WatchIt: Simple Gestures and Eyes-free Interaction for Wristwatches and Bracelets

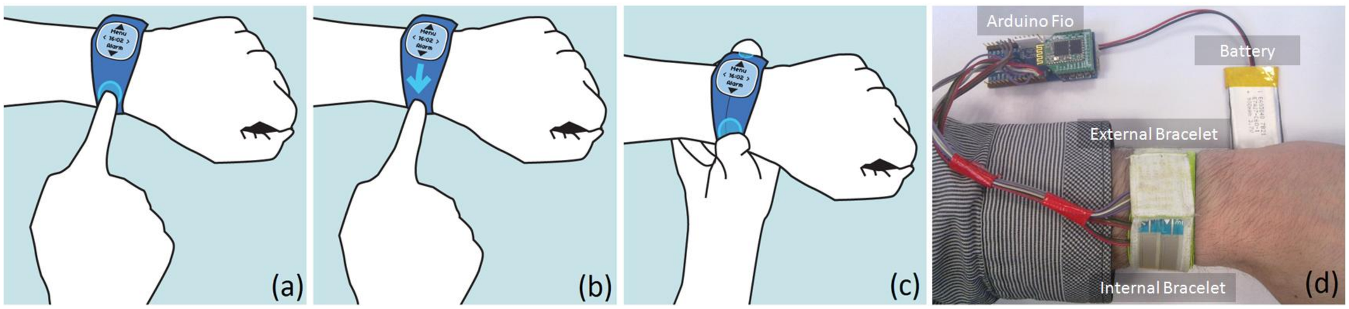

Figure 1: WatchIt enables interacting with the wristband using gestures: (a) with a finger pointing on the internal strap, (b) with a finger sliding on the internal strap, (c) with two fingers on opposite straps, (d) the final experimental WatchIt prototype. Gestures (a) and (b) can also be performed on the opposite, external strap (not shown)

ABSTRACT

We present WatchIt, a prototype device that extends interaction beyond the watch surface to the wristband, and two interaction techniques for command selection and execution. Because the small screen of wristwatch computers suffers from visual occlusion and the fat finger problem, we investigate the use of the wristband as an available interaction resource. Not only does WatchIt use a cheap, energy efficient and invisible technology, but also it involves simple, basic gestures that allow good performance after little training, as suggested by the results of a pilot study. We propose a novel gesture technique and an adaptation of an existing menu technique suitable for wristband interaction. In a user study, we investigate their usage in eyes-free contexts, finding that they perform well. Finally, we present a technique where the bracelet is used in addition to the screen to provide precise continuous control on lists. We also report on a preliminary survey of traditional and digital jewelry that points to the high frequency of watches and bracelets in both genders and gives a sense of the tasks people would like to perform on such devices.

Author Keywords

Digital jewelry; wearable computing; watch; watchstrap; watchband; watch bracelet; input; eyes-free interaction; continuous input; scrolling

ACM Classification Keywords

H5.2 [Information interfaces and presentation]: User Interfaces – Input Devices and Strategies..

General Terms

Human Factors.

INTRODUCTION

Wrist watches have long inspired visions of their use for ubiquitous interaction. As early as 1946, comic book hero Dick Tracy used a two-way radio watch [15]. In 2001, IBM released a functional computer in their Linux Watch [10]. Interaction with these devices is heavily constrained by their small interactional surface. Occlusion and the fat-finger problem [16, 19] hinder the selection of small targets, both on-screen and via buttons. While it is feasible to shrink the size of the display and of the hardware circuits, shrinking the human hand remains an open problem. As such, enlarging targets reduces the complexity of the graphical interface, in terms of number of widgets, and number of available commands as well. Instead of limiting input to the screen and bezel of a watch, we have created WatchIt, a prototype device that extends interaction beyond the watch surface to the wristband. By embedding 1-D position sensors into the wristband, it becomes possible to use this surface to move interaction off the screen of the watch, avoiding problems of occlusion. Furthermore, WatchIt can be used as a simple input device, on a bracelet without any screen, or on a watch with a non-tactile screen.

In this paper, we:

- Introduce a prototype device that extends the interactional surface of a watch to the wristband using cheap, low-power sensors;
- Explore its usage both as an extension to a watch-screen interface and as a stand-alone, eyes-free interactive bracelet;
- Evaluate users' abilities to perform two kinds of interaction techniques for scrolling lists on bracelet, with encouraging results.

RELATED WORK

Various approaches have been taken to address the problems of occlusion and eyes-free interaction on small devices such as wristwatches. We are not aware, however, of other attempts to use the surface of the wristband.

Various approaches explore using additional sensors on digital jewelry, such as a bracelet [14], wristwatch[3, 4], or ring [2]. Ashbrook *et al.* and Blasko & Feiner have studied the use of the screen bezel as a tactile guide for the user's finger, but do not address the occlusion problem.

Rekimoto [14] also uses a wristband to extend interaction off the screen, but uses higher-power capacitive sensors to detect large, hand-sized gestures in air. It does not use the surface of the band for input, nor does it provide for fine manipulations.

Pasquero *et al.* [11] use a haptic wristwatch to provide simple, discreet interactions in an eyes-free context, but they focus primarily on output and do not make use of the wristband for interaction.

Harrison & Hudson's Abracadabra [8] extends interaction off the watch display using a magnetometer in the watch and a small magnet affixed to a finger. Users can discriminate up to 22 angular sectors but must wear a magnet on their finger.

Ashbrook & Baudisch's Nenya [2] also uses a magnetometer to track the rotation of a ring around a finger. The nature of its interaction is well-suited to eyes-free interaction, but it offers only a limited set of eight commands.

With Tarun *et al.'s* Snaplet [18], the user interacts with a deformable device that can be used as a wristwatch, a PDA or a phone, depending on its shape. While this device offers touch interaction, the use of pressure sensors involves a very limited number of tactile zones and degree of precision. The pen interaction offers high precision, but requires the use of a stylus, which is not suitable for a real wristwatch.

Moving beyond digital jewelry, other approaches aim to address the challenges of occlusion and the fat-finger problem. Baudisch & Chu's back-of-device interaction [5] uses sensors on the back of the device to allow pointing through the rear. This elegant technique cannot apply to watch-based interaction because the rear surface is unavailable, neither does it allow eyes-free interaction.

Finally, Butler *et al.'s* SideSight [7] uses proximity sensors to track finger position around the device for mid-air multitouch interaction, but it does not use the materiality of the wrist-band.

DIGITAL JEWELRY

In order to better understand the context of digital jewelry, we conducted a preliminary online survey. We were primarily interested in understanding what kinds of jewelry (digital or otherwise) people wore, to gage interest in various kinds of digital jewelry, and to understand what kinds of tasks users envisioned performing with such devices.

We surveyed 38 men and 30 women, aged 19-52 (average: 26) using an online poll. 79% of respondents stated that they wore at least one piece of jewelry daily. The wrist was the preferred location (Figure 2), with 48.5% of respondents (39.5% of men and 60% of women) reporting wearing something on their wrist.

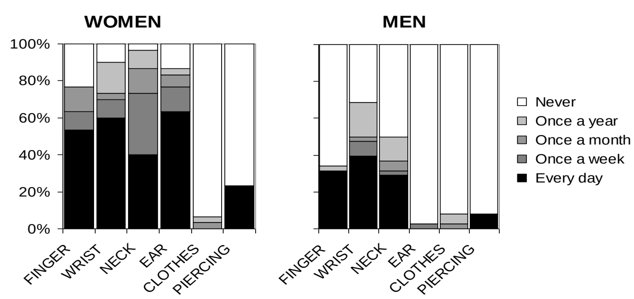

Figure 2: Frequency of traditional jewelry worn at various bodily locations, for women and men

We provided some examples of digital jewelry and asked participants if they felt like using them. Sixty percent of the participants were interested, with more men (66%) expressing interest than women (53%). This proportion rose to 74% for those wearing some article of jewelry more than once a week. Among those not interested in digital jewelry, some judged that such devices would be redundant with smartphones, while others felt that a piece of jewelry should remain a purely decorative item, expressing the concern that adding visible sensors might jeopardize this.

We also asked respondents to rank their interest in various common tasks, providing them with a list of tasks typically available on smartphones and welcoming suggestions (under the assumption that everything is feasible using digital jewelry). Ten tasks were found to be at least "quite interesting" by at least 3/4 of the respondents (Figure 3). Preferred tasks were playing music, reading/sending text messages, GPS navigation, phoning and taking pictures/videos.

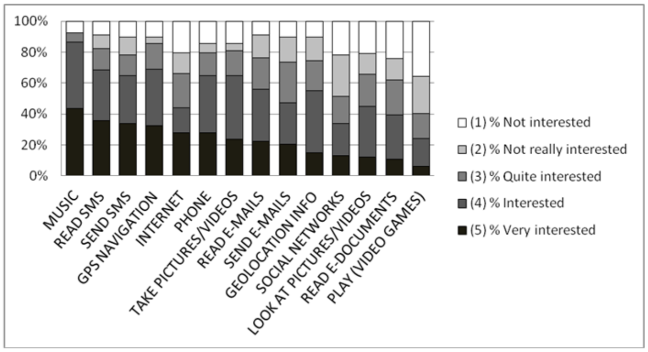

Figure 3: List of tasks, ranked by respondent

Ignoring tasks that require text entry, each of these tasks requires approximately 8-10 discrete commands. For instance, a music player—a common example in the wearable-computer literature [8]—involves the following commands: play/pause, next/previous song, volume up/down, shuffle, plus perhaps commands for repeat, playback position control and playlist navigation. This last feature itself requires several commands (e.g. select, exit) and, more importantly, analog control for list scrolling. The above suggests that the interaction technique we need should allow selecting at least ten different discrete commands, plus some continuous control.

INTERACTING WITH A WRISTBAND

This preliminary survey indicated a strong interest in digital jewelry, with a particular interest shared across both genders for the wrist. As such, we decided to focus our efforts on bracelets and wristwatches.

Interacting with the wristband offers several distinct advantages: intuitively, there is a natural interaction between the dominant hand and the non-dominant wrist: it is natural to clasp one's wrist. Furthermore, because of the shared tactile response and proprioception, people tend to have good dexterity and precision, even when touching one's wrist in the dark. It is possible to point to specific parts of the wrist, and it is a part of the body that naturally affords rotation. Additionally, it helps avoid screen occlusion and the fat finger problem [10]; it provides ready access to the device because no auxiliary object is required; and finally, watchstrap interaction can act as a complement to touchscreen-based wristwatch interaction: for instance the watchstrap might serve for performing frequently performed favorite actions, for which fast and possibly eyes-free commands seem particularly desirable, while the screen itself might be used for direct pointing. These kinds of micro-interactions, defined as "interactions with a device that take less than four seconds to initiate and complete" [1], rely on unconditional availability and fast access [2].

Furthermore, while attention has been devoted to the interaction with watches, especially with their touchscreens or even bezels, to the best of our knowledge using the wristband has not been considered in previous research. As such, the wristband provides a natural avenue for exploration.

The WatchIt Prototype

We studied the tasks identified by participants in our online survey in order to identify what kinds of fundamental interactions would be necessary to perform the various tasks identified. We identified three specific kinds of interaction: invoking specific commands (*e.g.* play/pause), choosing an item among several possibilities (*e.g.* choosing between a contact's home, business, and mobile numbers), and continuous, analog control (*e.g.* scrolling in a long list of albums).

We wanted the device itself to be cheap to build, low-power so as not to overly tax the limited battery power of a watch-sized device, and finally to be compatible with the aesthetic demands of jewelry.

The use of resistive sensing technology gives prominence to a tradeoff between the possible complexity of the interaction on one hand and cost, power consumption on the other hand. Although resistive sensors require more pressure than capacitive sensors, which react to contact, and fail to support multi-touch gestures, they enjoy some interesting features for the equipment of an interactive wristband. First, they require less power than capacitive technology, being also more energy efficient than magnetometer-based techniques such as Abracadabra (which requires 0.15 mA, while our prototype only needs 0.03 mA per potentiometer). Second, the fact that finger pressure is needed for a contact to be registered is advantageous because it helps prevent inadvertent activation. Finally, thin resistive bands like those we used in this study still work when hidden under an opaque layer, which means one need not degrade the appearance of the device—a concern that our survey participants expressed about digital jewelry.

We have thus designed the *WatchIt* prototype (Figure 1), a 2-cm wide (0.79") wristband that is composed of four resistive potentiometers, two for each band. These potentiometers are attached to a cloth wristband with a circular-shaped piece of plastic in the middle to simulate the watch bezel. The potentiometers (position sensors) consist of thin bands with enough flexibility to be used around the wrist. Each works like a variable resistor (max. 10 kΩ) with low variability (< 1%). Their size (81x7.5x0.5mm) enables their integration into a watchstrap. The available tactile surface of our prototype is 16 cm², which is 2.3 times greater than a typical interactive watch screen (about 7 cm² for a 1.5" LCD, the size of an iPod nano). The prototype interfaces with a computer using an Arduino Fio board and a bluetooth shield for communication. An external battery provides power to the Arduino board. The experimental software was programmed in C# and Java.

Simple gestures for interaction

Our goal was to propose fundamental input gestures that could be combined to support richer interactions. Below we describe fairly simple gestures that take advantage of the wristband form factor, that should be combinable to create a richer interaction vocabulary, and that should be unambiguous to recognize. All the gestures presented here are combined to create different interaction techniques for either eyes-free interaction or continuous control. We thus consider two types of gestures: finger pointing and sliding.

A **pointing** gesture for selecting an item in a list or calling a shortcut consists of a brief press of the fingertip on the band. To make the technique robust, we partitioned each band (or half-bracelet) into three zones: one next to the bezel (the top position), one next to the clasp (bottom) and the zone in between (middle). We reasoned that the clasp and the bezel would provide passive tactile feedback. This feedback is not available in the central zone, so we made this zone wider than the two others (2.4 cm vs. 1.3 cm).

A **sliding** gesture consists of sliding the fingertip along a half-band, moving either towards the bezel (upward slide) or towards the clasp (downward slide). The location of the slide is irrelevant, again to make the technique more robust. Two slide gestures are thus available per band. We used a 7 mm threshold for slide amplitude, determined in pretests. Sliding is meant to be used to scroll in a list, provide fine continuous control or correct a selection in a list.

Each of these five gestures (3 pointing and 2 sliding gestures) can be performed on either the internal or external band (Figure 1-d), yielding 10 different gestures (1-contact gestures). We also considered gestures that combine finger contacts on opposite bands, with one finger (typically the thumb) touching the internal band and another finger (typically the index) touching the external band (Figure 1-c) (2-contact gestures). The presence of a second finger on the external band is seen as an all-or-none modifier (the reverse combination was not considered to avoid ambiguities). A total of 15 gestures (5 gestures x 3 band configurations) can thus be obtained (Table 1) for activating commands.

Type	Internal band	External band	Both bands
Upward Slide	#1	#6	#11
Downward Slide	#2	#7	#12
Top Pointing	#3	#8	#13
Middle Pointing	#4	#9	#14
Bottom Pointing	#5	#10	#15

Table 1 : List of the 15 gestures

Alternatively, the 6 (2x3) sliding gestures could be considered as analog continuous gestures. They could then serve for continuous control, for instance for scrolling a list. Finally, an important property of the double-band gestures is that they are most unlikely to be performed unintentionally as they require pressing fingers on both bands.

PILOT STUDY

In order to test the usability of our first prototype and the 15-gesture vocabulary of Table 1, we conducted a pilot study in which the participants were asked to reproduce quickly and accurately a gesture displayed on a screen.

12 participants (two females, aged 25-37, average 28.6) took part in this study, and each of them performed 5 blocks x 15 gestures x 4 repetitions = 360 trials (60 of them as training). Participants wore the prototype on their left wrist and performed the gestures with the right hand.

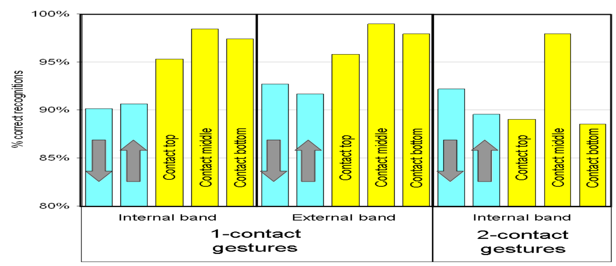

Figure 4: Mean correct recognition rate for each item of our vocabulary.

The results support the view that simple pointing and sliding gestures on either side of a watchband enjoy a relatively high degree of usability (Figure 4). Although the WatchIt technique was quite new to our participants, we still observed good performance with little training. The success rate was particularly high for one-band pointing gestures (> 97%), which confirms the results in [17] and a bit lower for other gestures although always above or close to 90%, for each gesture category.

The few errors that were recorded were typically due to a sliding gesture being confused with a position gesture (7.4% of the slides). The curvature of the wristband being imperfect, small interruptions occasionally occurred in the signal as the finger skipped along the surface. To fix that for the rest of the study, we made our recognition algorithm more tolerant to small interruptions by ignoring interruptions shorter than 200ms.

Another lesson drawn from the pilot study was that our first prototype (Figure 5) suffered from insufficient stability around the wrists in the face of finger pressure. We decided to use a plastic slap bracelet reinforced with a flexible steel band inside to obtain a firmer surface. Compared to the previous prototype, movements are significantly reduced in amplitude because the band is now worn directly on the wrist. Another advantage of this solution is that the new prototype (Figures 1 and 6) is thus very similar to a standard wristband. There are resistive potentiometers on the top of it, but they are easily hidden by a fabric or leather covering. It is also more confortable to wear, with the flexible steel being mostly unnoticed by the participants.

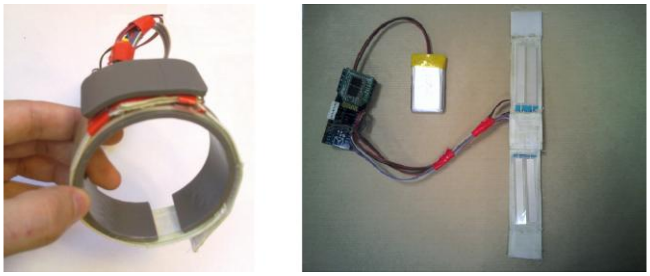

Figure 5 : The first prototype (left) vs the final Watch It prototype, its Arduino Fio with its Bluetooth shield, and its battery (right)

This solution also partly addressed another problem with 2-contacts gestures being recognized as single contact gestures (2.43% of them). With the last prototype closest to the wrist, users need to spread the fingers less, thus facilitating 2-contact gestures. Figure 5 shows the first vs. the final prototype.

EYES-FREE INTERACTION

The next step of our experimentation was to evaluate the usability of our prototype for eyes-free interaction, of interest in a variety of situations where the user cannot easily look at his or her watch screen, as when walking, jogging, holding a suitcase, or when the shirt sleeve covers the watch. Eyes-free interaction can also potentially facilitate more discreet micro-interactions like silencing a vibrating ringer in a meeting. It is essential for use in other jewelry such as a bracelet, which offers no screen. Assuming wireless auditory output from a mobile phone, a bracelet may be conveniently used as an input-only device to provide auxiliary input.

We designed an audio menu technique that provides three different top-level menus. Similarly to our gesture technique, each band configuration (internal, external, or both) corresponds to one of these three menus. As with earPod [20] and Nenya [2], these audio menus use interrupted playback: an auditory item is immediately played back when it is selected, cutting off any ongoing playback. The technique exploits both pointing and sliding: while an item is spoken in response to a pointing contact on the wristband, a slide allows the exploration of the auditory list.

The band is divided into as many zones as there are items in the associated menu. An experienced user can thus directly point on the appropriate zone, or, at least, on a neighboring zone, provided that there are not too many items in the menu. If the auditory return is not correct, she can adjust and reach the right zone by sliding in the appropriate direction. A novice user can thus browse the whole menu.

USER STUDY 1 — EYES-FREE INTERACTION

In this study we wanted to evaluate the WatchIt prototype in eyes-free interaction. We conducted a 2x3 within-subjects experiment with two factors: *band configuration* (external, internal, both) and *interaction technique* (the audio menu described in the preceding section vs. the gesture technique of the pilot study). Audio menus were provided with 5 items to make comparison possible with the gesture technique (5 gestures). To ensure that the experiment would be eyes-free, participants wore an apron that hid their arms during the experiment.Stimuli

For the Gesture technique, we used the same stimuli as in pilot study, with a visual representation, and, for position gestures, the number of the area (1: near the bezel, 2: the middle zone and 3: near the clasp).

For the Menu technique, we used real world names, as in EarPod [20], and as suggested by Miller [9]. Each stimulus had one or two syllables and an audio duration of less than one second. Table 2 shows the stimuli used.

Band	Hierarchy	Items
Internal	Animals	Cat, dog, eagle, horse, pig
External	Shapes	Circle, ellipse, rectangle, square, triangle
Both	Color	Blue, green, pink, red, white

Table 2 : List of stimuli used for the Menu technique

Methods

The experiment started with 6 blocks of training (5 gestures on internal, external and both bands, plus 5 menu items on each of the internal, external and both bands). This pattern was then repeated 5 more times after training, for a total of 36 rounds (6 blocks x 2 techniques x 3 band configuration). The interaction technique factor was fixed for every participant (P1 started with gestures, P2 with menu), but the band configuration was randomized for each set of blocks and techniques. During training, participants were allowed to look at the bracelet and were strongly encouraged to explore the surface, to locate points of interests such as the "screen" and clasp, so that they could better familiarize themselves with device for subsequent eyes-free interaction. At the end of the training round, they were instructed to don the apron. Each block included 5 gestures or 5 item selections, each with 2 occurrences, presented in a randomized order for a total of 10 trials per block). The experiment lasted about 35 minutes per participant with 6 x 3 x 2 x 10 = 360 trials performed (including 60 for training). Participants wore the prototype on their left wrist and performed the gestures with the right hand.

Each block began with an indication of the technique involved and the band on which to interact. Users were encouraged to take breaks between blocks and could start the next block by pressing the space bar. At the beginning of every trial, a stimulus was shown on the screen (Figure 6-a and b). Participants then had to reproduce the indicated gesture or select the specified item quickly and accurately.

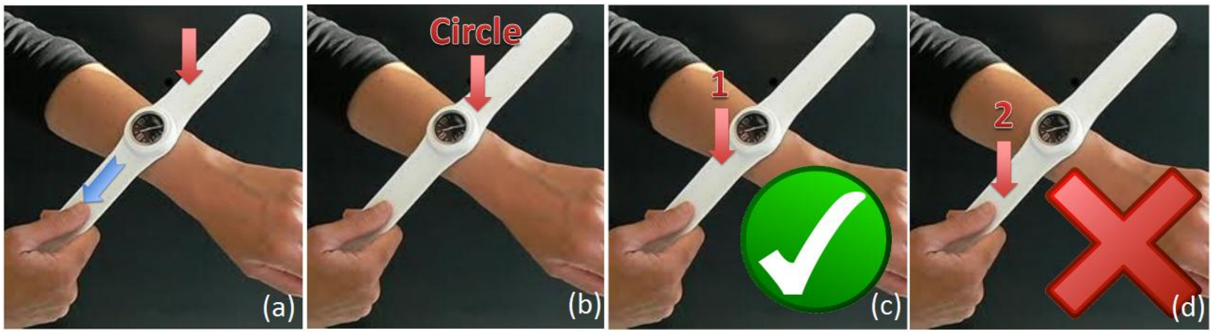

Figure 6: Example of picture displayed as a stimulus (a) for the Gestures technique, (b) for the Menu technique. Example of feedback if (c) the performed gesture was correctly performed or (d) incorrectly performed

Below, we consider two dependent measures, percentage of correct recognition and total trial completion time for correct performance (*TTc*), measured from the time the stimulus appeared to the time a gesture was completed or an item was selected. Upon completion of a gesture, the system showed feedback with a picture of the gesture it had recognized and an indication whether it was the same gesture as the stimulus (Figure 6-c and d). After a 3-s delay, the next trial began. In addition to this final feedback, we provided continuous audio feedback for the menu technique, the name of the currently selected item being spoken back to the user.

We recruited 8 volunteers (one female) aged 25-30 (mean 27.5), including 2 participants from the pilot study.

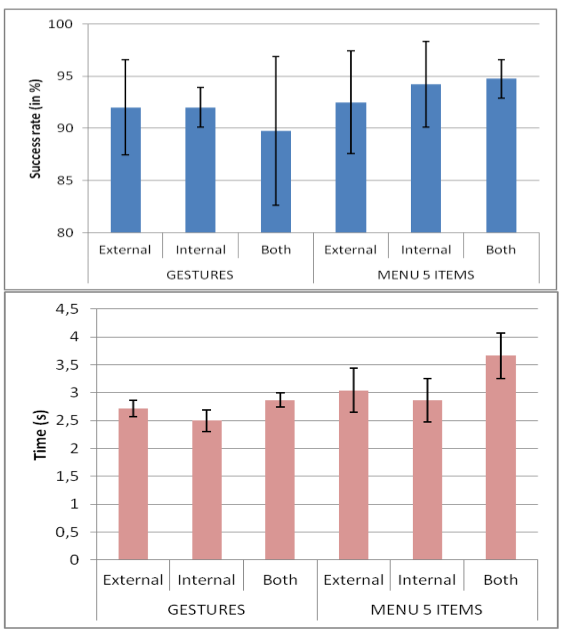

Figure 7: Mean correct recognition rate (up) and mean total trial completion time (down) for both the gesture and the audio menu techniques. Error bars show standard deviations.

Results

As shown in Figure 7, the audio menu technique was slightly more accurate than the gesture technique (93.83% vs. 91.25%, $F_{1,7}$=8.5, p=.02) but it was substantially slower (3.19s vs. 2.69s, $F_{1,7}$=10.94, p=.01). The internal band proved faster than the other two band configurations (2.68s vs. 2.88s vs. 3.27s, $F_{2,14}$=6.22, p=.01), with no significant effect of the band configuration factor on accuracy ($F_{2,14}$<1).

Gestures

As visible in Figure 8, upward slides were more accurate than downward slides (95% vs. 88.3%, $F_{1,7}$=11.2, p=.01) while being slightly slower (2.93s vs. 2.75s, $F_{1,7}$=8.06, p=0.02). Two-contact slides were more accurate than 1-contact slides (95% vs. 90%, $t_{1,7}$=, p=.03) and were slightly but not significantly slower.

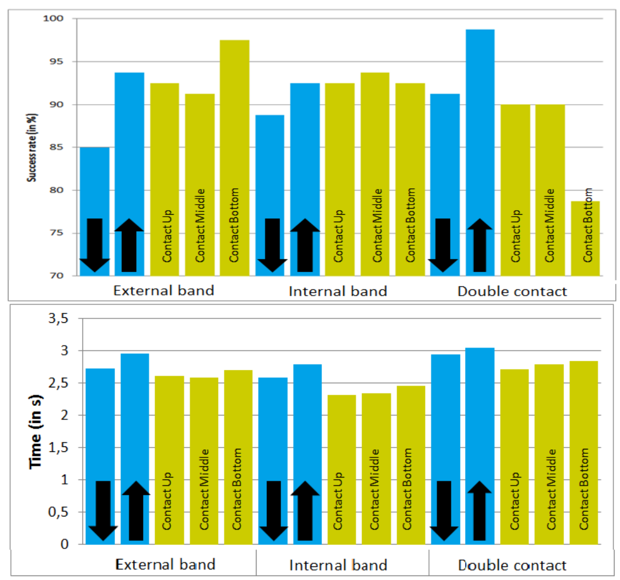

Figure 8: Mean correct recognition rate (top) and mean TTc (bottom) with the gesture vocabulary in eyes-free mode.

For positions, a two-way ANOVA on band configuration and zone showed that only the band configuration had an effect on accuracy (93.75% on external vs. 92.9% on internal and 86.25% on double, $F_{2,14}$=5.61, p < .01), and none of these two factors influenced *TTc*. Thanks to our more tolerant algorithm for the recognition of slides, the average the success rate was now comparable for sliding and pointing gestures (91.7% vs. 91%, p=.37), even though *TTc* was still slightly longer for the slides (2.84s vs. 2.59s, $t_{1,7}$=2.88, p=.01).

Audio Menu

The audio menu technique had a high success rate in general (94.75% for 2-contact, 94.25% for internal and 92.5% for external). The band configuration factor did not significantly affect accuracy ($F_{2,14}$=1.38, p=.29), although it did influence TT_c ($F_{2,14}$=11.96, p<.01). A Tukey HSD Test revealed differences between dual-contact (3.66s) and single-contact gestures (p<.01), but no significant difference between the internal and external configuration (2.87s vs. 3.04s). We also found that item position was not a factor for accuracy ($F_{4,28}$=2.29, p=.09), but was for time ($F_{4,28}$=10.33, p<.0001). A Tukey HSD Test showed differences (p<.01) for *TTc* between the item close to the clasp and screen and the others (2.8s vs. 3.44s).

Discussion

This study provided evidence that the WatchIt prototype is quite usable in eyes-free usage, showing that the menu technique was more accurate but slower than the gesture technique and that one-contact interaction was generally faster than two-contact interaction.

With the new version of the recognition algorithm, slides become comparable with pointing in terms of accuracy, but still take more time to perform. The average rate for each gesture was above 90% (Figure 8), except for single downward slides on the external or internal bracelet and for the 2-contact pinch near the clasp.

One of the 15 gestures of our vocabulary was problematic for users (78.75% success rate, the only position gesture with less than 90% success): the pointing gesture, with 2-contacts, on the position closest to the clasp. The explanation is that some users tended to perform the 2-contact gesture by pinching around the wrist instead of from below the wrist, thus losing one or both contact or pointing in the middle rather than clasp zone.

For menu interaction, the watch case and the clasp also offer tactile marks, which may explain the shorter times for items close to the extremities. No factor was found between band configuration and item to increase precision. That could be explained by the fact that the menu techniques allow for correction. By looking at the detailed log, we observed that users tended to correct less after a few blocks, suggesting that item positions were learned.

CONTINUOUS CONTROL

The small tactile screen available on interactive wristwatches, usable for discrete interactions like pressing virtual buttons, is less suitable for continuous control like setting a sliders or scrolling a list. Many of the tasks mentioned in our initial survey involve list scrolling. Lists are often long (e.g., contact lists and playlists). One difficulty for scrolling on small tactile screens is occlusion, which is less of a problem if the user knows the exact content of a list (e.g. the order of the songs in her favorite album), but can be significant if the list must be explored.

Because the form and the orientation of watchbands and bracelets make them suitable for vertical scrolling, we decided to investigate two interaction techniques that allow list scrolling on the bracelet. For practical reasons and after some pretests, we determined that scrolling would be more comfortable on the internal band of the watch, due to a less tiring hand position: in the case of scrolling on external bracelet, the whole forearm of the hand performing interaction moves, whereas interaction on internal bracelet is performed mainly by moving the thumb.

Scrolling on the bracelet

The first technique we studied is a transposition of the interaction from the tactile screen to the bracelet: the user simply scrolls by sliding her finger on the bracelet, with flicking taking place if the speed at release is sufficient. Scrolling is relative, meaning that only the length and final speed of the slide, not the location of its starting point, are important. This is a familiar technique to users of tactile screens. Given the larger surface available on a bracelet, the scroll can cover larger amplitudes than on an interactive watch screen, and it is free of any occlusion.

Absolute pointing

The bracelet can also serve as a frame of reference for absolute location. The second technique we investigated relies on a mapping of the whole list with the bracelet, allowing for very fast exploration of a list: if the user points close to the screen, the screen will display the first items on the list, if he points close to the clasp, the last items will be shown.

USER STUDY 2 – LIST SCROLLING

In this study we wanted to evaluate the efficiency of the techniques described in the previous section for list scrolling. Users were asked to reach one particular item located at various distances in the list. These two techniques were compared to a baseline technique allowing the user to pan and flick on the tactile screen. We conducted a 3x3 within subject experiment with *interaction technique* (baseline, sliding on the bracelet, and absolute pointing on the bracelet) and *list size* (15, 60, and 240 items) as factors.

Stimuli

We used three different lists for the experiment: a short list (15 items) containing city names, a medium list (60 items) containing state names, and a long list (240 items) containing names of countries and dependencies. We considered 6 different distances: 5, 10, 20, 40, 80 and 160 items as explained on Table 3.

List type	Available distances
Short list	5
Medium list	5, 10, 20
Long list	5, 10, 20, 40, 80, 160

Table 3: List of distances depending on list size

Procedure

The experiment started with a training of 9 blocks, (technique 1 with short, medium and long list, same for technique 2 and 3). This pattern was then repeated 4 more times after training, for a total of 45 rounds (9 blocks x 3 techniques x 3 list sizes). The interaction technique factor was fixed for every participant (P1 started with baseline, P2 with sliding on bracelet, P3 with absolute pointing), and the list sizes were in ascending order. During training, participants were strongly encouraged to use the bracelet and familiarize themselves with device. After training, users were instructed that they could also use the tactile screen when using any technique. Each block included 2 occurrences of all possible distances (this depending on the size of the list: 1 for short lists, 3 for medium lists and 5 for long lists). The experiment lasted about 30 minutes per participant with 3 techniques x (1 + 3 + 6) distances x 4 blocks x 2 repetitions = 240 trials performed (plus 30 for training). Participants wore the prototype on their left wrist and performed the gestures with the right hand. To simulate the screen of a watch, we used an HTC Hero smartphone, running Android 2.1, bound on the wrist and forearm of the user. The whole surface of the screen but a small rectangle (1.5" diagonal) was hidden under an opaque plastic layer.

Task

Each block begun with an indication of the technique involved. Users were encouraged to take breaks between blocks and could start the next block by pressing the space bar. At the beginning of every trial, the name of the target item was displayed in the center of the screen. Participants then had to select this item in the displayed list quickly and accurately. Navigation time (NT) was measured from the time the user started performing a gesture (pan/pointing) to the time of the end of the last gesture occurring before the selection of the item. With all techniques, item selection was performed by clicking on the desired item on the tactile screen. Upon completion of a gesture, a 3 seconds timer appeared on the screen, and then the next trial began.

Participants

We recruited 12 volunteers (1 female) aged 23-31 (mean 27.4), including 3 expert participants from the first study.

Results

A two-factor ANOVA (on technique and target distance) showed that both factors had a statistically significant effect on navigation time. For the technique factor, the global average navigation time (NT) varied a lot, and absolute pointing had a slight advantage over the tactile screen and the scrolling technique (4.82 vs 5.47 vs 7.5s; $F_{2,11}=64.6$, $p<.01$). Unsurprisingly, navigation time tended to increase with target distance ($F_{5,11}=134.7$, $p<.01$); with the only exception that absolute pointing tended to stick to 6.3 secs for long distances (>=40 items) as shown on Figure 9.

One of our hypothesis was the length on pan in the bracelet would be longer than on the tactile screen. The average distance of pan (defined as the absolute value of [index on release – index on touch]) was slightly longer for pan on bracelet (3.07 items/pan on bracelet vs 2.94 items/pan on screen for the technique; $t_{1,11}=1.85$, $p=.04$). Let us consider another metric, namely the cumulated distance of pan. This distance is calculated by the sum of absolute distances from touch to release. There is a significant difference between tactile screen and bracelet (3.28 items/pan on screen vs 5.23 on bracelet; $t_{1,11}=12.79$, $p<.01$). The average number of pans on the tactile screen is higher than on the bracelet: 4.52 pans/trial vs 3.43 ($t_{1,11}=2.98$, $p=.01$).

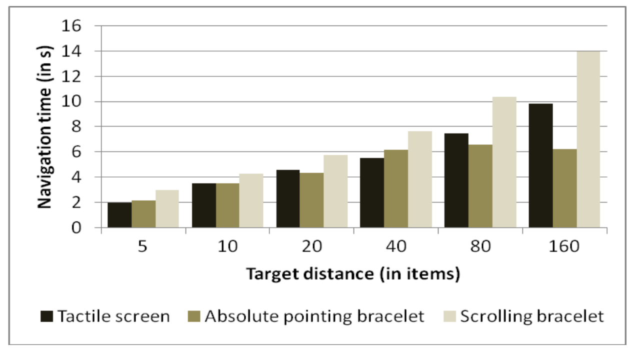

Figure 9: Navigation time depending on target distance for each technique

Interaction on tactile screen

As a baseline technique, users tended to be more familiar with this technique, and understood both panning and flicking. An interesting metric is the average distance of pans on the screen: while the list displays 5 items (so every pan on the screen could have such a maximal distance), results show that for this technique, participants only achieved an average of 2.94 items/pan. It means that user tend to pan on roughly 60% on the screen surface. Unsurprisingly, users tended to execute more flicking gestures (from 0.58 for distance=5 items to 6.74 flicks/trial for distance=160; $p<.01$), with longer distances depending on the distance target ($p<.01$).

Absolute pointing on bracelet

As the Figure 9 shows, it is already noticeable that the NT remains quite constant for long distances, which is confirmed by a Tukey HSD test (no differences in terms of NT for target distance >= 40 items). In that mode, the length of the list is quite important: absolute pointing is easier in a short list than a longer one.

To determine the quality of absolute pointing, we considered the distance between the last absolute pointing before selection and the target. The size of the list had quite an important effect on this value: 1.23 for short list vs. 3.39

for medium vs. 10.36 items distance for long ($F_{2,22}$=138.96, p<.01). Target distances had an impact on absolute pointing in terms of NT ($F_{5,55}$=21.66, p<.01), with two groups of distances: 5, 10 and 20 versus 40, 80 & 160 items, this factor also affected the total number of absolute pointing per trial, with differences ($F_{5,55}$=12.23, p<.01).between 5 and 10 on one hand (1.29 pointing gesture/trial), and 20 to 160 items on the other hand (2.55 pointing gestures/trial).

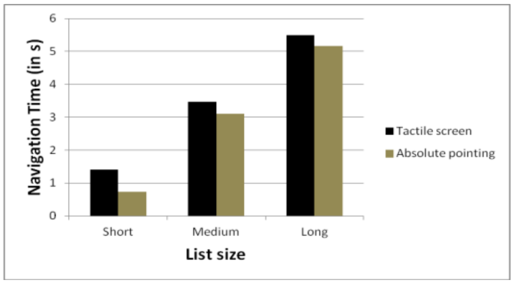

Figure 10: Navigation time depending on list size

Overall, absolute pointing is the fastest navigation technique. In the case of short lists, absolute pointing is nearly twice as fast as baseline (0.74s vs. 1.4s for baseline, $t_{2,22}$=3.69, p<.01) as shown on Figure 10. It is also fastest for 80 (6.57 vs. 7.44s; $t_{2,22}$=2.54, p=.04) and 160 items distances (6.2 vs. 9.84s, $t_{2,22}$=4.89; p<.01).

Discussion

The two techniques designed on the bracelet had a different performance in terms of NT. When the absolute pointing tended to be the fastest technique overall, (faster than baseline), scrolling on the bracelet was proven to be a bit limited. At the end of the experiment, participants were interviewed about the techniques, and all agreed to say that the absolute pointing was the best technique, in terms of precision and usability, especially on long lists. 9 participants (out of 12) stated that it was also well suited for short lists, since the 5 cm bracelet is divided in 15 items, absolute mapping can be considered easier.

Although participants were allowed to interact on the tactile screen any time (and were aware of that), they tended to stick with scrolling on the bracelet (average on only 1.02 pan on tactile screen/trial on the scrolling on bracelet technique). 6 participants explained how they liked the scrolling on bracelet (despite its least overall performance) because it allowed them to explore the list. They would then precise that while interacting on the screen, it would be hard to see the screen, because of occlusion. Another good point of this technique is the length of the panning gestures: less panning gestures means a bit less clutching as well. The bad part is about flicking on the bracelet. The main reason that explains the overall performance of this technique, and the flicking issue is that since users have to apply pressure to activate the bracelet, it creates friction, thus slowing down users.

DISCUSSION AND GUIDELINES

The first user study proved the usability of WatchIt in eyes-free environment. The kind of interaction that potential users would like to perform in such a context would be punctual and quick interaction, as defined by Ashbrook [1]. The audio menu technique was the most accurate technique in this condition also be used and provides up to 3 top-level menus with 5 items. This technique achieves a high success rate (93.83% on average) and was described by users as easier to perform.

The gestures technique offers up to 15 possible commands or shortcut, which is sufficient for most tasks presented in the survey section. The satisfying accuracy rate and very fast speed makes this technique more desirable for shortcuts. Participants were sometimes frustrated with the gesture techniques, since it is not possible to correct a gesture once started. This suggests that it may be necessary to add an escape sequence to gestures. Users reported that two-contact sliding gestures were easy to perform since they could use the finger on the external band to increase pressure on the device, thus preventing the device from rotating, as it did with the first prototype. This trend is also confirmed by the equivalent rate on the 2-contact menu technique (95%).

Interaction with a screen

The second experiment was about continuous input and list scrolling. While the absolute pointing technique was the best in terms of speed, only being slightly outperformed in two target distance conditions out of six, the “scroll on bracelet” performed less well, possibly because of resistive technology and the friction inducted. However, participants still tended to enjoy the technique, especially for exploring lists with unknown items, by taking advantage of the long vertical surface (which allowed them slightly longer pan, and corrections) and the fact that this technique also prevents occlusion. Absolute pointing was preferred by every user (even over baseline), especially for long target distances and long lists, where it notably outperforms other techniques. Also, contrary to the scrolling on bracelet technique, participants tended to use the whole surface of the bracelet to navigate in the list.

In the second experiment we also only considered the case where a tactile screen is present, but some products, like Pebble [12], do not provide tactile interface on their screen. On such devices where energy is crucial, interaction is generally very limited. The Watch It prototype offers a viable alternative to tactile screen: very low energy consumption, eyes-free interaction, and the two scrolling techniques on the bracelet can be used.

APPLICATIONS

The interaction techniques presented in this paper are useful in complementary situations. When the screen of the wristwatch is off, WatchIt can be used in “eyes-free” mode, with only the gesture technique and/or audio menu activated, thus providing fast access to fifteen shortcuts or menu items. This is enough to cover the majority of tasks presented in the survey section. In order to wake up the screen and unlock the device, the user could perform a 2-contact sliding gesture. The device would then go in "precise" mode, with interaction possible on the bracelet and the screen.

Managing a music application in both modes

We envision a user performing certain microinteractions [1], such as play/pause/next/previous song and even continuous volume control, using gestures in eyes-free mode, then unlocking the screen and navigating through the whole playlist with all songs for finer-grained control.

Checking messages

Another scenario would be to use the audio menu technique to browse in the most recent message list, even provide basic commands to answer with prerecorded messages, and a simple 2-contacts slide would give access to more sophisticated features, where the user gains access to his whole inbox.

FUTURE WORK

Our current prototype only considers interaction with one finger per band (internal or external). The use of two potentiometers on each band could allow for pseudo-multitouch interaction, and would thus make the interaction richer. It would be possible to combine the two scrolling technique presented, using 1 finger for relative scrolling and 2 fingers for absolute pointing.

CONCLUSION

WatchIt is a prototype device that supports interaction through a watchband or bracelet. Interaction with wristwatch computers is constrained by their small size. Previous work has addressed problems of occlusion and the fat-finger problem, but has largely ignored the relatively large surface of the wristband, or do not also provide eyes-free interaction. We have developed a new gesture technique and adapted an existing menu technique for micro-interactions. In a user study we have found these techniques to be effective in eyes-free usage scenarios. In a second part, we designed two scrolling techniques for fast and precise continuous control that were evaluated in a second user study. The two techniques avoid occlusion, which helps users for exploring long lists.

The WatchIt concept proposes a cheap, low power consuming solution to enhance existing interaction on smart wristwatches (with or without tactile screen), in complementary situations. On one hand, it allows punctual and simple interaction without having to allocate too much attention on the device (eyes-free). On the other hand, it also provides occlusion-free alternatives for precise interaction with the device in situations where attention is focused on the screen (list scrolling).

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