Belt: An Unobtrusive Touch Input Device for Head-worn Displays

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ABSTRACT
Belt is a novel unobtrusive input device for wearable displays that incorporates a touch surface encircling the user's hip. The wide input space is leveraged for a horizontal spatial mapping of quickly accessible information and applications. We discuss social implications and interaction capabilities for unobtrusive touch input and present our hardware implementation and a set of applications that benefit from the quick access time. In a qualitative user study with 14 participants we found out that for short interactions (2-4 seconds), most of the surface area is considered as appropriate input space, while for longer interactions (up to 10 seconds), the front areas above the trouser pockets are preferred.

Author Keywords
Wearable input; Unobtrusive; Touch; Spatial mapping.

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation (e.g. HCI): User Interfaces. - Input devices and strategies.

INTRODUCTION
Head-worn displays (such as Google Glass) allow for a quick access time to information and by that can serve to augment the user's memory [15]. Interaction with such a display, however, is yet a problem. Especially when it comes to user input, the challenges of interacting with a virtual screen image become apparent. The virtual image is neither tangible nor touchable, making direct interaction a difficult task. Pointing gestures in mid-air have strong social implications and can call unwanted attention upon the user. In addition, such gestures can suffer from arm fatigue [7]. Voice input allows for hands-free interaction, but has inherent limitations. It is obtrusive and in a shared focused environment, like a meeting or a lecture, it is prone to disturb other people. Another option is to use a handheld input device, such as the Twiddler [11]. This allows for rich interaction, but implies another device has to be carried along by the user. To prevent this, interfaces can be interwoven into clothing and worn at the body. By this, technology and fashion is combined into an electronic-textile interface. Besides being usable, such an interface has to bound within the user's fashion choice and perceived social comfort.

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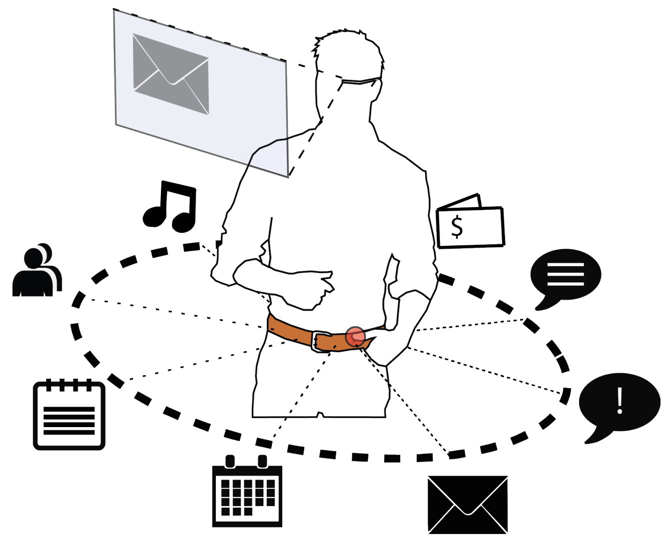

Figure 1. ***Belt*** **is a touch-enabled input device. Information and applications are quickly accessible on the large horizontal input space.**

In this work we present *Belt*, an e-textile input device that extends the surface of a common belt by touch sensing functionality. Belts have a long history as being worn for decorative reasons as a fashion accessory as well as practical reasons to support trousers. The inherent properties of a belt make it a useful tool for a body-worn interface. Being worn at the hip, a belt is close to the resting height of the human hands, enabling a quick access time to the surface area. The large horizontal surface area is reachable with both hands without interfering each other, allowing for bi-manual user input. The tight nature makes it suitable for touch input without having to clutch the interface. Depending on hand and pocket size, it can be reached comfortably with the thumbs while resting the hands within the trouser pockets, enabling unobtrusive input. A belt can be worn and combined with a diverse collection of garments, making it easier to blend the input interface within the user's style of clothing. By this, the e-textile interface has only to be interwoven into one accessory, rather than multiple garments, reducing potential expenses for the user.

The contributions of our paper are: (1) a novel unobtrusive on-body touch input device with immediate access, (2) information access leveraging users' spatial mapping around their hip and (3) a study investigating the user's perceived social acceptance of touch input on a belt in public.

RELATED WORK

Surprisingly, the belt as a wearable input device has gained little attention within the literature. ActiveBelt [18] is a wearable interface that enables users to obtain directional information via vibrations around their hip. By this, the user's tactile sense is used to generate an unobtrusive information channel. Sumitomo et al. present a belt-like input interface worn around the abdomen to measure changes in its circumference as a concealed mean for user input [16].

Belt utilizes the large horizontal input space to enable a body-centric spatial mapping of information, in which the user can use the belt to place or open shortcuts to digital content (such as their contacts or a digital wallet). Spatial mappings for information, contents and virtual displays for wearable computers have been introduced in multiple works [3]. Chen et al. used a mobile device to navigate and manipulate digital content that is visually anchored around or onto the user's body [5]. In Virtual Shelves [10], the orientation of a mobile device in relation to its user is used to realize a user-centric shelve-metaphor, where information is stored around the user and is being retrieved by holding the mobile device in the associated direction. It was shown that users can use their spatial awareness and kinesthetic memory to select shortcuts in an eyes-free interface. In addition, the proprioceptive and tactile senses help in reaching parts of the user's own body with their hands blindly [6]. This allows for a quick access time for a belt-like interface.

Wagner et al introduced a body-centric design space for multi-surface interaction [19]. A belt as a touch-enabled input device has a fixed-to-the-body input space that involves two body parts, arm and torso, but only constrains the arm during interaction.

On-body interaction has mainly been researched for projection-based and eyes-free user input. In Pinstripe [9], pinching and rolling gestures on folds of smart garments are used for fine and coarse analog input control. Holleis et al. built capacitive touch buttons in diverse garments such as a helmet, phone bag, glove and an apron [8]. The hip and thigh area was mentioned by users most of where to potentially accept wearable touch controls. In PocketTouch [14], it was shown that capacitive touch input can work through diverse fabrics, so that users can operate a touch device located within their pocket. With Rekimoto's Gesturepad [13], a touch sensor module is attached to the inside of clothes to sense finger touches in conjunction with a transmitter worn at the wrist. Another eyes-free input device that doesn't rely on touch input is Nenya [1], a magnetically tracked finger ring that allows subtle twisting and sliding movements for 1-dimensional input. Social acceptance is increased by embodying the input device in a commonly worn item, in this case, a ring.

CONCEPT AND INTERACTION

In *Belt*, a common belt is envisaged that blends within the user's clothing but is additionally extended with input capabilities. We chose to base on touch interaction that is currently familiar within society, which is swiping and tapping interaction on mobile touch devices (e.g. smartphones, tablets and laptop touchpads). In contrast to such devices, the belt does not have to be taken out of pocket to be accessible and is quickly reachable with both hands. The input space is large by embedding touch functionality into the whole surface area encircling the user.

Spatial Mapping of Information

The large input space can be leveraged for a horizontal body-centric spatial mapping of information and applications.

Users retrieve a lot of information frequently on their personal mobile devices, such as messages, news feeds, time, voice calls and many more. The amount, a mobile device, such as a phone is taken out of one's pocket and being unlocked is reaching over 100 times on average on a daily basis [4]. Interaction can be enhanced by enabling a quicker access time to these informations. *Belt* allows placing virtual shortcuts and bookmarks to frequently requested information on the belt around the user. By this, the user can quickly reach for information with low effort to enable microinteractions that only last a few seconds [2]. As an example, a wallet application can be placed on the belt above the user's back pocket (a frequent place to store one's wallet). Reaching for and tapping this location will open the user's account balances in their wearable display. Likewise contacts and missed calls can be placed on the belt in proximity to the phones storing position in another pocket.

Even though the belt offers no visual cues for placed shortcuts, attention awareness and kinesthetic memory help the user in reaching the desired location. Users often develop habits, such as using their tactile senses to quickly check their trouser pockets whether they carry along their belongings (e.g. their wallet, phone and keys). In a similar way, the belt can quickly be checked for information by tapping desired locations or sliding along its surface. Additionally, it is possible to extend the awareness for application-related notifications by using spatial vibration cues such as in [18].

Unobtrusive Interaction

By embedding the input sensors in a conventional wearable item, an input device can be used in everyday situations in varying social contexts [13]. When not being in use, the device is potentially unnoticeable to bystanders and therefore doesn't have the social implications of an unusual looking electronic device. The unobtrusiveness of the device however is only one part of the interaction. To minimize social consequences, interaction should either visually communicate intent [12] (e.g. by interacting with conventional technology) or appear as if the user is not interacting with technology at all [17]. For this reason, *Belt* allows for user input that is designed to be as unobtrusive as possible. Users can subtly interact with the belt by performing small swipe and tap gestures on the sides, e.g. with the thumb while resting the hand in their pocket. Shortly fumbling on a belt or pocket to keep one's resting hand busy is socially acceptable and not obtrusive to bystanders. The input space is close to the resting level of the hands while standing, so that only small hand movements are required to reach for the belt, which by itself is no uncommon sight to bystanders. These movements, as well as the interaction, are not at eye level in a typical face-to-face conversation and can be performed without calling attention upon the user. This is important, because the perceived level of social acceptance affects in whether or not users are willing to perform the interaction in public [12].

Benefits and Limitations

Besides being quickly accessible, *Belt* allows to instantly interrupt the interaction. This immediately leaves both hands free, allowing users to shift their full attention to a different more important real world task at any time when required. This is an advantage compared to a handheld input device that needs to be put aside first.

Figure 2. Left: Subtle user input with the thumb. Right: Opening a digital wallet application. Shortcuts can be placed anywhere around the touch surface.

Due to the hip height of *Belt*, users can interact with the device while maintaining a relaxed body posture. The hand has to be raised only slightly from a dangling resting position to reach for the touch surface. Even when resting the hands within trouser pockets, users can comfortably reach for the belt with their thumbs, depending on shape and size of the pocket. As the body's center of gravity, the hip is relatively steady while walking. This supports touch gestures in mobile settings.

The spatial accessibility however has its limitations. Reaching for the back of *Belt* is less subtle and comfortable than reaching for the sides, because of the larger involved motion. Related work suggests that the forefront area and belt buckle are less appropriate for interaction because of their proximity to the users private parts [8]. Likewise, reaching for the back of the belt can be misleading. Interaction in these areas can communicate wrong social intents.

DEVICE IMPLEMENTATION

For the *Belt* prototype, a common leather belt was extended with small metal rivets (see Fig. 2). While this extension diminished the unobtrusiveness of the device, it allowed us to use the rivets' surface for touch sensing functionality. Each rivet is wired to one of 6 touch sensing units that are placed on the inner side of the leather belt (see Fig. 3) coated by woven fabric. Each unit is composed of an Arduino Pro Mini (ATmega328), a Bluetooth low energy module (BLEmini) and four MPR121 capacitive touch sensor controller boards. A small wearable battery is hidden behind the belt bucket, powering all of *Belt's* modules. By embedding all of these electronics into the device, *Belt* can be used in a mobile setting. Overall 288 rivets can be sensed independently as a touch point. Detected touch point locations are sent via Bluetooth to a connected phone, which distinguishes a simple touch gesture set composed of left, right, up and down swipes as well as a tapping gesture using blob detection. A Google Glass is connected via Bluetooth to the phone and serves as a wearable display.

We implemented five sample applications (music player, digital wallet, facebook, contacts and a reminder app) that benefit from the quick access time. These applications can be placed anywhere around the belt and opened by tapping the respective location. By swiping and tapping, the user can navigate within each application. These gestures are enabled anywhere on the belt, allowing to reach for the most comfortable input location.

USER STUDY

While we are planning on conducting larger user studies, in a first investigation we wanted to find out if the implemented features of *Belt*, the spatial mapping of information and the unobtrusive input are comfortable for potential users to use. We were especially interested in whether they feel that this kind of interaction is

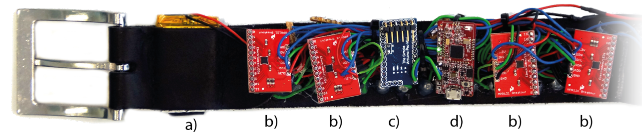

Figure 3. Inside *Belt* (without paling woven fabric): a) battery to power all modules and one of six touch sensing units each consisting of b) four touch sensor boards, c) Arduino and d) a Bluetooth low energy module.

appropriate and to what extent they are willing to perform touch gestures on their belt in a public setting.

We recruited 14 participants between 18 and 30 years (*m*=24; 7 female). All but one stated to retrieve information on their personal mobile devices very frequently. The study lasted about 45 minutes and was conducted in two consecutive settings: The initial part took place in a lab environment, where the participant used the worn *Belt* prototype and Google Glass to retrieve information using spatial aligned shortcuts and by navigating within the applications. Applications were aligned on the belt by the participant themself.

The second part of the study took place in the passage of a university cafeteria as a public setting that was heavily frequented throughout. For this second part we did not use the technical prototype but a common leather belt for interaction instead. This was chosen because we anticipate a touch-belt that does not expose itself as a technical input device. Using a common belt allowed us to study the appropriateness solely of the interaction gestures rather than the look of the device. For the same reason, Google Glass was not worn for this study part. We asked participants to repeat the very same tapping and swiping gestures on the common belt that they performed before and asked for their willingness to perform these gestures in public. This was done while participant and experimenter were standing and talking in front of an openly visible bar table directly within a heavily frequented passage.

Participants were motivited to think aloud during the study. In addition, participants provided feedback using structured-interviews with open-ended questions and 5-point Likert scales (from 1 – no agreement to 5 – strong agreement). Feedback was mostly positive. Participants saw the quick access time to applications as a benefit and strongly agreed that they would like to be able to interact with a device as unobtrusively as possible (*m*=4.71) and without calling attention upon themselves (*m*=4.64). There was also agreement that unobtrusive interaction is possible with a belt as a touch input device (*m*=4.28). While participants did not necessarily want to make bystanders aware of their interaction (*m*=2.28), there was a slight fear that other people might be confused upon noticing it (*m*=3.28). For the input at hip height, the touch interaction was seen as easy to use and quickly reachable with small hand movements. As a downside, the potential effects of complementary worn garments such as warm clothing were mentioned. Participants were wearing light clothing during the study due to warm weather, but with colder weather conditions, warm tops such as jackets or long pullovers could cover the belt, making it harder to access. Also other garments, such as skirts, are not typically combined with a belt. As an alternative, participants suggested the strap of a messenger bag or handbag as a location for touch input.

For the spatial mapping, participants were asked to place the five sample applications (music player, digital wallet, facebook, contacts and reminders) at any convenient location on the *Belt*

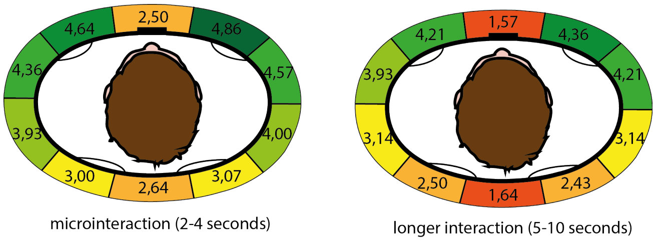

Figure 4. Level of perceived social acceptance in which participants felt comfortable interacting in public on a 5-point Likert scale (from 1 – very uncomfortable to 5 – not uncomfortable at all)

prototype for retrieval. Three strategies for placing applications were frequent throughout all participants: (1) Placing the preferred applications quickly available on the front next to the pockets, (2) placing applications in close proximity to a relating physical object within a pocket (e.g. wallet, mp3-player, phone) and (3) grouping applications by mental links (e.g. social applications on one side and notifications on the other). Participants utilized the whole touch area with a slight preference to the side of the dominant hand.

The front area next to the trouser pockets was preferred for touch input in general, while the area next to the belt buckle as well as the very back were seen as least suitable. We asked for the user's perceived social acceptance in public on a 5-point Likert scale (from 1 – very uncomfortable to 5 – not uncomfortable at all), which highly depended on the length of interaction. For very short interactions, participants did not feel awkward or very uncomfortable interacting around the belt, since shortly fumbling at hip height was perceived as common sight. Yet, the front pocket areas were preferred (see Fig. 4). When it came to longer interaction for up to 10 seconds, the preference for the front pocket areas was more distinct. Other areas were perceived as less suitable, because of a less comfortable arm position and the fear of sending wrong social intents. This confirmed our design assumption to use the whole belt surface to quickly access information with just a single tap and to mainly use the front pocket areas for subtle swipe gestures within applications.

CONCLUSION AND FUTURE WORK

Belt is a touch input device for head-worn displays that does not expose itself as a technical device. It allows for quick access to information due to a spatial mapping on a large horizontal input space and for unobtrusive interaction supporting subtle swipe gestures while resting the hands in the pockets. In a user study it was shown that participants perceived this interaction as socially acceptable in public.

In the future we want to improve *Belt* with a higher touch resolution to enable swipe-based text entry. We also plan on implementing subtle rotation based touch gestures for quicker navigation and on conducting a user study regarding the perceived social acceptance of bystanders.

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