Shimmering Smartwatches: Exploring the Smartwatch Design Space

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ABSTRACT

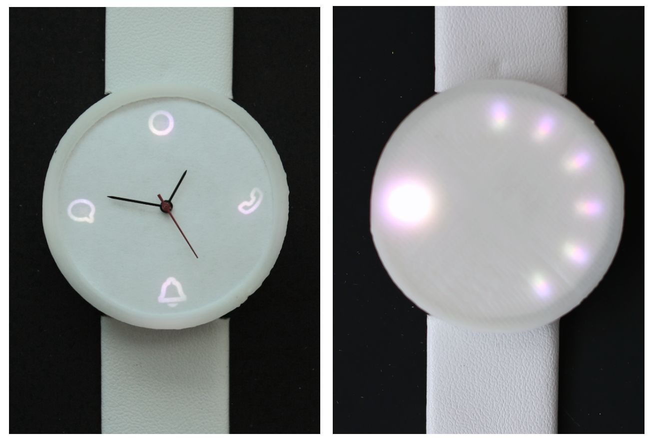
We examine the nature of smartwatches and explore their associated user interface design space in this paper. Several smartwatches are using small graphical displays and as such are adopting similar forms. However, there are indications that other designs could be feasible. We discuss how smartwatches might use non-graphical displays and still offer "smart" capabilities. To demonstrate feasibility, we present two smartwatch prototypes and show how LED arrays can be used to dynamically support several functions needed by smartwatch applications. Finally, we discuss some tradeoffs associated with this approach and point to additional opportunities for investigating smartwatch designs.

Author Keywords

smartwatch; LEDs; displays; wearable

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous



(a) (b)

Figure 1: Our two prototype smartwatches. *Point* (a) has four backlit icons for different apps and an analog watch face. *Circle* (b) uses 12 LEDs to show time and app data.

INTRODUCTION

Smartwatches are one form of wearable computing that is seeing a lot of activity with companies large and small now offering smartwatch products. While there are numerous devices being labeled as smartwatches, we are seeing some diversity in designs with differing capabilities. Many design choices are being driven by technology limitations (such as power use) and other decisions are centered around different user experience goals. While we are seeing some convergence around devices with small capacitive touch screens running a variety of apps, we believe there is a larger design space that encompasses the notion of a smartwatch.

To begin, it is useful to ask the question: What is a smartwatch? For all of the smartwatches on the market, the "watch" part of the device is conceptually rather straightforward. These devices are designed to be worn on the wrist and provide quick access to the time. As such, they have various watch faces controlled by an embedded processor to show the current time. In contrast, the "smart" aspect of these devices is more nuanced.

Superficially, we can examine the functionality of the devices to understand their smart (or not) aspects. Analog watches offer rather limited functionality. For the most part, these watches focus on displaying the time. A digital watch might have additional features and offer a few different modes (time, alarm, timer, stopwatch, etc). At the opposite end of the spectrum are smartwatches with fully capable computing hardware and operating systems. For example, the inWatch Z[1] is an Android device that runs apps on the watch and even has a GSM radio. Other smartwatches seem to be positioned more towards the middle of the spectrum. For example, the Pebble smartwatch can run apps, but these tend to be more limited. It is focused on a very power conscious design with a black and white display and buttons. The Pebble is still a smartwatch, but leverages its hardware to enable "smart" capabilities in a different way. A commonality of smartwatches is that they offer the user the ability to run general purpose apps on the watch.

TEI 2015, January 15–19, 2015, Stanford, California, USA.

ACM 978-1-4503-3305-4/15/01...$15.00.
http://dx.doi.org/10.1145/2677199.2680599

[1] **http://www.inwatchz.com/**

In this paper, we explore the notion of a smartwatch more broadly to understand possible alternative smartwatch designs. We examine the different capabilities of existing smartwatches, several product concepts, and research to show how different smartwatches use different hardware capabilities to create their "smart" functionality. Our first contribution is to articulate the design opportunities for smartwatches that emerge from this analysis. Furthermore, we show that there is a portion of the design space that is currently rather underexplored. In particular, there is an opportunity to create devices that provide smartwatch functionality that do not use the small high resolution graphical displays often associated with smartwatches. To validate this gap in the design space, we present our second contribution as a pair of prototypes that provide general purpose smartwatch application support (Figure 1).

RELATED WORK

In the research literature, there was a lot of early work exploring the technical challenges of creating watches. The work on the IBM Linux watch by Narayanaswami *et al.* details the efforts of creating a device which offered general purpose computing in a watch form-factor [13, 14].

Other research has investigated novel ways to provide input to watch-like devices. For example, Blasko *et al.* researched watch touch input [3] while Ashbrook *et al.* specifically looked at input for round displays [1]. Text entry for small watch sized devices is also explored [16, 17]. Alternative forms of input have also been the subject of research. There has been work looking at capacitive wrist sensing for input [20]. Perrault *et al.* extended the interaction space to a watch band [19] while Oakley *et al.* examined the use of touch on outside edge of round watch-sized device [15]. Other work has moved beyond the body of the watch. For example, GestureWatch used infrared proximity sensors to detect gestures made above and around a watch [9] and Blasko and Feiner examined string-based watch interactions [4].

With all of this work exploring novel input, there has been comparatively less work examining watch output. Some research here includes wrist worn non-visual displays such as electro-tactile [10] and vibro-tactile displays [11, 18]. Moving beyond watches, there have been several concepts proposed that utilize LEDs worn on the wrist often with forms resembling jewelry [6, 12]. One of the first efforts in this area was by Hansson *et al.* They prototyped a notification bracelet connected to a PDA where LEDs would "twinkle" 15 minutes before a meeting. More recently Harrison *et al.* looked at the time it takes to notice and react to an LED notification on the wrist (amongst other onbody locations) [8]. Wrist worn LEDs have also been explored for social purposes in various bracelet forms. Kanis *et al.* showed "logos" on a 5x5 LED array for people that met at a conference, while Williams *et al.* investigated remote messaging using a few LEDs for a display [23]. Although notification and messaging fall into the category of smartwatch apps, these explorations tended to provide only a small set of functionality. Notably, these devices do not offer the diversity of apps one might expect from a smartwatch and most do not have very watch-like forms. There has also been some work exploring the use of LEDs to encode information. For example, there was a series of research by Campbell, Tarasewich and others investigating how much information could be encoded and understood by users in only a few LEDs [5, 22]. Time varying patterns have also been investigated [7].

SMARTWATCH SURVEY

Moving beyond the research literature, it is useful to examine current products and associated product concepts. Most smartwatches on the market today utilize small high resolution graphical displays, have onboard computation and are tethered to a smartphone using Bluetooth. In general, these watches somewhat resemble a traditional digital watch but have additional "smart" functionality (Figure 2a, 2b). They have the ability to run different apps which tend to be tightly coupled to a smartphone. For example, many smartwatches provide a notification mechanism showing the user information about incoming messages, phone calls, etc. The Kairos is a smartwatch concept[2] that combines a traditional analog watch with a transparent OLED display as an overlay. This is a hybrid design and various renderings indicate that it typically acts as a traditional analog watch. However, by using the transparent OLED display, the watch can switch modes to show graphical information like other smartwatches.

Another take on adding some additional "smart" capabilities to an analog watch is the HotBlack[3]. This device again resembles a traditional analog watch; however, there are several additional small hands that can be controlled by an app. One example provided by HotBlack shows details about an ongoing soccer match by moving the secondary hands to indicate the score. Similarly, the Casio G-Shock GB-6900B[4] is a traditional digital watch with Bluetooth Low Energy. A connection to a phone enables a few "smart" capabilities. Instead of using a user interface on the watch for configuration (set the time, alarm, etc.), a phone app is used. It also has a small graphical display showing one of four notification icons (phone call, email, calendar and social network).

While not specifically smartwatches, several activity monitors are worn on the wrist. Some of these devices have display capabilities to show fitness information and might have a mode to show the time. One example of such a device is the Nike Fuel (Figure 2c). The Fuel uses an LED array embedded in the body of the device that shows through small holes. As a result, when the LEDs are off (the default state) they are not visible. While these type of devices might offer several different modes, in general they would not be considered smartwatches since they do not offer the ability to run general purpose apps. They also echo some of the research explorations investigating wrist worn LEDs [8, 12, 23].

ANALYZING THE DESIGN SPACE

As we can see from current smartwatches and the research literature, the notion of what constitutes a smartwatch is still

[2] `https://kairoswatches.com/`
[3] `https://www.kickstarter.com/projects/1087611122/hotblack-the-premium-watch-with-live-football-scor`
[4] `http://world.g-shock.com/us/en/ble/`

(a) (b) (c)

Figure 2: Smartwatch faces of the Samsung Gear (a), Pebble (b) & the Nike Fuel showing time (c).

and emerging concept with various capabilities being explored. The extreme end of the smartwatch spectrum is rather easy to identify offering most of the capabilities of a smartphone in a scaled down form (such as the inWatch Z). The Samsung Galaxy Gear (Figure 2a) and Android Wear watches are not quite as capable, but still offer a lot of functionality in the watch itself. They have capable processors, capacitive touch input and color graphical displays.

Once we look at smartwatches like the Pebble (Figure 2b) and include other devices like the HotBlack or Casio G-Shock, we see there are several additional points in the design space that could be included in the notion of a smartwatch. All of these devices support general purpose applications on the watch which are supported by being tethered to a smartphone. As we examine these smartwatches in more detail, we see rather large differences in the various watches' computation, input, and output capabilities.

Computation: While smartwatches support general purpose applications, they do so in a few different ways. In particular, there are a few different architectures used to enable smartwatch application experiences. For example, the Samsung Gear runs a full mobile phone OS (originally Android and now Tizen). Applications are deployed and run on the watch hardware. The Android Wear smartwatches use a similar approach. Even the Pebble which is on the opposite end of the compute spectrum with a small embedded processor, runs apps on the watch. However, all of these devices are tethered by Bluetooth to a smartphone. The smartphone might run software supporting the watch app or provide a bridge to web services. The Sony Smartwatch 2 relies on the smartphone even more. For this device, the watch acts as a thin client. It again uses a Bluetooth connection to the phone; however, the watch software is rather minimal. The phone runs all of the application logic and the watch is only responsible for displaying the graphical user interface generated by the apps on the phone. The Casio G-Shock also depends heavily on the phone to support applications. Given that these smartwatches are tethered, it does not matter too much where the processing occurs as both of these architectures support a user interface with "smart" capabilities.

Input: Next, we turn to the different input capabilities of smartwatches. Current products are relatively limited. The more capable watches offer capacitive touch screens. Watches like the Pebble and Casio instead opt for the lower power of a physical button. Many of the watches also have sensing such as an accelerometer that could be used for input. While current products have relatively modest input options, the research literature has explored many more potential solutions as discussed above.

Output: There are comparatively fewer options for smartwatch displays. The smartwatches using touch screens also have full color OLED or LCD displays. These include the Android Wear watches, the Samsung Gear and the inWatch Z. The Kairos relies upon an analog watch to show time; however, the transparent OLED would enable full color graphics. The Pebble uses a different display technology in an effort to conserve power. It uses a bi-stable LCD that takes minimal power to show a static image onscreen. While it does not offer color, it can otherwise display arbitrary 2D graphics. Finally, the HotBlack and Casio push the boundary the farthest on what might be considered a smartwatch. By using the secondary mechanical hands the HotBlack can display a limited set of information to the user. Even though it can only show a few 1D parameters, we include this in our smartwatch analysis since it can be controlled by different apps to represent different types of content. Finally, while not smartwatches, the fitness devices described above and the several research projects uses LEDs to convey different information for some specific functionality.

Smartwatch Opportunities

Given this analysis, we can see where there might be opportunities for novel smartwatch designs. In particular, as long as smartwatches are tethered to smartphones, the amount of processing power on the watch itself is probably not a key differentiator for "smart" capabilities. Furthermore, Moore's Law implies that in the future we will have more processing capabilities in even smaller forms. Likewise, while input options are relatively modest on many smartwatches, the research literature has investigated this area in some depth.

In contrast, many current smartwatches utilize graphical displays but there are hints at a larger smartwatch design space that still use visual displays but in different ways. These devices may not offer as much flexibility as a graphical watch but could be sufficiently capable so as to allow for numerous smartwatch applications. For example, building off the HotBlack, might there be other ways to add richer smartwatch capabilities to traditional analog watches? Likewise, the research literature has proposed a variety of wrist worn devices using LEDs that offer fixed functionality. Is it possible to support a broader range of applications on such devices?

In the rest of this paper, we investigate these questions and we present two smartwatch prototypes we built that explore this part of the smartwatch design space. The key research question we address is not how to show a limited set of information on a relatively simple display. Instead, we want to understand if these types of displays can support basic watch functionality while simultaneously allowing the device to show information from a diversity of applications. As such, our prototypes serve as validation that this portion of the smartwatch design space is viable.

SMARTWATCH PROTOTYPES

Here we present two different smartwatch prototypes that explore the broader smartwatch design space (Figure 1). Our prototypes use LED arrays for a display in two different ways. Our first prototype, *Point*, uses an analog watch face and four LEDs to illuminate icons to dynamically show needed information (Figure 1a). In contrast, *Circle* uses 12 LEDs arranged similar to the hours on a watch face to present data (Figure 1b). Both of these emit light through the face of the watch with time varying patterns. This design aspect inspired the notion of *shimmering* smartwatches.

For these prototypes, we selected eight different applications to represent a breadth of possible apps. We show how our watches support those apps to demonstrate our approach. For our applications we selected a few different types including basic time keeping (time, countdown timer), information from a smartphone (messaging, phone call information, calendar reminders) [21] and other more general applications we are seeing emerge on smartwatches(weather, fitness tracking and sports scores). This list is not intended to be all-inclusive of smartwatch apps, but instead to cover several different types of content.

For each of our applications, there are numerous parameters to convey to the user. For the time, we show the hour, minutes and seconds. The timer shows the length of time until a count down expires. For messaging, we show message notifications, status about unread messages, and information about who sent a message. For phone calls, we again show notifications, missed call counts, voice mail, and the caller. Calendar reminders are shown for upcoming events (e.g. informing the user 15 minutes before a meeting).

As we consider these applications, there are a few different primitive types of information our watches need to support. Some require notifications while others rely upon a more persistent display of content (e.g. time, unread messages). Many also require showing numeric information about one or more quantities. Again the time requires showing three numbers (hours, minutes, seconds), messaging would benefit by showing the number of unread messages, etc. Finally, some applications need to show the source of information (the message sender).

From the opposite perspective, our use of an array of LEDs offers a variety of capabilities. Each LED is individually addressable and therefore we can control which LED is illuminated. We can also control the color and/or brightness. Finally, we can change these aspects over time; for example, showing blinking or breathing patterns. Harrison *et al.* explored time varying patterns of a single LED of one color [7]. We leverage these patterns and use his nomenclature in the following prototype descriptions. Furthermore, we vary position and color to encode additional information needed for our different apps. To reiterate, our contribution is not to create novel LED encodings. Instead, we show how those encodings can be used to represent the different pieces of information needed for a variety of smartwatch applications. The examples we provide are one possible mapping we made as a design decision to demonstrate this concept and other mappings with different affordances are possible.

Hardware and Software

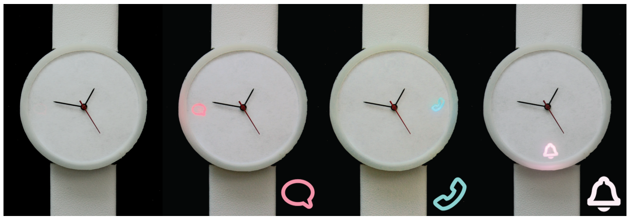
For our prototypes, we used a Bluetooth Low Energy (BLE) module that has a Nordic Semiconducor nRF51822 SoC. This SoC has an embedded BLE radio and a 32-bit Cortex M0 processor running at 16MHz. It also has 16KB of RAM, 256KB of flash, and numerous GPIO pins. Overall, this device compares very favorably to most Arduinos and has the bonus of the built-in radio. We are also using Adafruit NeoPixel RGB LED arrays that have the built-in WS2812 controller. The NeoPixels only require supply voltage, ground, and one control line. These devices have very specific timing requirements and we ported the NeoPixel Arduino library from AVR to ARM assembly. We are using a fully self contained solution with a LiPo battery and a custom breakout board for a Xuntong BLE module.

Our software is split in two parts similar to other smartwatch solutions. We used the ARM CPU on the Nordic SoC to run firmware that reads commands over the BLE connection. That software is responsible for driving the LEDs in the patterns needed and keeping high resolution timing. We connect to our prototypes over BLE from an Android phone. The phone runs a custom app that simulates a variety of smartwatch application functionality. In this work, we did not tie into any specific smartwatch applications and associated data. Instead, our software controls the display sequences to show what applications look like. Likewise, we have not implemented any on-watch input such as buttons or capacitive touch. Such additions should be straightforward engineering exercises.

Finally, we 3D printed different enclosures for our prototypes to hold the electronics. We used a translucent white filament that acts as a diffuser for our LEDs. For our *Point* prototype we dismantled an analog watch and incorporated it into our design. We also attached off the shelf watch bands to our prototypes.

Point

Our first smartwatch builds off a traditional analog watch as a platform to show the time. We added four backlit icons that are under smartphone control to show app data (Figure 1a). This design is a bit reminiscent of the HotBlack watch that uses an analog watch face to show the time. However instead of controlling hands to show data, we use our LEDs. For this design, we placed LEDs underneath the watch face so that they are not visible until they are illuminated (Figure 3a). We use a mask over the LEDs so they show an icon instead of just a glowing point. While our watch is clearly a technology prototype, this design allows for a form more reminiscent of traditional analog watches when just showing the time. For apps, we focus on three categories (messaging, phone, and calendar), while the fourth is a generic indicator for other applications. We selected these applications as they account for many notifications a user interacts with on smartphones [21]. Figure 4 details our encodings for the different applications.



(a) (b) (c) (d)

Figure 3: Our *Point* prototype showing only the time (a), a message (b) and a call (c) from different people, and a calendar event (d). Our icons are also overlayed for clarity.

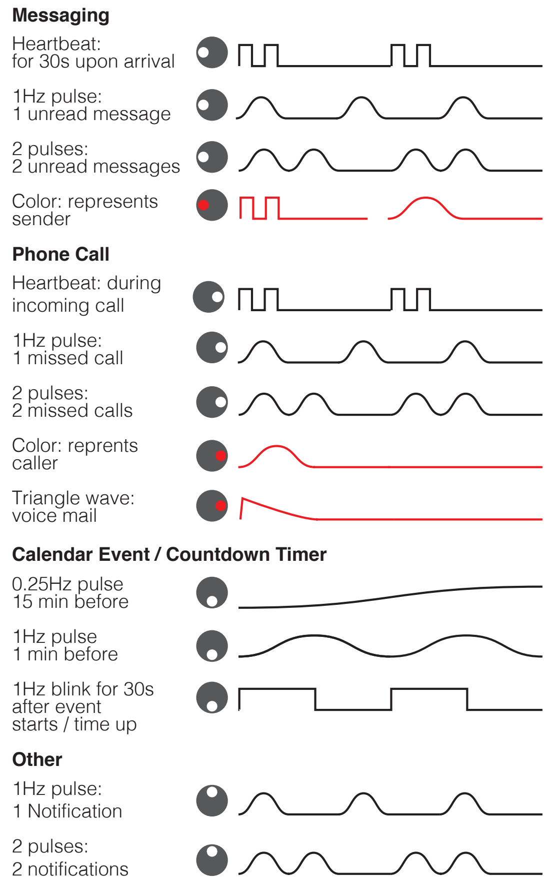


Figure 4: Our *Point* prototype application mappings. The circle depicts the watch face and associated illuminated icon and LED used by our different applications. The sparklines represent illumination intensity over time (similar to [7]).

For messaging, we have an icon that represents various forms of text messages (Figure 3b). Here we use color to show the identity of the message sender. We allow the user to specify a color for up to 5 people. By default, we show the total number of unread messages by encoding the count into the number of pulses. Multiple messages are shown in succession with their appropriate color. Finally, for the notification of a new message, the icon is modulated with a with a heartbeat pattern periodically for 30 seconds, again in the correct color for the associated person. Our second icon shows information about phone calls (Figure 3c). Again we use color to show the identity of the caller. The number of missed calls is displayed by showing that number of pulses. We also show the presence of a voice mail in the same sequence by using a fast in, slow out pattern.

Our next icon is for calendar events (Figure 3d). Starting 15 minutes before an event, this icon is slowly pulsed in a 0.25Hz frequency. In the last minute, we switch to a 1Hz pulse. Finally, at the start of an appointment, we show a blink (square wave) for 30 seconds. We also use this icon to display a countdown timer. The encoding is the same, only driven by setting a timer in the phone app.

Finally, our forth icon is for generic notifications. Given our limited display capability, it is probably not feasible to generate an LED encoding for all possible smartwatch apps without becoming extremely complex. Instead, we reserved this last position for informing the user that information from another source is waiting. Here, we pulse the LED to show the notification count, but otherwise the user needs to turn to their phone for details. In many ways, this is similar a notification LED on a smartphone.

Circle

Our second prototype is *Circle* which has a circular array of 12 LEDs that echos an analog watch but otherwise lacks a watch face or mechanical hands (Figure 1b). In addition to having more LEDs relative to *Point*, *Circle* relies upon changing modes to display different app information instead of simultaneously displaying multiple apps. This design decision allows us to support more applications directly. Figure 5 shows photos of several applications and Figure 6 show our the encodings diagrammatically.

First, we use the LED array to display the time. We use the same circular arrangement as an analog watch. For the hour, a single bright pixel is shown at the hour hand position. To show minutes, we display a dimmed arc extending from the 12 o'clock position to the position where the minute hand would be located on an analog watch. This representation provides a 5 minute resolution. Finally, we blink the final minute LED at 0.5Hz to show the passage of seconds.

To show messages, we use a similar encoding as *Point*. When a new message arrives, we shift out of the time mode and flash with a heartbeat for 30 seconds. To show multiple messages we illuminate multiple LEDs (instead of showing a number of pulses over time). Finally, we again use color to denote which person the message is from. Building off of the messaging display, our phone app shows a notification by pulsing all of the LEDs. To show missed calls, we illuminate all of the LEDs at a low intensity echoing the use of all of the LEDs for a phone call. The number of calls is then represented by full illumination on the corresponding number of LEDs. Finally, to distinguish missed calls from a voice mail, we alter the shape of the pulse and use color to denote the individual.

To show a notification of an upcoming calendar event, we display a wave animation from the current minute LED to the

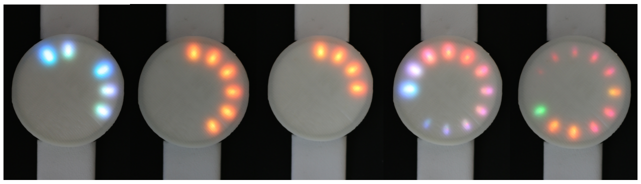


Figure 5: Our *Circle* prototype showing the calendar overview (a), countdown timer (b, c), weather (d) and fitness tracker level (e).

minute LED corresponding to the start of the meeting. This representation thus serves as a countdown in 5 minute increments. We show this animation at a 0.25Hz frequency starting 15 minutes before the event. Starting one minute before the event we show a 1Hz pulse and for the first 30 seconds we show a blink to denote the start of the event. For this prototype, we also support an overview showing free and busy times from the calendar. In this mode, we display which hours are currently scheduled. The start of a meeting is displayed in dark blue and subsequent busy hours are shown in light blue (Figure 5a). Our countdown timer uses a similar encoding as calendar events, only it is not overlayed with the current time. An arc corresponding to the duration of the time in minutes is displayed and animated at 0.25Hz (Figure 5b,5c). With one minute left, we use a 1Hz pulse and it blinks for 30s when time expires.

Given our ability to switch modes, we are also able to directly represent other apps as well. For weather, we use a color coding to show temperature over the next 12 hours (Figure 5d). We map cooler temperatures onto blue and warmer temperatures on to orange. To show the chance of precipitation, we flicker the LED using the transmission pattern for the given hour position. For fitness tracking we have a mode that again uses a color mapping to show information over time (Figure 5e). Here we display fitness tracking going into the past 12 hours (red low activity, yellow moderate, green high). Finally we prototyped a pair of modes to show information about a sports game such as a soccer match. The first mode shows an arc similar to the timer to denote time passed in the game. The second sports mode shows the score. Here, we split the 12 LED segments into left and right halves to represent the two teams. We illuminate the LEDs to match the team's color and the number of segments denotes the current score. We also use the heartbeat notification pattern from our other modes to highlight when a team scores.

DISCUSSION

When embarking on this work, we wanted to explore the breadth of possibilities that might be encompassed by the notion of a smartwatch. Through our examination of the literature, products on the market and product concepts, we can see that the "smart" aspect of these devices is in their ability to move beyond the fixed functionality of a tradition watch and to support a variety of apps. In doing so, these watches rely upon a smartphone as a conduit to external services and in

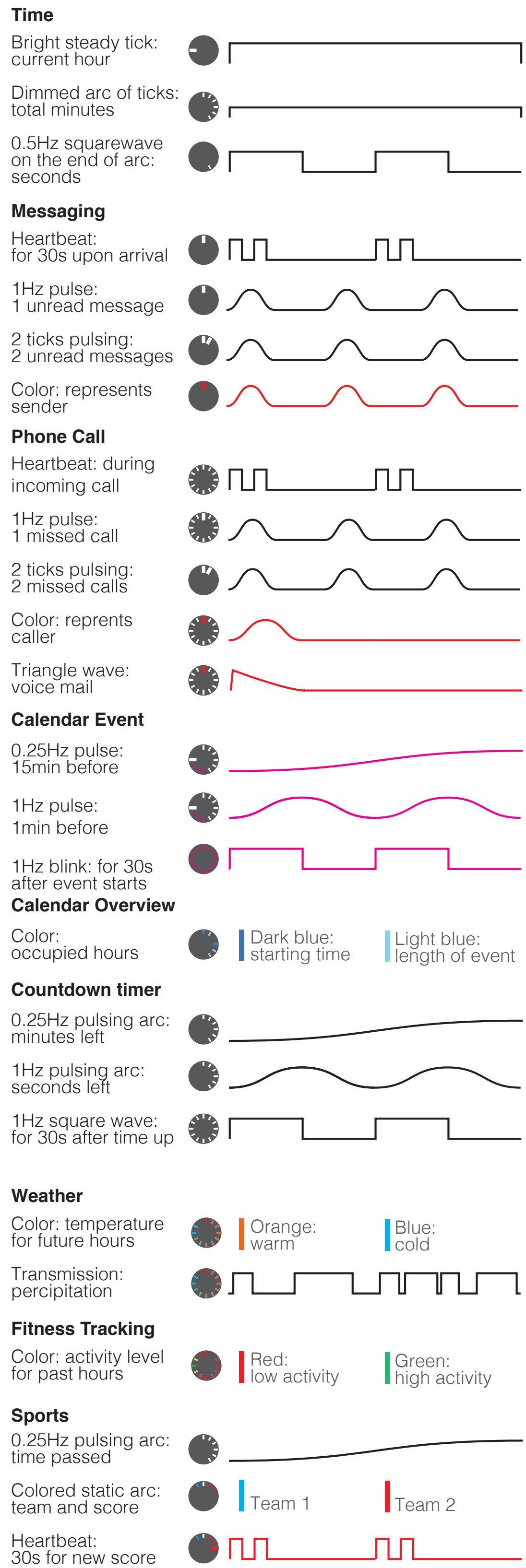


Figure 6: The *Circle* prototype uses a circular array of 12 LEDs. This figure details the applications and associated parameters we display on the LEDs. Similar to *Point*, the circle depicts the watch face and LEDs and the sparklines show variation over time.

many cases the phone runs application logic. With this architecture, we see a larger design space open up — well beyond devices with small 1 inch graphical displays. Our prototypes help demonstrate how one might develop smartwatches in this design space and some of the issues that might be raised.

First, it seems possible to support a subset of smartwatch apps without the use of high-resolution graphical displays. Our *Point* prototype offers the ability to show several different aspects of three different apps in detail in addition to the time and general purpose notifications. In contrast, *Circle* uses modes and therefore is not constrained by the spatial limitations of *Point*. As such, we are able more directly support several additional applications.

Through these prototypes, we can see there are several tradeoffs that can arise. By eliminating a full graphical display, we are also likely reducing the types of applications a watch might support. Presenting different types of notifications, small numerical values, and displaying the category of an item from a small set (e.g. a specific person from a predefined group) is rather straightforward. More complex information, such as the details about an email message, are likely impossible to show without at least a small graphical display. However this issue might not be a huge limitation. In general, smartwatches support quick glancable interactions [2]. And while it might be possible to read the full contents of an email on a Pebble of Android Wear watch, extended uses like these are probably going to be rare. Instead, a user will fall back to a smartphone. By using less capable displays, we still support showing small pieces of information from numerous application sources, but for more details the user will also need to turn to their smartphone.

The need for displaying persistent information also poses some design challenges. For information that only needs to be shown for a short time (like a notification), the device can switch modes. However to show persistent information (like message counts), this mode shift strategy does not work as well. Furthermore, given that this is a watch, ideally the time is always displayed as well. For *Point* the dedicated analog watch makes this easy. For *Circle* it is more of a challenge since the LEDs are used for both the time and app content and could require mappings that allow both to be displayed simultaneously.

A related issue in using these displays is that of encoding information. Our prototypes make use of relatively few patterns and for the most part our designs use those patterns in similar ways across the different applications. *Point* makes further use of iconography to expose semantics about the information we are displaying to a user. We made these design decision so that the information is relatively easy to understand. However, other choices are possible. For example Campbell, Tarasewich, and others showed more complex mappings between LEDs and information sources can be learned [5, 22]. Such patterns might allow even deeper application support.

One of the interesting prospects of using different types of displays is to move away from the design constraints imposed by small capacitive graphical displays. Just as the touch screens of smartphones have driven a lot of variation out of smartphone designs (they have converged to large pieces of glass wrapped in a shell), many smartwatches are adopting similar forms. In contrast, traditional watches have a variety of forms and are as much a piece of the user's fashion identity as they are a piece of technology. This framing will likely extend to smartwatches as well. Other display options like the LEDs from our prototypes or the controllable hands of the HotBlack provide some more flexibility in the watch design.

FUTURE WORK

This research points to several additional areas to explore. First, our prototypes were functional enough to demonstrate several different smartwatch apps. However, it would be interesting to tie into smartphone data sources. This development work would let us start to explore issues that might arise from daily use. Likewise, we decomposed input and output in our analysis of the design space. It might be useful to investigate how various display options might be complemented by input techniques to create novel interactions.

We explored two different designs in this work. One could imagine many more options that provide smartwatch application functionality. For example, we built a version of *Circle* that had an analog watch in the middle similar to *Point*. It is conceptually rather similar to our two designs so we excluded it here. However, there are likely other configurations of analog watches, digital display technologies (LEDs or graphical), and physical forms that might present interesting opportunities. *Point* uses masks to show the icons. Our current implementation uses fixed icons; however, we might be able to increase that number by having a mask that that rotates between different icons. We could also revisit existing devices. How might we alter a digital watch to provide more smart capabilities? The Casio G-Shock uses a small 2D display to show icons. However, even a fixed function LCD might be programmatically controlled to offer additional features much like we did with *Blink*'s icons. Alternatively, one could explore modulating the LCD backlight colors to provide an extra dimension of expressivity. It would also interesting to take devices like the Nike Fuel and add more general purpose application support.

We would also like to further explore the different embodiments that might be enabled by having LEDs illuminate through the surface of a device. We used the translucency of our 3D printed forms in both of our designs. This notion could be extended in several ways. For example, the watch might be covered with fabric and therefore look more like a bracelet when not illuminated. While there has been some work exploring digital jewery, this approach might lead to functional devices that provide different aesthetic options.

CONCLUSION

Smartwatches are still in their formative stages of development and adoption. While there are some commonalities in designs, we believe we have demonstrated that there are a broader set of opportunities to provide "smart" capabilities in watch-like devices. Our two prototypes use LEDs in different ways to enable smartwatch apps. By building off existing work on LED encodings we developed mappings to display the information needed for several different smartwatch apps and their associated parameters. In doing so, our implementations show the feasibility of this approach and more broadly provide evidence that this larger smartwatch design space is viable. As we continue to develop the notion of what constitutes a smartwatch, this work points towards a larger space of possible smartwatch designs.

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