Extending Interaction for Smart Watches: Enabling Bimanual Around Device Control

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Abstract
The size of a smart watch limits the available interactive surface for the user. Most current smart watches use a combination of a touch screen and physical buttons. Unfortunately, a small touch screen's usability is limited when it can be easily occluded, such as by a finger. In this paper, we look at extending the interactive surface for a smart watch to the back of the hand. Our approach reduces screen occlusion by enabling off-device gestural interaction. We define a range of supported bimanual gestures and present a prototype device.

Author Keywords
Bimanual Gestures; Mobile Devices; Around Device Interaction; Surface Appropriation; Haptic Feedback; Display Occlusion;

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces.

Introduction
Current trends in mobile technology development have seen an increased focus on wearable devices, especially smart watches. While the uses of such devices can be

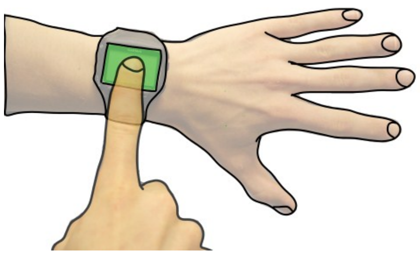

Figure 1. Interacting with touch screens on smart watches includes a range of difficulties; including occluding the display. The green area indicates the available interaction space.

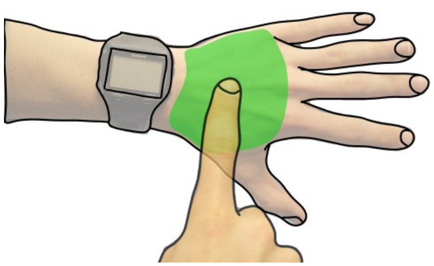

Figure 2. By moving the interaction to the side of the device, the interaction area can increase significantly and remove the problem of occlusion. The green area now indicates a much larger interaction space.

varied, they are increasingly positioned as peripheral devices for smartphones (for example the Galaxy Gear [2]). In this way, they are used for performing already common tasks such as email and notification checking, while also allowing for additional functionality, such as fitness tracking and health monitoring.

Similarly to smartphones, touch screens and physical buttons are still the main input methods for smart watches and the output typically consists of a small screen. In this form factor, this set of inputs and outputs has various shortcomings, such as the difficulty to carry out complex tasks with a limited number of physical buttons and a limited area for touch interaction. Furthermore, the size of the screen leads to easy occlusion by the user's fingers (figure 1). Whereas with smartphones there has been an increase in screen size to enable the display of more information and afford easier interaction, the size of a wrist constrains a similar increase for smart watches.

This paper proposes a new way of interacting with smart watches by extending the interaction area to the back of the wearer's hand (figure 2). By using near-range sensors attached to the device, we enable the use of manual and bimanual gestures. While other work has previously presented mid-air interaction around small-screened devices, we suggest back of hand interaction beside the device. Our approach removes the problems of finger occlusion (also present with mid-air interaction), adds haptic feedback through skin contact during interaction, and supports the continuation of the surface-based input style that smartphone users have become accustomed to.

Related work in this area is reviewed and used as an inspiration for our ideas. We scope the bimanual interaction affordances of our approach and discuss the design and implementation of our prototype device. Finally, we discuss how our work could be developed and further angles for future exploration.

Related Work

We divide the related work into 2 sections: skin-based sensing and around device interaction.

Skin-Based Sensing

A major predecessor of this work is the Gesture Watch [5]. By utilizing an array of infra-red proximity sensors, gestures made over the device could be detected. The Gesture Watch allows multiple gestures to be recognised and works well in different conditions. Above-device sensing of this style extends the available space for interaction but does not reduce screen occlusion. By moving the sensable area to the side of the watch, our approach benefits from a similar scale of interaction, while reducing occlusion and adding haptic feedback. Such sensor positioning has previously been explored around other devices, such as adding sensors to the side of mobile phones as in SideSight [1] and HoverFlow [6].

Another related technology is Skinput [3], which detects touch on the skin as vibrations through sensors in an armband. Multiple cantilevered piezoelectric sensors are used to localise finger taps anywhere on the arm, including the finger tips. The piezoelectric sensors are configured to be highly resonant allowing the system to function even while the user is in motion. While these sensors are highly accurate for determining touch-based interactions, they are unable to detect dynamic gestures. By combining an approach similar to this with infra-red sensors, we are able to determine both tap and dynamic gestures, extending the interaction possibilities.

Around Device Interaction

Around Device Interaction is a populous area of research, especially when concerned with mobile phones. Given the further decrease in size for smart watches, we predict that this area of research shall continue to grow in prevalence. In the previously mentioned SideSight [1], users were able to, for example, rotate an image on screen using both hands placed either side of the phone. B. Jones et al. [4] also explore this, adding 'Around Device Interaction' to allow gestures in the free-space surrounding the phone. Both [1] and [4] found an equal performance between touch-screen and non-touch-screen -based gestures.

In HoverFlow [6], Kratz and Rohs scope an around-device design space. They envision the use of Around-Device mid-air interaction for a variety of future small devices, such as wrist watches, jewelry and wireless headsets. However, they focus on mid-air interaction. While this serves to provide the largest possible interaction space, it removes and reduces some of the privacy and subtlety of use that would usually be associated with small wearable devices. Further to this, smart watches are tightly anchored to the wearer and, as such, we believe that tightly coupling the interaction to the wearer will provide the most natural and comfortable usage. We aim to explore this point in our future work.

We draw on this body of previous work by extending the interaction space to the side of the watch, optimising the relationship between achievable screen-size for display and interaction area for input, whilst minimising the effect of display occlusion and allowing for haptic feedback.

Extending Interaction for Smart Watches

By extending the available interaction area we enable users to perform gestures, such as pinch-to-zoom when navigating maps, on the back of their hand as opposed to on the small surface of the watch. Alongside minimizing display occlusion, this increases the space available for interaction, reducing the required granularity of the gesture and thus making it easier to perform.

By combining different sensors in different positions, for example infra-red proximity sensors on the side of the watch body and strap and piezo-electric sensors underneath the watch, we are able to determine and identify a range of different inputs, such as the location of taps, swipes and multi-finger interaction. Further to this, our approach also supports gestural interaction from the wearing hand – thereby enabling *bimanual interaction*.

Interaction Affordances

Here we shall briefly present the interactions supported by our approach (figure 3) and some example use-cases. We break these interactions down into 2 sections, those performed by the non-wearing-hand and those by the wearing hand.

Non-wearing-hand Interactions

These interactions are performed on the back of the hand, beside the watch. As we do not currently project any content onto the back of the hand, these

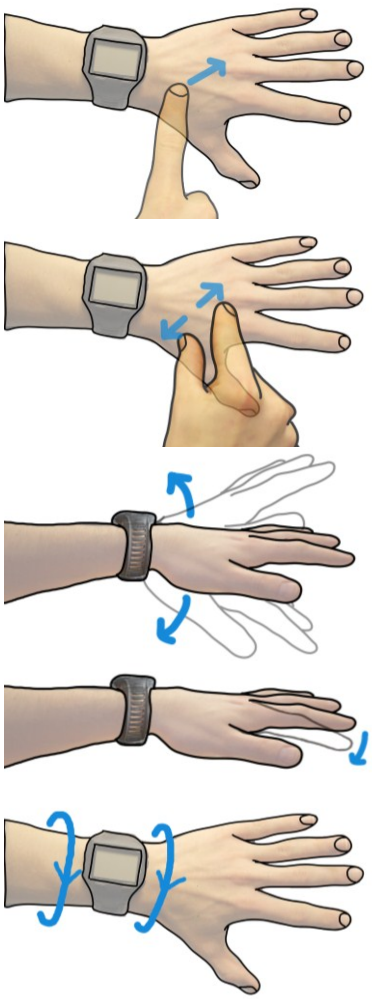

Figure 3. Set of available interactions. From the top: single finger taps and gestures, multi-finger gestures, whole-hand selections, individual finger taps and whole arm gestures.

interactions require an unguided spatial mapping between the display of the watch and the interaction space. By anchoring the interaction space to the back of the hand, the scope of the available space is more apparent and as such we believe the mapping is similarly apparent. Further to this, visual feedback can be provided on the watch face to further aid the understanding of this mapping. As part of our future work on this project, we aim to explore that mapping, to corroborate this concept.

Single Finger Taps

Enabling the selection of individual items displayed on the watch. For example, taps could be used to enter numbers on a number pad (virtually translated to the back of the wearer's hand).

Single-Finger Gestures

Such as left-right and up-down swipes, could enable scrolling through large information blocks such as web-pages.

Multi-Finger Gestures

Such as the previously suggested pinch-to-zoom, for navigating through larger data such as maps.

Wearing-hand interactions

These interactions are performed by the hand wearing the watch in order to make quick selections. They are still conceived of as discrete or subtle movements.

Whole-hand selections

By pivoting the hand up or down at the wrist, the user could perform a selection, such as accept or dismiss an incoming call. This needs to be carefully implemented in practice to avoid undesired reactions. For example, on watch accelerometers could be used to confirm that the watch face has been visually attended to.

Individual Finger Taps

Individual taps could be used for finer-grained selection, i.e. from a multi-option menu, or for the performance of shortcuts, such as opening a frequently used or 'favorite' app.

Whole-arm Gestures

By including accelerometers in the watch, arm based gestures can be incorporated, such as a wrist flick for a quick view of the calendar.

Prototype Device

In order to explore our idea we built a prototype device. We attached three infrared proximity sensors to the hand-side of a watch strap next to the face (figure 4). These were positioned such that they would capture any movement performed above the hand. As we wished to enable the use of bimanual gestures and thus needed to be able to sense movement of the wearing hand's fingers, we placed additional sensors on the side of the strap underneath the wrist. To examine the suitability of different sensors, we used ultrasound sensors underneath the watch. The ultrasound sensors were significantly larger and required more power to operate than the IR sensors without providing a higher granularity of signal, so in the future infra-red sensors would be used throughout our device (i.e. infra-red sensors would also be used for the underside of the watch). Finally, we attached a piezoelectric sensor underneath the watch face where it would be in contact with the user's skin, to detect taps.

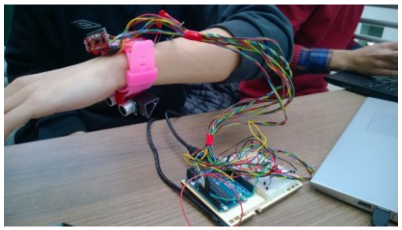

Figure 4. Our prototype device for exploring our proposed interactions. The IR sensors for detecting gestures on the back of the hand can be seen on the top left of the strap. On the underside of the strap are the ultrasound speakers and microphones.

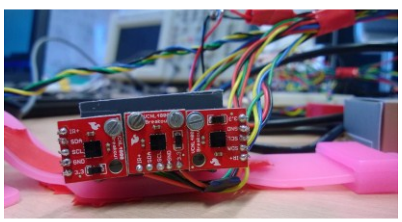

Figure 5. Three infrared sensors were placed on the side of the device to triangulate interaction data above the hand. By including three sensors, we can mitigate against sensor occlusion during interaction.

Our intention was to utilise the piezo-sensor as a 'skin-contact trigger' or reserving clutch (a means by which to determine when contact was made with the back of the hand so that we could begin recognising gestures). Due to a lack of cantilevering however, the piezoelectric sensor was not tuned to a certain frequency as in the Skinput [3] project. This made it difficult to distinguish between purposeful taps and sudden movements of the wrist. This would need to be addressed through further development and exploration in future refinements to our prototype.

Our prototype device can detect taps, swipes and wearing-hand selections. In order to identify any input gestures, we utilized the $1 Gesture Recogniser [10]. Our use of this could be extended to recognize more complex gestures, such as alphabetic characters.

Discussion

The prototype allowed for an effective demonstration and early exploration of extending interaction for smart watches. Our device demonstrates the possibility of bimanual gesture input to minimise screen occlusion and maximise the interaction surface.

In order to gain some preliminary feedback for our device, we developed a demo application that allowed a user to explore a map. Panning around the map was conducted using swipe gestures on the back of the hand and zooming was performed by pivoting the wearing hand up and down. We tested this application with 5 users. The user feedback was positive; the larger interaction area was found to be beneficial supporting the points raised in our related work, and the use of bimanual gestures were described as 'natural' and 'intuitive'. This initial feedback was not conducted as a formal study and was only intended to provide lightweight feedback from which we could derive further design refinements in the future.

Future Work

Our early prototype device supports a small subset of the interaction affordances that we present above. We will further develop our device such that all of these interactions can be supported. Throughout this process there will be important design decisions to be explored. For example, our current design supports interaction to one side of the device, the hand side, such that the interaction is not constrained by the wearer's clothing. However, if the wearer is sporting a t-shirt, then we are not utilising a larger interaction space on the other side of the device. We are keen to explore the possibility of supporting interaction around the entirety of the watch and the different affordances that this would allow.

Alongside the completion of our prototype device, we seek to gain a greater understanding of the differences in performance between around watch interaction and watch-screen interaction. We aim to conduct a series of controlled user studies to compare our proposed interaction approach with the standard device interaction approach (buttons and a touch screen), in order to compare efficiency, comfort and ease of use.

As our proposed bimanual interaction is a novel paradigm in this space, we plan to conduct studies to explore its use. This will help us to determine and derive the best mappings between our available interactions and the input needs of the watch.

By moving the interaction away from the touch screen, it is spatially separated from the content with which it is concerned. Another possible area for future work is the use of small pico-projectors to augment the back of the wearer's hand and, as such provide clearer visual cues for the interaction. Research into optimum screen sizes for mobile devices, such as that by D. Raptis et al. [8], have concluded that a large screen size is beneficial, increasing efficiency when completing tasks such as Internet browsing and viewing media. While this once again leads to occlusion of the device during interaction, the usage would become more similar to that of a smart-phone, thus removing the need to learn any new interaction styles.

Conclusion

This project furthers development on smart watch design, looking at new and interesting gestures and addressing the issue of small interactive surfaces. Ideas from Skinput [3] and Gesture Watch [5] have been further developed and combined. A prototype has been constructed that can detect six different distinct gestures and uses a combination of infra-red sensors, ultrasound sensors and a piezoelectric sensor. Additional research is required to explore the exciting possibilities of intuitive bimanual hand gestures for smart watch interaction.

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