Improving the Form Factor of a Wrist-based Mobile Gesture Interface

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Abstract
We present the form factor design iteration process of the Gesture Watch, a wearable gesture interface that utilizes non-contact hand gestures to control mobile devices while non-visual feedback is provided from its tactile display. Based on limitations discovered from a previous prototype, we identified three design challenges: wearability, mobility, and tactile perception. In addressing these challenges, we focus on three main parts affecting the form factor: the sensor housing, the strap, and the motor housing.

Keywords
Design iteration, wearable interface

ACM Classification Keywords
H.5.2 User Interfaces: Haptic I/O,

General Terms
Design, Human Factors

Introduction
The Gesture Watch is a mobile gesture interface worn on the wrist [1]. Using proximity sensors, the Gesture Watch captures a user's hand movements performed above the wrist wearing the device and interprets these non-contact hand gestures as commands for controlling

electronic devices such as MP3 players. As mobile devices become smaller, arranging enough appropriately-sized buttons for the interface in the available space often becomes a design challenge. By utilizing non-contact hand gestures, the Gesture Watch demonstrates how a large interaction space can be created for a small mobile device. An additional benefit is that the user can interact with the device even when his hand is dirty or contaminated. Four motion sensors capture hand gestures performed with the dominant hand while flexing the non-dominant wrist triggers a fifth proximity sensor to enables or disables the interface (Figure 1).

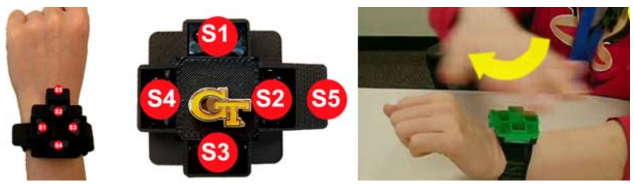

Figure 1. Gesture watch: motion sensors (S1-S4) and trigger sensor (S5)

However, since the Gesture Watch does not provide immediate feedback as to which proximity sensors are being triggered, the user's visual attention is required while gesturing to correctly position the hand with respect to the sensors. To lessen such visual distraction, we proposed using tactile feedback [2]. In this first design iteration, the function of the trigger sensor changed from a *trigger* switch to a *confirm* switch. Unlike the original watch where the motion sensors captured the gesture and transmitted the data to the pattern recognition system only while the trigger sensor was enabled, here the motion sensors are always enabled and the gesture data is temporarily stored in a buffer. The tactile array on the bottom of the watch (Figure 2-right) synchronously displays movement sensed by the proximity sensors on the top of the watch (Figure 2-left). This tactile feedback enables the user to "feel" the correctness of the gesture input and decide to confirm or reject the gesture temporarily stored in the buffer. If the user confirms the gesture by flexing his wrist, the data is transmitted to the pattern recognition system. Otherwise the gesture input is canceled [2]. As a follow-up investigation, this paper presents challenges and guidelines we discovered while implementing the proposed system in various form factors.

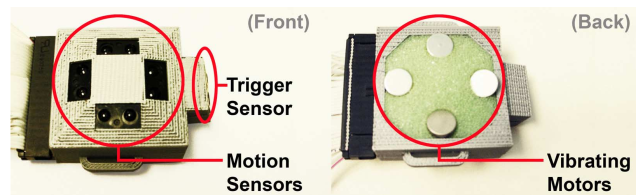

Figure 2. The first design iteration: Four motion sensors and one trigger sensor on the front (left), four vibrating motor on the back (right).

Motivation

In our first design iteration, a vibro-tactile display with four vibrating motors (Precision Microdrives^{TM} #310-101, http://www.precisionmicrodrives.com/, diameter=10mm, height=3.4mm) are added to the back side of the Gesture Watch (Figure 2-right). Each motor is coupled with one of the motion sensors on the front side reflecting the sensors' geometry (Figure 2-left). When a sensor is activated by a hand gesture, the corresponding motor provides vibro-tactile feedback. The motors are inserted in a piece of soft plastic foam that loosely holds the motors. The foam isolates vibrations while maintaining the desired geometry. To ensure firm contact between the motors and the skin, the backside surface of the plastic housing is curved following the contour of the dorsal (back of the hand) side of the wrist.

Target domain	Challenge	Iteration
Upper part (sensors)	Wearability	Layout of components
Connector	Mobility	Strap design
Lower part (tactile display)	Tactile perception	Layout of rubber motor housing

Table 1. Overview of the second design iteration.

During a pilot test, we observed that the perception of the tactile feedback was difficult and did not reflect the promising effects that we observed when applying the tactile display to the volar (palm) side of the wrist [2]. At the dorsal side of the wrist, the vibration from each motor was hard to localize, possibly because of the inappropriate motor geometry and support material. The motor geometry was envisioned as the middle points of the four outer segments in a 3x3 array rather than the four corners of the square. In addition, the soft cushion of the plastic foam failed to maintain tight contact between the tactile display and the skin and even absorbed vibration. Thus, we assume that rotating the layout perpendicular to the wrist and applying an alternative material for housing the motors is required. Since the stacked layout of the sensors and tactile display made maintaining tight contact between the vibrators and the skin impossible, we decided to separate the tactile display and the sensors. We moved the tactile display to the volar side of the wrist. Our second design iteration focuses on solving problems discovered in the pilot test and investigating the details of the design of each part (Table 1).

Design Challenges

The new design of the Gesture Watch focuses on three challenges: wearability, mobility and tactile perception.

Wearability concerns overall comfort while wearing a device with a particular shape, material, weight, and tightness. Considering the forearm as our main design space, our main challenge in wearability is to discover appropriate form factors and layouts to arrange each component. Components in the Gesture Watch are added or rearranged as the design is iterated (Table 2). The problems discovered in the pilot test indicate that the arrangement of components may affect the system's wearability which will eventually affect its overall functionality.

Stage	Upper (dorsal) side	Lower (volar) side
Original	Sensors, power regulator	Battery, others*
1st iteration	Sensors, power regulator, battery, others*, tactile display	-
2nd iteration	Sensors, power regulator, battery, others*	Tactile display

Table 2. Allocation of components around the wrist per design iteration (**others* indicates electronic parts such as the microcontroller and Bluetooth radio).

Mobility describes the characteristics associated with the user's movements. As the elbow or wrist is twisted, rotated, or tilted, the corresponding muscles, joints, and bones moved with respect to each other. This change may cause misalignments of each component of the Gesture Watch. We observed that the watch often became misaligned when the user twisted their forearm (Figure 3). When the palm faced down, the length of the watch was parallel with the arm. However, if the user turned the palm faced up, the watch had a tendency to twist and misalign.

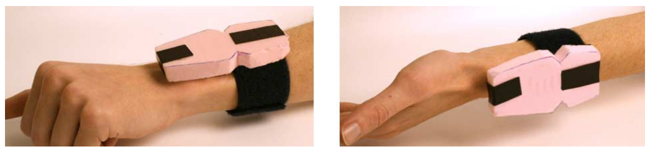

Figure 3. Gesture Watch alignment with respect to the palm position: palm down (left) and palm up (right)

Tactile Perception corresponds with the challenges of providing clear feedback from the watch's vibrating motors. The previously mentioned difficulty in perceiving vibration distinctly from each motor was due to the inappropriate layout and material in designing the motor housing for the tactile display.

Design Iterations

Based on the challenges illustrated above, our design iterations examine three components: the sensor housing layout to improve wearability, the wrist strap design to avoid misalignment during motion, and a rubber housing design to enhance tactile perception. Observation and findings in this section are based on a pilot test performed by the authors.

Sensor housing design

We designed two types of sensor housings: a layout where all components are placed on a single plane (Figure 4-left, Figure 5-left) and a layout where all components are stacked (Figure 4-right, Figure 5-right). The single plane layout provides a short profile in height (25mm) but larger footprint in length (90mm) along the forearm while the stacked layout provides a tall profile in height (38mm) and reduced footprint in length (65mm) along the forearm.

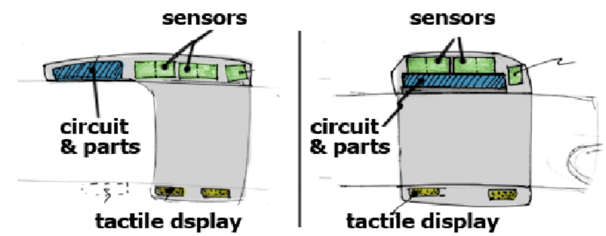

Figure 4. Single plane layout (left) and stacked component layout (right)

Figure 5. Foam model of single plane layout (left) and stacked component layout (right)

The foam models in Figure 5 were worn to assess their overall wearability. The short profile of the single plane layout was preferable to the stacked layout. With the stacked layout, the tall volume of the sensor box is often accidentally hit while users gesture and the high center of gravity makes arm movements awkward. The single plane layout does not have these problems because it fits better along the forearm. However, the motion sensors must sit farther from the trigger sensor to avoid possible interference between dominant hand command gestures and the non-dominant hand gesture for confirmation as described in the introduction. Based on these insights, we improved the sensor housing and printed the design in ABS plastic using a Dimension 3D printer (Figure 6).

Figure 6. Final version of the single plane layout

Strap Development
Next, we focus on the alignment problems associated with mobility (Figure 3) through iterating on the strap design. More issues will be highlighted in the discussion section. The misalignment of the components is undesirable from an ergonomic and functional standpoint. Ergonomically the misaligned components can cause discomfort from the watch pressing against the side of the arm. Functionally, when the watch becomes misaligned with the top of the arm, the trigger sensor can be accidentally turned on by detecting the thumb.

Studying the relationship of the arm and the strap shows that when the forearm rotates, the bones rotate independent of the skin. The strap holds onto the skin and thus rotates independently of the bone and forearm. This problem also becomes more apparent in males who tend to have more muscle in the forearm than females. A number of strap locations were tested to investigate how direct movement between the watch and the bone might be more tightly coupled. From these studies we observed a reduction in twisting as the strap attach point is moved closer to the hand. This reduction is because there is less muscle on the forearm towards the hand, and the watch can sit much closer to the bone. Thus the watch can follow the bones' movement more closely.

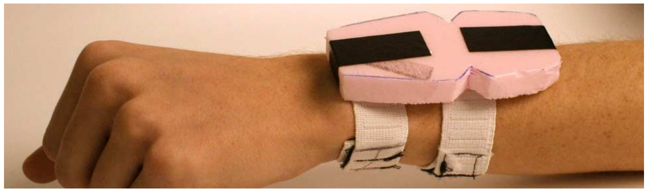

Figure 7. Final dual strap concept model

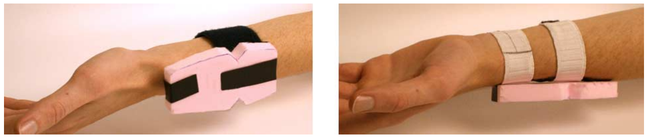

Figure 8. Improving the strap design: The twisting problem in the single strap (left) is solved with dual strap design (right)

The final design with two straps solves most of the difficulties. It is shown in Figure 7 and Figure 8-right.

Motor Housing
To enhance the feedback from the vibrating motors, we placed the motors in a rubber housing. The rubber, which is denser the foam used previously, helps increase contact between the motor and the arm. The center-to-center distance between two motors in a row is 30 mm. The rubber housing also provides the benefit of steadying the layout of the motors, which will be important for formal testing.

Two versions of the rubber housing were developed:

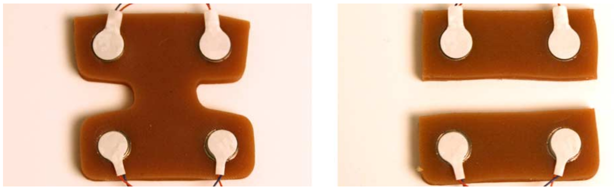

Figure 9. Rubber motor housing: single housing (left) and separated housing (right)

a single connected housing (Figure 9-left) and separated row housing (Figure 9-right). Similar to the design of the strap, separating the housing enables isolated tactile perception within the rows by avoiding the transmission of vibrations through the connecting material. Since previous research [3] revealed that the vibro-tactile perception *across* the back of the forearm (from thumb to pinky) is easier than the perception *along* the back of the forearm (from wrist to elbow), separating the rows is more reasonable than separating the columns. Thus, the separated row housing is preferable in the final design in supporting tactile perception.

Discussion and Future Work

During our investigations detailed in this paper, more issues became apparent for future exploration.

Our iteration in the form factor and the strap design was performed with separate mock-ups of the sensor box and tactile display. Other than the shape and the size, factors such as the weight and the tightness of the band need to be investigated to verify the benefit of our design. High fidelity prototyping that reflects the real physical profile of the system is required to support our findings in the form factor layout and the strap design.

While iterating on the design of the motor housing, two factors were changed. The motors layout was changed and the material was changed from foam to rubber. Since the factor that improves the perception of the tactile feedback is unclear between these two, exploring the effect of each factor is required for future work. In addition, as we rotated the motor layout to enhance tactile perception, the sensor layout was also rotated. Investigating the effect of the new sensor layout with respect to gesture recognition is also required for future work.

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