Shoe Integrated Displays: A Prototype Sports Shoe Display and Design Space

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ABSTRACT

In this paper, we address shoes as a platform for wearable displays. To open research on the area, we present a functional prototype of a display integrated to a sports shoe. The prototype utilizes three different areas of LEDs attached to the shoe as a display mechanism, and indicates the wearer's running pace relative to a preset target pace. To explore perceptions of the concept, and ideate further on the topic, we conducted semi-structured interviews with a group of regular runners. Initial findings suggest that the ambient, peripheral visibility of the sports shoe display is appreciated as fitting well to the running activity. To provide a structure for future work in the area we present a design space for shoe displays, identifying aspects such as scope of visibility, content, visualization style, and usage context.

Author Keywords

Wearable displays; shoes; running shoes; activity trackers; gait analysis; ambient displays; sports; wellness; running; skiing; design space.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Wearable technologies are rapidly becoming commonplace. Whilst smartwatches and bracelets were the first to gain mass market adoption, now clothing integrated technology is on the rise. Smart textiles, flexible computing materials and declining energy consumption requirements are providing increased opportunities to add different input and output functionalities to smart garments. In this paper, we focus on shoes as a wearable computing platform, more specifically, on their use as a visual output platform through the integration of display elements.

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Figure 1: Running shoe display prototype in use. Blue, green and red visual output indicates below pace, on pace and above pace, respectively. The images are extracted from the video shown to study interview participants.

Whereas prior art has considered wearable displays in, e.g., shirts and jackets [13, 18, 20] and embedded in accessories such as handbags and jewelry [1, 6], shoe integrated displays are a novel area for HCI research. Shoes are a large and important category in clothing, including products developed for a range of special use cases, ranging from sports to safety-wear and fashion, each representing huge global markets.

In our research, we take outdoor sports, particularly running and cross-country skiing, as an example use case for shoe integrated displays. Running and jogging are mainstream hobbies with, e.g., 55 million participants in USA during 2017 [29]. Many of those running or jogging as a hobby regularly utilize a tracking device to measure their performance, e.g. a heart rate monitor or a GPS based tracker. For advanced runners, tracking devices that measure details of form and gait are commercially available [37]. Currently the primary output mechanism for such trackers is via a connected smartwatch, smartphone, or web interface. Whilst such presentation formats are able to present large amounts of data, they are not optimal for use whilst running. Further, such devices are abstracted from the actual running activity, which centers around leg and foot motion, hence requiring the user to interpret the displayed data, e.g. stride length and pronation. The number of devices worn or carried by runners is increasing, with many runners using multiple devices. As an alternative, we propose a solution whereby the runner's existing running clothing is augmented.

To initiate work on the area we created a running shoe which includes visual output elements integrated to its surface (Figure 1). This solution potentially enabling the wearer to receive contextually situated feedback on their performance and running form, both during and after running. Evaluation of the prototype indicated that the running shoe display was appreciated for its ambient display properties and considered to have potential for selected use cases. To provide a basis for further work in the area, we introduce a design space for shoe integrated displays, highlighting the potential advantages and disadvantages of display locations and formats.

RELATED WORK

Prior work of relevance to our topic falls in the domains of wearable displays, smart shoes and technology for running.

Wearable Displays

There is a large body of work on wearable displays, covering e.g., smartwatches [27], bracelets [16] and displays on handbags [1]. However, prior research focusing on shoes as a platform for wearable displays is limited, with Dierk et al.'s inclusion of shoes as one location for their battery-free e-ink displays being a rare example [3].

In the context of running, Mauriello et al. present a display worn on a runner's back to display information to other runners in the group [13]. In Fluxa, Liu et al. present a wearable display utilizing persistence of vision (POV) and suggest "visualizing biological signals or other sensor data during activities" as a potential use case [12]. In the consumer novelty fashion market a variety of shoes with LEDs integrated into the sides of the sole are available from shoe manufacturers [33] or customization workshops [34]. Typically, these feature a flashing lighting effect when the foot impacts the ground. Recently companies such as Vixole [35] and ShiftWare [36] have announced shoes incorporating high resolution displays, motivated primarily by fashion. At the time of writing, these are not available for purchase.

Smart Shoes

An overview of research on smart shoes is presented by Eskofier et al. [5]. Here, the prior works presented have primarily explored instrumenting the foot with sensors, enabling gait analysis for sports, wellbeing and medical application areas. Works considering the use of shoes as an output device have utilized vibration based mechanisms and focused on either gait correction [25] or navigation guidance [8, 19, 23]. Using instrumented shoes to control music, e.g. in a performance or as part of therapy, has also been a topic of research [17, 21, 28]. We were unable to find any works utilizing shoes as a platform for functional visual output.

Technology and Running

Design Space

Jensen and Mueller [14] present a design space for technology interventions in the running domain, describing the range of possible feedback as *representative-to-assistive*. Here, highlighting the lack of research on providing assistive feedback to runners and issuing a call to action "… there is a need to investigate how we can provide complex technique-related feedback to the runner in an assistive and expedient way" [14]. Exploration of a wearable system measuring running kinematics in-the-wild is presented by Strohrmann et al. [22]. Considering motivational and support aspects, Mueller et al. provide an overview of 13 different approaches to gamification of jogging [15], whilst Knaving et al. [11] inform on future motivational technology to support committed runners. Notably, past research indicates that runners are eager to use devices that provide new feedback through devices which they already wear on a regular basis. For example, Woźniak et al. [26] successfully extended the sports watch form factor to provide social feedback during a running race. Our work aims to further expand the design space of augmenting existing running gear, rather than introducing new devices.

Output Modalities

The dominant output modality for technology addressing the running domain is visual, via the screens of smartphones, smartwatches or online web services, e.g. [30, 31, 32]. In their RunMerge application, Kiss et al. [10] explore how post-run visualization can provide a runner with an increased understanding of their body movements, enabling reflection and improvement. Audio coach type features are common in commercial sports trackers, e.g. [31], typically giving guidance on the runner's pace. Fortmann et al. [7] explored the use of rhythmic pulse beats to guide runners' cadence. A few works have applied electrical muscle stimulation (EMS) as an output modality, e.g. in FootStriker EMS aims to correct runner's form [2]. Jogging in Virtual Reality has been described by Häkkilä et al. [9]

Our Contribution

Visualization on shoes is commercially available in the fashion domain [33, 34], yet functional applications have not yet been explored. Whilst there is a huge body of work on sensor equipped shoes (almost 40000 papers at 2016 [5]), we were unable to find any cases where output, based on measurements from the integrated sensors was visualized directly on the shoe itself. Prior works have highlighted the need for research to address real-time technique related guidance for runners [2, 14]. However, the potential of shoe based visualization has so far not been explored.

As a contribution we present:

- A functional prototype of a sports shoe integrated display and its demonstration in outdoor running and cross-country skiing.
- Initial user feedback on the running shoe display concept and deduced design recommendations.
- A design space for visual displays on shoes.

SPORTS SHOE DISPLAY

As an initial exploration into the area of shoe integrated displays we created a functional prototype display on a running shoe, and used it as a design probe to elicit feedback on the topic from a group of running enthusiasts.

Prototype Implementation

Our initial shoe display implementation utilized RGB LED strips as the output mechanism. A strap that fitted over a running shoe was constructed from elasticated tape, to which the LEDS and other electronics were attached. This enabled us to easily transfer the shoe display to different shoes. The LEDs were attached in 3 areas (see Figure 2):

- Around the toe (vamp) of the shoe
- Vertically along the tongue of the shoe, extending over the toe box
- Around the heel of the shoe

Figure 2. Right to left: Setting the target pace on the smartphone app. Toe display area. Tongue display area (wearer's view), heel display area (following runner's view).

The LEDs were controlled by an Arduino microcontroller with onboard Bluetooth 4.0 connectivity. The microcontroller and a small flat battery were located in a small padded cloth pouch, that could be comfortably tucked inside the top of the runner's sock. We implemented an Android application, running on a smartphone carried with the runner, that allowed the runner to define a target running pace in min/km (Figure 2). Based on the movement speed measured by the smartphone's GPS sensor the color of the shoe-mounted LEDs was set:

- Below target pace - Blue
- Within +/- 0.5 km/h of target pace - Green
- Above target pace - Red

Only one of the LED areas was active at once, this being selectable from the mobile app UI. This provided the possibility to individually analyze the potential of each display area.

Evaluation

To evaluate the shoe display, the researchers used it on a short outdoor run and recorded a video demonstrating the functionality and features of the prototype in use. To provide insights into the use of shoe displays in other sports, video material of the shoe display in use on a cross-country skiing boot was also produced (Figure 3). The recorded video materials were edited to create a short one-minute introduction to the concept which was then used as a probe in a user study.

Figure 3. The prototype sports shoe display in use in cross-country skiing. Left: on the heel of the ski boot. Right: Skier's view of the display on the tongue area of the boot (red LEDs).

Aiming to gain further understanding of the domain, we conducted semi-structured interviews with running enthusiasts to explore attitudes towards and willingness to adopt shoe displays. Our interview protocol focused on three key aspects: the potential use of shoe displays for everyday running, how displays can integrate into training, and potential social effects. Additionally, we aimed to collect ideas for further development of running shoe displays e.g. data to be displayed, location and format of the display. After introducing the context of the study and discussing what data was important for good training, we showed the video of our running shoe display prototype in use to the participants. Some participants attached the prototype to their shoe, and we demonstrated how the shoe display would work during training, by manually triggering the different display states. These probes enabled us to contextualize any further questions and produce richer feedback.

We recruited 8 participants from a local running group (3 female, aged 25-31). The participants were interviewed individually, and offered coffee and cake as remuneration. We recorded a total of 3:05 hours of interviews. As this study aimed at primarily deepening design empathy and understanding the design space, we applied a light analysis approach where we transcribed only statements considered relevant. We then clustered these statements using an affinity diagramming session with two researchers.

Results

Overall, the video of the prototype in use produced a positive response in the participants. While they were initially surprised by the novelty of the idea, all participants remarked that a shoe display could become an effective training device for them:

> *These would significantly help me in controlling pace.*

Participants commented extensively on how a shoe display would complement and/or replace other parts of their running attire. One participant commented on the ambient qualities of the shoes display and how it was advantageous compared to the explicit attention required by using a running GPS watch:

> *I would not need to look at my watch all the time (I don't always take it running with me) [...] and [my app] only gives you cues from time to time and it interrupts music. This is a minimally engaging, intuitive way to communicate pace.*

In contrast, another participant commented on how the color-coded display offered limited granularity and precision. While they believed the shoe display was useful for everyday training where exact pacing played a smaller role, they remarked that more precise indications may be needed during a race. Thus, a GPS watch would be superior in that case:

> *During a race, you are happy when running faster than your target pace, and then you need to look at your watch. With the watch, you can control if your running 5, 10 or 30 seconds faster. The shoes wouldn't give you much information then.*

When asked about visualizing data other than pace/speed on the shoes during a run, participants were rather skeptical. They dismissed visualizing values such as pronation or shoe wear, remarking that it was more important to visualize more dynamic values. One participant commented explicitly that she was only interested in seeing parameters she could affect displayed on her shoes:

> *While running, the shoes should visualize things over which you have direct control.*

Similarly, another participant wondered about the motivational consequences of a perpetual shoe display. They remarked that constant feedback on how one was slower than their target pace could have a negative effect on performance:

> *I'm unsure how I would act. If I can't keep my pace because I'm exhausted then I'm not sure if showing a red light would be beneficial… rather negative. Oh, I'm exhausted and I'm seeing that…*

Participants were also eager to discuss possible alternative visualizations and uses for the shoe display. One participant suggested that the shoes could provide fitness tracking throughout the day, much like commercially-available wearable devices. They suggested that the shoes should then display a progress bar:

> *Progress bars are quite common. So, if they [LEDs] are all lit up and the last one is blinking, then you know you are that you are at the last one […]. People who run or go to the gym would appreciate that.*

Further, two participants were puzzled by the choice of color for the visualization. While red and green appeared to be easy choice, the choice of a third color was problematic:

> *The green is very easy to understand and so is red. And then you cannot use red for 'you're too slow' and 'you're too fast'…*

Another user drew an analogy to displays in cars, which have a 'neutral' state, i.e. if the state of the control is the desired state, nothing is displayed:

> *I took an [electric car brand] yesterday […]. It's green, nothing and red. They have this grayish 'eco' mode and this way they indicate the three states.*

The participants were also eager to comment on possible social consequences of the shoe displays. One participant remarked that knowing that another person was training and that they were most likely tired would enable them to take extra care:

> *With the back light, it would make sense. If I'm on my bike and someone is running in front of me and I know that he or she is a bit slow, maybe I can cheer them and definitely take extra care when passing them with my bike.*

Another participant envisioned that shoes' displays would be easy to use for those training together. Even if different color schemes were used, they should be understandable after some time.

> *If I walk next to or run next to a person, I will figure it out sooner or later. If I would see them for a short time, I am not sure if I would guess it correctly*

DESIGN SPACE

Informed by our findings from the running shoe display prototype, we created an initial design space for shoe situated visual displays. Design spaces have proved valuable in other domains, e.g. Döring et al.'s for ephemeral interfaces [4]. Our design space divides the shoe display domain into axes of visibility, content, context and visualization. Here we aimed to create a design space into which the characteristics of future research in the area of shoe integrated displays may be mapped.

Visibility of Shoe Displays

The visibility dimension of the design space refers to when the shoe display may be seen, and by who (Figure 4). The display may be designed for visibility by the wearer whilst wearing, to others nearby whilst wearing, e.g. visualization on the soles of the shoes, or with the shoes removed.

Figure 4. Visibility of shoe displays

Display Content

One logical content type displayed on shoes relates to the shoes themselves and to the wearer's leg and foot parameters and movements (Figure 5). For example, information on the wearer's pronation or stride length may be displayed in situ on the shoe, easing comprehension and interpretation of the presented data. In addition, data on shoe performance may be presented, such as information on the remaining lifetime of the shoe. Other data related to leg-motion based activities, such as running pace, distance or heart rate, may also be logical to display on shoes. A variety of other status or notification data, unrelated to leg movement, may also be mapped to shoe situated displays, e.g. message and social media notifications. Additionally, displays on the shoe's surface may be for purely aesthetic purposes, enabling dynamic presentation of graphical designs and logos.

Figure 5. Potential content types displayed on shoe displays (Aesthetic image from [34])

Context of Use

Shoe displays may be applied in a variety of usage contexts (Figure 6). In the sports domain, various approaches may be taken depending on the requirements of the sport, enabling the athlete to directly adjust their performance based on the displayed information. For example, football boots may indicate kick strength, ice skates the distance of movement during a spin, or a long-distance runner's actual vs. target pace. In the wellness and hiking domain footwear displays may indicate e.g. the amount of sitting time per day or the distance walked.

Navigation use cases, that prior work has addressed with other shoe based output modes [8, 19, 23], may also be supported using shoe mounted visual displays. There are many potential medical applications for shoe displays, ranging from guiding rehabilitation after an injury to managing foot ulcers or sensory loss due to diabetes [38]. The more static home and office environments may also provide potential applications for shoe displays, e.g. in conjunction with other displays in the environments. Finally, fashion may present future applications beyond the current illuminated sole sneakers [33], e.g. changing the color or patterning of shoes to match an outfit.

Figure 6. Shoe displays: Potential application contexts

Visualization Approaches

Considering data visualization, Ward et al. [24] present an overview of the range of possible approaches. Based on the restricted visibility of shoe displays, the most promising direction are likely to be those based on information coding through color, shape and orientation, size and position on the shoe. It should be noted that the 'dual display' possibilities provided by the two shoes in a pair may offer additional opportunities e.g. utilizing the relative position of the two shoes. In addition, due to the rapid motion of shoes during running activities, persistence of vision (POV) based visualizations may prove interesting to explore [12].

DISCUSSION

The results from our user study suggest that users are eager to accept new possibilities for running data displays if they are embedded to existing equipment. Our prototype implementation, its demonstration and the feedback obtained in our user study indicated that shoes present a potential to be used as a wearable display channel.

Although prior art has identified the need to investigate improved ways to provide technique-related feedback to the runner [14], this was not echoed by our study participants. Surprisingly, participants did not consider the shoe to provide a suitable platform for running form related information such as stride length and pronation. This finding appears to partially conflict with the findings of Kiss et al. [10], who concluded that runners would welcome real-time feedback on running technique. We still believe that a shoe display offers potential to provide such feedback in a contextually meaningful location, and speculate that the format of our display and our evaluation approach are factors affecting our current findings. Here we note that applications beyond running, e.g. medical gait analysis, may have different appreciation of the issues. To probe this issue further, would require the implementation and long-term evaluation of a shoe display visualizing walking and running form. One approach may be to include 2 modes in shoe displays, during wear and when not being worn, with different information being displayed in each mode.

Whilst our chosen visualization approach of utilizing color as the information channel no doubt contributed to the ambient visibility of the concept, this also received some negative comments from participants. For example, participants commenting on its limited granularity and ease or lack of ease for semantic understanding. Our presented design space provides a basis to explore visualization alternatives, with further progress on the issues requiring gaining a better understanding the data to be presented.

As with other wearable publically-visible displays, the social implications of shoe displays raised by our study participants are an issue to be considered - the display is visible to everyone, not just the wearer. Beyond the question of social acceptability, this may inspire secondary effects, such as motivating friendly competition or producing social pressure to perform.

Whilst we have currently focused our prototype to our design space's *sports* context, with small adaptations it could function in the *navigation* or *wellness/hiking* contexts. A significant question is how to integrate the proposed concept into (running) shoes, to turn it into a feature of the shoes rather than an *add-on*. Whilst it is technically possible to embed such a system into shoes, there are challenges that need to be addressed, such as water resistance or the distribution of the additional weight. Here technologies such as flexible printed electronics and electrochromic displays may offer a potential avenue to explore.

We acknowledge that our work has limitations, particularly our sports shoe display prototype was of somewhat crude construction and not fully representative of a final product. However, our prototype was fully functional and in this respect enabled the researchers, and subsequently our study participants, to gain a good picture of the potential, and potential challenges with such products. Whilst our evaluation was based on interviewing a small number of participants, we highlight that the subjects were dedicated regular runners and hence may be considered as expert interviewees.

As a future work, we plan to conduct a set of studies using an improved implementation of our design to assess its acceptability and usability, as well as to compare different visual feedback approaches. Further, a long-term study will evaluate the behavioral effects of the design on runners, such as its impact on motivation, performance and social interaction. We also plan a collaboration with a sports shoe designer, to gather insights on the production of running shoes, and to focus on seamless, aesthetic integration with sports shoe designs.

CONCLUSIONS

We have presented functional prototype running shoe integrated display and its evaluation in a user study (n=8). The running shoe display was commented positively by regular runners, who appreciated its ambient, peripheral display format. Study participants preferred that the information displayed during running is directly related to the ongoing actions and of a density suitable for the display format. Our design space for shoe integrated visual displays provides structure for future work on the area of shoe integrated displays.

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