

AugmentedForearm: Exploring the Design Space of a Display-enhanced Forearm

Simon Olberding¹, Kian Peen Yeo², Suranga Nanayakkara², and Jürgen Steimle¹

¹ Max Planck Institute for Informatics
Cluster of Excellence MMCI
Campus E1 7, 66123 Saarbrücken, Germany
{solberdi, jsteimle}@mpi-inf.mpg.de

² Singapore University of Technology and Design
20 Dover Drive, Singapore 138682
{kp, suranga}@sutd.edu.sg

ABSTRACT

Recent technical advances allow traditional wristwatches to be equipped with high processing power. Not only do they allow for glancing at the time, but they also allow users to interact with digital information. However, the display space is very limited. Extending the screen to cover the entire forearm is promising. It allows the display to be worn similarly to a wristwatch while providing a large display surface. In this paper we present the design space of a display-augmented forearm, focusing on two specific properties of the forearm: its hybrid nature as a private and a public display surface and the way clothing influences information display. We show a wearable prototypical implementation along with interactions that instantiate the design space: sleeve-store, sleeve-zoom, public forearm display and interactive tattoo.

Author Keywords

Wearable display; forearm interaction; augmented human.

ACM Classification Keywords

H5.2. [Information Interfaces and Presentation]: User Interfaces - *Interaction styles*

INTRODUCTION

Wristwatches have existed for many years and have become an always visible and always available information display [10]. Glancing at a wristwatch to see information has become a natural behavior and is part of our everyday life. With recent advancements in ubiquitous mobile computing (smartphones, PDAs etc.), people carry a lot of processing power, memory and connectivity, which provides a gateway to access digital information. Combining the above two, researchers have come-up with wrist-worn devices that provide an always available input/output interface to digital information [7,9,2,1]. However, these wrist-worn interfaces typically rely on a small screen to display contents.

Following Harrison *et al.* [3], we believe that extending the

screen to cover the entire forearm is promising, since it allows one to conveniently wear the screen, similarly to a wristwatch, and provides a fairly large area to display contents. Emerging research currently starts exploring the interaction space of an augmented forearm, mostly focusing on technical aspects such as how touch input can be detected. Skinput [5] uses a body-worn projector that projects a display on the forearm. Touch input is detected by acoustical tracking of fingertips on the skin. Alternative approaches rely on computer vision for detecting input [11]. Harrison *et al.* [4] leveraged palm and finger movements for interaction with projected interfaces.

We add to this stream of research by focusing specifically on interaction on and with the forearm, taking into account its unique physiological properties, which were unaddressed in previous work. We investigate three aspects. The first is based on the observation that depending on the physical configuration, the forearm has a public and a private nature. This allows the forearm to be both a *personal and public display*. The second aspect is based on the fact that the forearm is often covered with clothing. We will show how clothing, specifically *sleeve-based interactions*, can become an integral part of the interaction. Finally, we address the esthetic dimension of body-worn displays and suggest decorative ornaments as a promising use case.

We developed a functional prototype using several mechanically interconnected displays that are attached on the human forearm. In the next sections, we present the interaction design space, details of the prototype system, as well as interactions that instantiate the design space. We conclude the paper with an outlook of future work.

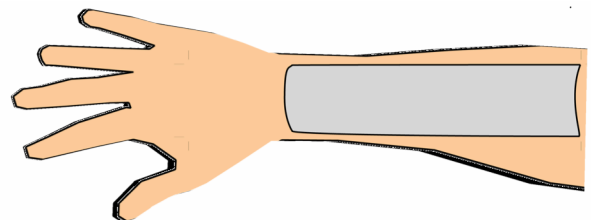


Figure 1: We envision the forearm display to be flexible and breathable, covering the entire upper forearm (grey area).

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INTERACTION DESIGN SPACE

We envision an augmented forearm display to be extremely thin, stretchable and fully breathable (Fig. 1). The display is worn directly on the skin or, more radically, may even be implanted [6]. It can cover the entire forearm or just parts of it. Promising candidate areas are the upper and the lower side of the forearm. Due to its physiological properties, we focus on the upper side, since it allows a wider spectrum of visibility, ranging from public to personal.

Forearm as personal and public display

Being a part of the human body, the forearm has first and foremost a personal character. As such, it lends itself to being a personal display surface, for instance when the upper side of the forearm is oriented to the user, such as when looking at one's wristwatch. However, depending on its orientation, it can also be exposed to the public, for example, when held up or oriented to the other person in a face-to-face meeting. Hence, the physical configuration of the forearm can change its character seamlessly between private and public. This even allows for a mixed configuration, when a part of the forearm is rotated towards the public while another part is oriented to the user. This makes the display extremely versatile in terms of its usage, allowing for quick, frequent and seamless transitions from private to public and vice versa.

From a cognitive point of view, changes of the forearm's orientation often happen implicitly and are done in order to fulfill another task. Some examples include using the forearm for pointing, holding onto a handle in a subway, carrying a box or shaking hands with somebody. These physical configurations cannot be considered as explicit input for interaction with the AugmentedForearm. But the device can leverage the fact that different postures and contextual configurations have different characteristics related to the use as an information display. As an example, interactions that leverage this contextual input might show the next steps when holding up the arm on a handle in the subway.

Forearm covered by clothing

Parts of the forearm may be covered by clothing; so a forearm-worn display might not always be fully visible. The system design should account for this characteristic. It is a natural and common gesture to lift up or push back the sleeve to reveal information, for example checking the time on a wristwatch. Rolling up the sleeve can also have a symbolic value, for instance when one is about to tackle a task.



Figure 2. The hardware setup consists of four interconnect displays, each equipped with a light sensor to detect movements of the sleeve. An IMU measures the arm's orientation.



Figure 3. Using the sleeve as a container for storing items. The user can swipe-in an item into the sleeve (a, b) and bring it back by shaking the wrist while lifting the sleeve (c).

The augmented forearm should adapt the visualization depending on which parts of the display are visible. Moreover, it could use the movement of the sleeve as a novel gesture for revealing digital contents, zooming into them, storing and releasing items in an intuitive way.

Decorative ornaments

Since the forearm is a well-visible part of the human body, it has an esthetic quality. People wear jewelry bracelets and designer watches; they even augment the skin itself with permanent, sticky or slowly fading henna tattoos. We envision that future body art includes animated tattoos that make use of interactive body-worn displays.

PROTOTYPE

In order to explore the design space with today's technology, we must ensure that the display is not influencing the human motor system. Most notably, the display must be stretchable, since a non-stretchable display influences the rotation and twisting capabilities of the forearm. While recent advances in transparent and flexible woven electrodes [8] and smart fabric technologies [12] are promising, displays are not stretchable yet. To ensure that the human motor system remains unaffected, we suggest a tiled display approach for our prototypical realization. It consists of multiple displays, which are loosely connected and directly attached to the skin. We used sticky tape to bring displays as close to the skin as possible.

Our prototype consists of four WIMM [13] (see Fig. 2) computers aligned on the forearm (see Fig. 4b). Each WIMM features a full-color touch sensitive screen, which has a diagonal width of 1.5 inch and a resolution of 160x160px. They feature a 600 MHz processor, an accelerometer, WIFI connectivity and run on the Android 2.1 operating system. A nine degrees of freedom inertial measurement unit (IMU) consisting of a 3-axis gyrometer, 3-axis accelerometer and 3-axis compass is used to detect the orientation of the arm. To detect interaction with the sleeve, three additional ambient light sensors (photocells) are positioned at the outer side of each screen. We use an external server as a mediator between displays and the sensor data. Ambient light information and orientation data is sent to the server via WIFI. The data is then processed on the server, which in turn updates the view on the displays.

INTERACTIONS

We explore three different instantiations of the design space. All of them are using the specifics of the forearm as an information display.

Sleeve interactions

In many occasions, clothing covers the forearm and hides the display. This might look like a restriction at first sight; however, it also provides an opportunity for novel interactions that take clothing into account. We distinguish between the following two kinds of interactions:

Sleeve-Storage: Using the sleeve for storing items

Instead of storing the file inside a file system, which involves time-consuming navigation on the small display, the user can metaphorically store the item in the sleeve. Consider a situation in which the user places an item on the outermost display (Fig. 3a). When the user slightly lifts the sleeve, arrows appear on the screen to visualize that the user can store the file in the sleeve by swiping it into it (Fig. 3b). To bring back the item, the user lifts the sleeve and slightly shakes the wrist. The item then “slides out” of the sleeve and is displayed on the outermost screen (Fig. 3c).

Sleeve-Zoom: Using the sleeve for semantic zooming

The sleeve controls how much screen real estate is visible. Since the device tracks the sleeve’s configuration, it can adapt the visualization accordingly. The more of the forearm is exposed, the more detailed information is displayed. This allows the user to gradually zoom into information or, in the reverse direction, have a more condensed view. Figure 4 shows an example where the forearm displays a condensed overview of today’s appointments. By moving back the sleeve, information expands to show a more detailed view of the appointments.

Seamless transitions between public, personal and private views

The posture of the forearm in a given context allows the display to be public, personal, a hybrid of both, or even fully private. Leveraging physical postures allows for seamless transitions between these states. We implemented the following example with our prototype, using the IMU to distinguish between different physical postures.



Figure 4. Using the sleeve for semantic zooming. Moving back the sleeve reveals more details about the user’s appointments.

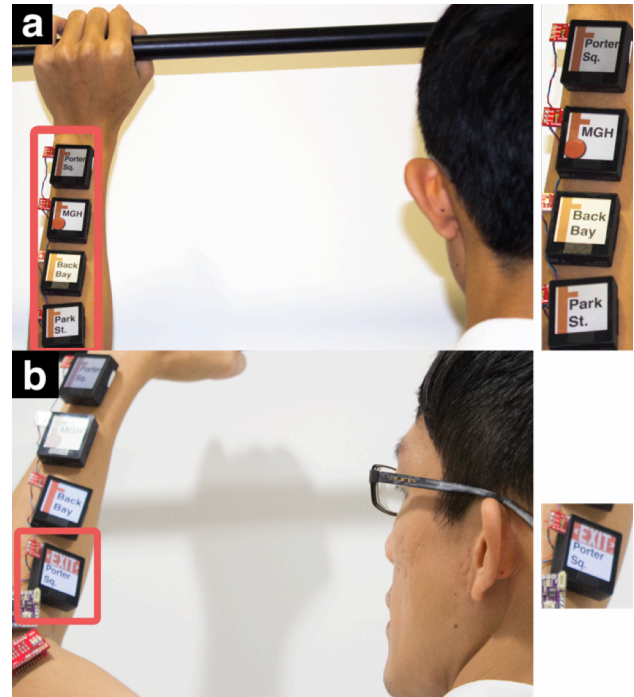


Figure 5. (a) The forearm serves as public display in a train, showing an overview of the next stops. (b) Seamless transitions between public and private content. The upper displays show the next stops of the train and act as public display, whereas the lower display shows directions for the user.

In Fig. 5a, the user stands in a subway train, holding onto a handrail. The forearm is lifted up and exposed to the public. In this posture, the display shows a graphical overview of the next stops and the current position of the train on the track. As such, the display, which is not visible to the user, displays helpful information for other passengers. When the user rotates the forearm, depending on the rotation angle, certain parts of the forearm may be orientated to the user whereas other parts remain orientated to the public. This posture is illustrated in Fig. 5b. The display becomes hybrid: the lower display becomes personal, since it is rotated towards the user, while the other displays remain public. The personal part of the display gives the name of the station where the user has to get off the train. It can alternatively be used to display other private contents such as those of a smart phone or smart watch. As soon as the user orients his entire forearm towards herself (see Fig. 6), the entire display becomes personal.



Figure 6. The arm is fully oriented towards the user and serves as a personal display. Here, it shows details of an upcoming appointment.

Such seamless transition between public and private display is also applicable to meeting scenarios. For instance, when the display is oriented towards the user, it shows personal meeting notes. When it is oriented outwards, to the other person, it shows the agenda of the meeting.

However, we can also leverage the sleeve for fully private information display. If the display is covered by the sleeve, its contents are not visible. By slightly lifting the sleeve, the user can take a glimpse on the display while ensuring that no one else can see it. This interaction is detected by the ambient light sensors and can be used by the application to display private contents or messages.

Interactive tattoos as decorative ornaments

It is common to decorate the forearm with decorative ornaments. Figure 7 shows our current implementation, in which every display shows a specific digital tattoo. In our prototypical implementation, these pictures are static. But we foresee that these automatically adapt to the user's context such as clothing, mood or location.

DISCUSSION AND CONCLUSION

In this paper we started to explore the design space of a display-enhanced forearm. We presented a fully functional prototype that instantiates the design space with sleeve interactions and seamless transitions between a personal and public display depending on the arm posture. Our current prototypical solution is limited by not offering a continuous display surface. While the concrete visualizations that make best use of a continuous display might be different, our interaction concept is fully transferrable to such displays.

In future work, we plan to enhance our prototype to feature a more sophisticated distinction between contextual postures and explicit interactions. We will do this by adding an additional camera to the display that recognizes whether the user is looking at the device. Additionally, we plan to augment the lower side of the forearm to have a display that goes all around the forearm. This will allow for integrating our interactions with the circular interactions from prior work [9]. Field studies of this device will eventually provide insights into the arm postures that are used in the wild and into further application cases.



Figure 7. Using the display as digital decoration. Our current implementation shows a digital tattoo.

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