by registering the display with the world (e.g., with an external tracking system or camera-based tracking on the watch), WatchThru enables lightweight, wrist-worn augmented reality (AR) capabilities.

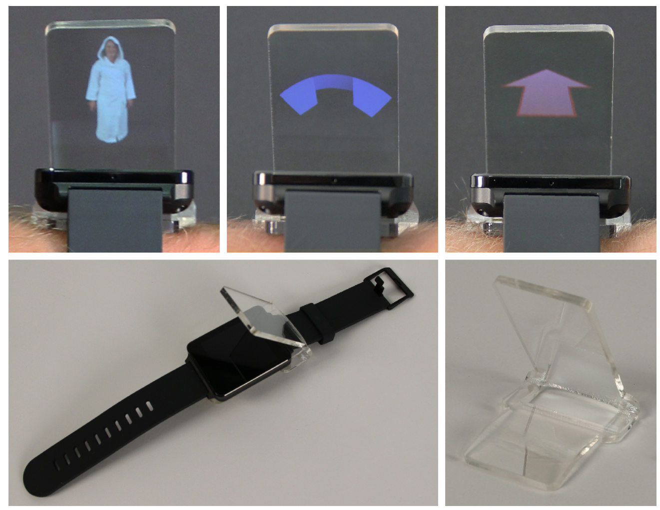

Figure 1: WatchThru is a lightweight and easy-to-build display extension for existing smartwatches.

Our contributions with WatchThru are the following:

- The concept, design and implementation of a smartwatch that is extended with a transparent display to increase the output capacity with mid-air visuals and wrist-worn AR.
- An exploration of novel interaction techniques enabled by our introduced concept that show how they can improve future interactions with smartwatches.
- Two prototypes of which we share the instructions how to replicate them, to enable others to extend our WatchThru concept. The first, demonstrating capabilities with a self-contained smartwatch. The second, using external tracking for a proof-of-concept implementation of techniques that we anticipate will be available with miniaturization of current inside-out tracking technology.

RELATED WORK

Fitzmaurice introduced the concept of *spatially-aware displays* [4], which use motion sensing to enable viewports, or

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peepholes [21], into a virtual information space. WatchThru leverages recent advancements, where wearable devices embed a variety of sensors that can track device motion and orientation. WatchThru is also inspired by early mobile AR concepts like NaviCam from Rekimoto and Nagao [16], as well as, wearable magic lens interfaces [2]. This work builds on an extensive body of research into mobile AR [17, 12], but focuses on the capabilities enabled by a wrist-mounted optical see-through display.

More recently, researchers have investigated wrist-mounted displays and displays around the user's body [3]. Pohl et al. [15] used LEDs mounted at the bottom of a watch for notifications through the user's skin. Grubert el al. [6] investigated interaction with multiple displays; in one variant a HMD combined with a smartwatch. Doppio [18] is a smartwatch with two screens; one of them is reconfigurable to allow tangible interaction.

Peripheral displays has been explored with multiple displays in Facet [10] and as edge notifications on recent smartphones (e.g., Samsung Galaxy S Edge). Skin Buttons [9] use direct projection to extend the display, whereas ScatterWatch uses indirect skin illumination [15]. The WatchThru display configuration is similar to the Sonic Flashlight [19, 20], which used a half-silvered mirror to combine an ultrasound image with the view of the patient's body.

WATCHTHRU INTERACTIONS

In this section we illustrate the interaction possibilities that arise from WatchThru. As WatchThru is focused on output, the interactions rely on known input techniques.

Pop-up Visuals: Extended Display for Mid-Air Graphics

Our concept of *Pop-up Visuals* enables information that visually extends out from the watch face. For notifications and incoming calls, the advantage is that the users do not necessarily need to lift up their hand and twist their wrist to look at the information on their smartwatch. Because of the additional WatchThru screen, the users notice them out of the corner of their eyes while having their arms in a relaxed position, e.g., arms hanging down.

When the user is directly looking at the screen, the WatchThru prototype naturally allows for more complex information, such as numbers (e.g., remaining minutes until the next bus), short text or symbols. Figure 1 (top, right) shows a conceptual app using the WatchThru screen to display static and animated notifications.

Second Perspective: Alternative Presentation

The *Second Perspective* enables users to quickly access alternative views on the WatchThru display. The main advantage is that additional information, e.g., navigational directions, become implicitly accessible to the user. Figure 2 shows a prototypical app with a 2D map on the main screen and an oriented 3D arrow on the WatchThru screen. It allows the user to navigate along a route on the main screen and, using the built-in compass, it shows the current direction on the WatchThru screen. Users simply orient their wrist to view the screen. When combined with pop-up visuals on the WatchThru screen, the main screen could display contextual information, e.g., for information about incoming calls. During a video call displayed on the WatchThru screen, the main screen could show the text chat window for sharing links and media.

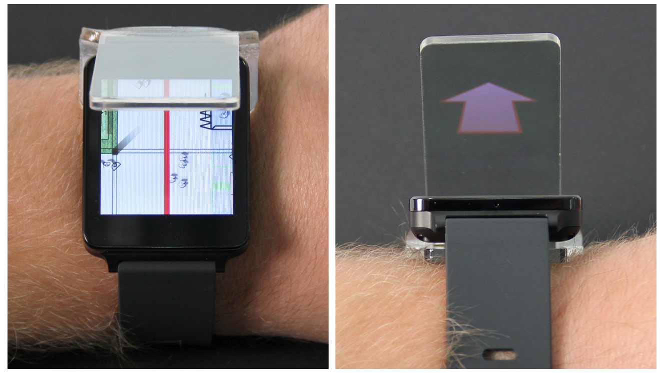


Figure 2: *Second Perspective* navigation with a 2D map (left) and directional arrows (right).

The second perspective could also be used to display independent information. In the mobile context, the user often has to perform multiple tasks at the same time. For example, with the second perspective, the WatchThru screen could display navigational directions while the main screen is used for notifications. In addition, the transparent screen has the advantage that it also enables the combination of additional information on the WatchThru screen with the real world. This means that, e.g., the arrow shown on the WatchThru display is aligned with the real world target.

Peek-through: Optical See-through Wrist-worn AR

The see-through display makes it possible to augment objects by overlaying registered graphics using the device. We call the interaction *Peek-through*. With peek-through, a navigation arrow on the WatchThru screen could be fully integrated in 3D into the environment. In contrast to most AR displays, this device does not obstruct the user's face, nor requires the user to bring it out and hold it (like a smartphone). It therefore has interesting potential as a wearable, unobtrusive and always-accessible AR device on the user's wrist.

For peek-through, we prototypically implemented several applications for different scenarios. Figure 3 (c, d) show a smart home scenario where objects in a room, e.g., power sockets, are augmented with information shown on the WatchThru screen. In Figure 3 (e), a learning scenario, a virtual globe is presented in the middle of a room. It could allow school children to explore the earth, including the orbiting moon, from different perspectives. Additionally, WatchThru could help children and adults learn board games, such as chess. With peek-through, the board could be overlayed with game strategies—not to cheat, but to help the player grow.

Figure 3 (f) shows an assembly scenario; WatchThru shows the user how to connect electronic components. Similarly, WatchThru could help technicians with maintenance, e.g. to repair elevators. WatchThru with a foldable display (see section on Limitations) could be a lightweight and unobtrusive add-on to (smart)watches that technicians usually wear and would not require an additional device. Additionally, similar to the Sonic Flashlight [19, 20], WatchThru could be used in a medical context to overlay the patient's body with information such as ultrasound imagery. Furthermore, we see WatchThru having the potential as an entertainment device, which could be used for location-based games with AR, such as the recently popular Pokémon GO [13].

IMPLEMENTATION OF PROTOTYPES

We developed two interactive prototypes by extending commercial smartwatches with additional display and tracking capabilities. The first was designed to support *Pop-up Visuals* and *Second Perspective* with minimal modification, while the other allowed us to explore the *Peek-through* wrist-worn AR experiences with 3D position and orientation tracking.

Prototype 1: Pop-up Visuals and Second Perspective

For the first WatchThru prototype screen we used a special acrylic glass (3 mm thick) with one reflective side and one transparent side, developed to enable projections on see-through materials[1]. The screen was fabricated with a laser cutter, including a mount, and bent into the right configuration while hot ($\sim 135°$). Given that only one side of the acrylic glass is laminated with the reflective layer, the image quality is barely affected when viewing through the WatchThru screen. We built several versions for different Android/Android Wear smartwatches, e.g., the LG G Watch and the Samsung Gear Live (Figure 1, bottom). Modifying the design for other smartwatches usually only requires scaling of the CAD drawings so that the WatchThru screen has the same size as the main screen of the smartwatch and, if necessary, to bend the mounting part so that it fits the back of the smartwatch.

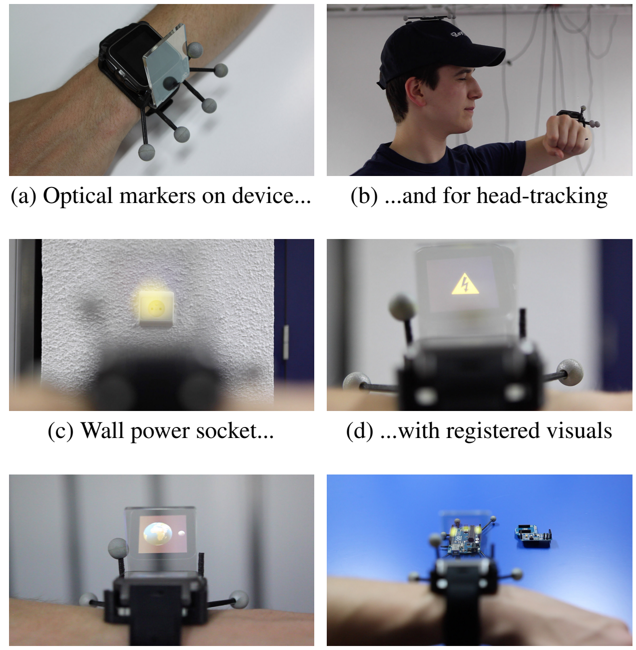
For correct display on the WatchThru screen, graphics need to be mirrored on the main screen. For the second perspective, we used the built-in inertial sensors to infer whether the user is looking at the WatchThru screen or at the main screen. In our proof-of-concept implementation, we activate WatchThru content when the smartwatch is held parallel to the ground and display main screen content otherwise. Using the built-in digital compass, we display orientation-sensitive information on the second screen.

Prototype 2: Peek-through AR

While current smartwatches are equipped with a great variety of motion sensors, they are not sufficiently sophisticated yet to track absolute position. Therefore, to explore the peek-trough interactions, we developed a second prototype that was tracked with an external tracking system.

We used a 12-camera OptiTrack System by NaturalPoint to accurately track position and orientation of the smartwatch in our lab using infrared illumination. Five retro-reflective markers were attached to the smartwatch and to the user's head (using a cap with attached markers) to track their pose in the room (Figure 3 a,b). The 12 cameras continuously broadcast UDP packets with position and orientation of the markers at 200Hz. Packets are directly sent to the smartwatch via WiFi to

[1] http://www.holocube.eu



(a) Optical markers on device... (b) ...and for head-tracking

(c) Wall power socket... (d) ...with registered visuals

(e) Virtual globe (f) Electronics assembly

Figure 3: The *Peek-through* prototype uses external cameras to track retroreflective markers on the (a) device and (b) user, which enabled the several implemented AR scenarios (c–f).

reduce latency and processed by a Unity3D application that is running on the device (Simvalley Mobile AW-414 Go). The field of view (FOV) is calculated and dynamically updated using the distance between the user's eye(s) and the watch.

Preliminary User Feedback

While developing the prototypes we continuously explored the WatchThru interactions in informal user tests with computer science students (representing early adopters) not involved in the project. For the second perspective interaction, the view switching angle of 12.5° was determined in an experiment, where participants experienced different angles of 45°, 22.5°, and 12.5°. The results indicate that when looking at the WatchThru screen, participants hold the device parallel to ground to see through the screen, such that switching to the first perspective at a flat angle is best suited. In general, participants commented that the WatchThru screen works well and is easy to recognize except under strong illumination. However, some of them criticized that the main screen can be distracting when looking at the WatchThru screen.

LIMITATIONS AND FUTURE WORK

World-registered graphics

For AR experiences, absolute and accurate 6DOF tracking is required. While techniques like PTAM [8], KinectFusion [7], and Google's project Tango [5] could be used, they currently require more computational resources and power than what is currently available in wrist-worn form factors. As these techniques have moved from desktop workstations, to tablets and smartphones, we expect future availability in smaller devices.

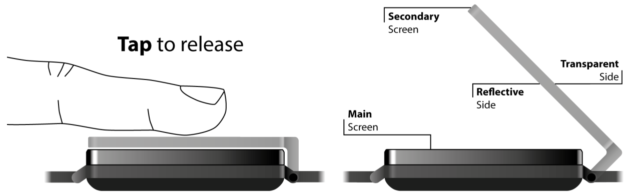


Figure 4: In the future for WatchThru, we envision a transparent screen that can be folded out when needed.

Tracking user's perspective

Given that the display is not co-located with the user's eyes, any AR experience need to account for the user's viewpoint. This makes WatchThru more challenging to calibrate than video see-through systems, where camera, tracking and display are combined. For peek-through AR, tracking of device and user's head are not yet solved in a practical way. In addition to perspective tracking with on-device sensing, tracking the user's head to calculate the field of view could be realized with front-facing cameras, similar to Amazon's Fire Phone [1].

Form factor

We chose the current transparent screen as a first step to implement the WatchThru concept, which can also be easily replicated by other researchers to explore the concept further. We are already working on iterations of the technical prototype to address some shortcomings. The current prototype requires the secondary screen to extend from the device at a 45° angle. While other display configurations are possible, e.g., using holographic optical elements, transparent LCDs or transparent OLEDs, it may still be impractical or undesirable with display components that extend out. As alternative, we could also envision an extendable screen with a mechanical folding mechanism (see Figure 4) such that the WatchThru screen could be pulled out (manually or automatically) when needed. A thin touch-friendly WatchThru screen, or increased projected capacitance sensitivity for touch through the WatchThru screen, could allow the user to interact with the smartwatch in a traditional way when the WatchThru screen is not expanded.

Dual content—one display source

Our current implementations are based on a passive optical combiner, which has advantages of simplicity, ease-of-fabrication, low-cost, optical see-through qualities and ease-of-integration. It works under the assumption that the user focuses on either the main or WatchThru screen, and that the device can adequately detect the user's focus to switch contents on the screen in a sufficiently responsive manner. Our prototype showed the feasibility of this idea, but also the time-sharing limitations when both displays are visible. Future implementations could address this with active translucent secondary displays, which would trade some simplicity for the ability to display simultaneous content on both screens.

Interaction requires both hands

While smartwatches do not occupy the hands when not in use, interacting with them requires both hands, in contrast to most current head-worn displays (e.g., Google Glass).

Usage in complex lighting conditions

As with other optical see-through displays, the display will have limited capability to function under strong illumination. This could be addressed with wavelength-selective and directional selective materials, such as holographic diffusers and optical elements, that only reflect light from a specific wavelength and incident angle, similar to ASTOR [14].

Focal planes

The semi-transparent display creates a virtual image 90° rotated from the wrist. This makes it challenging to fuse overlaid graphics with distant real-world objects. Additional optics could allow placing the virtual image at infinity, for objects that are further than a few meters away. We are also interested in close-up use cases as well as AR overlays onto paper documents and handheld equipment and tools.

User input techniques

The goal of WatchThru is to expand smartwatch displays, with focus on output. Therefore, in the presented use cases we used common techniques (e.g., touch and peepholes). To enable interaction with the WatchThru screen, we could use IR-based edge-lit touch-sensing (e.g., ZeroTouch [11]) or add a touch layer on top of the reflective layer (with added complexity). In the future, we will also explore input alternatives such as mid-air and around the device interaction.

CONCLUSIONS

We introduced WatchThru, a novel interactive method for wrist-worn display using smartwatches. Based on the small display of smartwatches and the limited interaction space on the device, WatchThru extends the visualization space into the third dimension, beyond the flat watch screen, and extends the range of interaction possibilities. We have shown how such a transparent WatchThru screen could allow for *Pop-up Visuals* for ambient notifications, *Second Perspectives* that extend the display configuration, and for *Peek-through* AR scenarios.

Pop-up Visuals extend the passive character of the watch to an ambient notification device. We plan to do deeper explorations into additional interaction techniques, application scenarios, and user-dependent factors that are relevant for the usability and user experience of WatchThru. In the *Second Perspective* mode, turning the wrist allows switching between the displays to leverage tilt-based interaction with smartwatches, to complement gestures, buttons and on-screen widgets. With *Peek-through* AR, we show that WatchThru has the potential to act as an always-available, wrist-worn AR device.

We are currently working on a self-contained version to allow peek-through interactions also in non-instrumented environments and prototypes that allow different viewports. Thus, our minimal addition to a smartwatch opens up a whole spectrum of new interactive capabilities for wearable devices.

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