

Extending a Mobile Device's Interaction Space through Body-Centric Interaction

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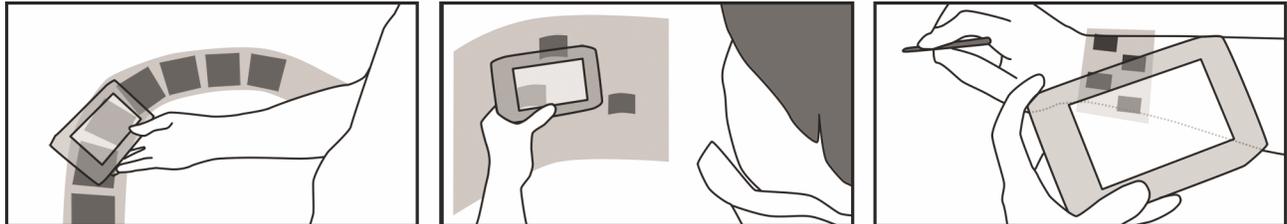


Figure 1. Body-Centric Interaction anchors digital content & actions on & around the body where one can position/orient the device to navigate multiple objects (left), place/retrieve bookmarks on a virtual canvas (center), select an application control options (right).

ABSTRACT

Modern mobile devices rely on the screen as a primary input modality. Yet the small screen real-estate limits interaction possibilities, motivating researchers to explore alternate input techniques. Within this arena, our goal is to develop *Body-Centric Interaction with Mobile Devices*: a class of input techniques that allow a person to position and orient her mobile device to navigate and manipulate digital content anchored in the space on and around the body. To achieve this goal, we explore such interaction in a bottom-up path of prototypes and implementations. From our experiences, as well as by examining related work, we discuss and present *three recurring themes* that characterize how these interactions can be realized. We illustrate how these themes can inform the design of *Body-Centric Interactions* by applying them to the design of a novel mobile browser application. Overall, we contribute a class of mobile input techniques where interactions are extended beyond the small screen, and are instead driven by a person's movement of the device on and around the body.

Author Keywords

Body-Centric Interaction, mobile device, mobile interaction.

ACM Classification Keywords

H.5.2 [User Interfaces]: Input devices and strategies, Interaction styles.

INTRODUCTION

Modern mobile devices, such as smart phones and PDAs,

rely on the screen as their primary input and output modality. For input, these devices rely mostly on direct touch, albeit augmented with a few physical buttons and sensor data. For output, small displays (i.e., between 3.5" and 4" diagonal) provide only a limited view of information displayed by the device. While enabling portability, the problem is that small screen space restricts designers to a limited interaction palette. Consequently, some actions require long sequences of on-screen operations (e.g. navigating through hierarchies, or swiping and searching through 'pages' of content). Interaction tedium is exacerbated as mobile applications increase in both number and complexity.

Prior work has suggested various solutions to address this 'small-screen' problem of mobile devices. For example, some systems allow people to place digital information onto different body parts so it can be easily retrieved later [1,7,24]. Others create virtual workspaces around a person's body [14,28] or more generally in space [6] where one orients the device to 'peep into' and navigate an information space that is significantly larger than the screen. Researchers also envision a wearable mobile device whose functions are shaped by the way it is held or worn on the body [27].

On reflection, we find this body of work shares an important design theme: they all extended the spectrum of interactions to include a person's body and its surroundings. Our own particular focus is on a subset of the above, where we define and develop *Body-Centric Interaction with Mobile Devices* – a class of mobile input techniques that allow people to navigate and manipulate mobile digital content by positioning and orienting the device *on* and *around* their bodies (Figure 1 shows three examples of *Body-Centric Interaction* techniques).

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While a limited amount of prior work in this area does cover this idea, the problem is that they mostly represent point solutions. A broader view of this design theme has not yet been established. Therefore, it is somewhat difficult to generalize ideas from one implementation, or to systematically leverage ideas found across several point systems, or to distill ‘guidelines’ that stimulate new mobile interaction designs based on a person’s body and the space anchored to it. Consequently, our goal is to explore the breadth of this design theme, where we go beyond point solutions in an attempt to create a network of design ideas.

To attain this goal, we began with a bottom-up path of prototypes and implementations, where each prototype represents a specific body-centric mobile input technique. We then reflected on our designs (as well as others found in the literature), to reveal and extract more general aspects of designing such *Body-Centric Interactions*. These aspects present three recurring themes that encapsulate how the interactions can be realized. In brief, proximal spaces on and around the body are identified and delimited to situate interactions; within these spaces, the spatial relationship between the body and the device serves as ‘raw input’; and, given such ‘raw input’, various considerations will influence the design of interactions to navigate and manipulate the device’s on-screen content. We summarize and present these recurring themes as a set of reusable design guidelines, which are further illustrated in our final prototype – the body-centric browser. By taking a body-centric approach, we create new experience of using a mobile browser where one can manipulate multiple tabs, bookmarks and controls on and around her body. Overall, this paper contributes a class of mobile input techniques where interactions are extended beyond the small screen, and are instead driven by a person’s movement of the device on and around the body.

PROTOTYPING BODY-CENTRIC INTERACTION

To begin our exploration, we implemented a set of prototypes, each of which represents a specific body-centric mobile input technique. (For clarity, Figures 2-7 use sketches rather than system photographs to illustrate these prototypes; however the accompanying video illustrates several of these in actual operation). During this prototyping process, we focused on three different design directions, each of which assigned a specific role to the body in mobile interaction. As we will shortly show, we considered how our body and its surroundings can afford (1) storing and retrieving digital objects (bookmarks, photos, etc.), (2) triggering digital shortcuts (making a phone call, starting the music player, etc.), and (3) controlling applications (navigating the calendar time line, selecting from a set of tools, etc.). Before presenting these prototypes, we first explain the enabling sensing technologies.

Implementation Technologies

While our prototypes are fully implemented, they are best considered as design sketches that develop and formulate basic ideas. However, we acknowledge that the technology we use is not yet suitable for day to day deployment on consumer mobile devices. This is not a problem for our purposes, as we see this setup as an enabling technology that allows us to explore possible interactions that leverage a device’s knowledge of where it is situated and how it is moved in the space relative to a person’s body.

When using a mobile device to situate interactions *directly on* the body, we need to identify the body location that the mobile device is referring to. We used two approaches. First, we embedded RFID tags in clothes, which in turn are associated with discrete locations representing the underlying body part. Tags are read by an RFID reader attached to the mobile device. Second, we also used the device’s integrated camera to recognize either fiduciary tags or shapes imprinted on clothes via computer vision. Both work to identify body locations. These vision-based approaches provided additional information, where they could also return a continuous stream identifying the device’s position relative to particular locations.

When situating interactions in the space *around* the body, we needed to capture the fine-grained changing spatial relationships of the device relative to the body. To do this, we attached reflective markers to both the body and the device. Using infrared cameras and the Proximity Toolkit [15] running atop the Vicon motion capture system¹, we could easily acquire the position and orientation of the device relative to particular body parts.

Body-Centric Digital Content Storage/Retrieval

The first two prototypes concern the storage and retrieval of digital content.

Body Viewer is an image viewer that allows people to place and retrieve digital content – in this case digital images – by anchoring them on one or more body parts. Figure 2 illustrates a person

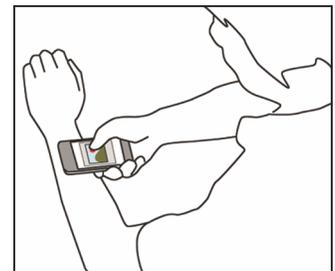


Figure 2. *Body Viewer*: anchoring digital content to the forearm

anchoring the image currently displayed on his device to his forearm: he simply brings the device over the forearm and then taps the screen. When the device is next brought to the forearm, a preview of that image appears: a further tap will retrieve and display it on the screen. If an image was already on display when the device was brought next to the forearm, both images are shown side by side: tapping the unanchored image will anchor it, while tapping the

¹ <http://www.vicon.com/>

anchored image will retrieve it. This can be repeated on multiple body parts.

Body Cobweb, inspired by Virtual Shelves [14], is a virtual 3D ‘cobweb’ contained in the space in front of a person’s body that, in our prototype, is used to manage web page bookmarks. Figure 3 illustrates this cobweb as consisting of two virtual layers (hemispheres) located at

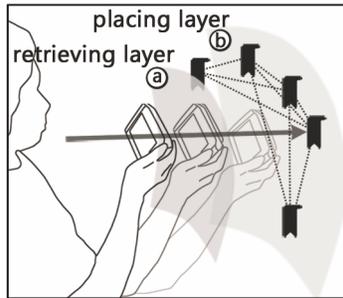


Figure 3. *Body Cobweb* is an imaginary cobweb anchored to a person’s body.

distinct distances from the body, where bookmarks (shown here in black) are scattered upon it. Figure 3 shows a person orienting the device and pointing to a bookmark on the cobweb (see the arrow). Pushing it to the ‘retrieving’ layer (Figure 3a) picks up that bookmark and displays the web page on the screen. To create a new bookmark, one pushes the device further to the ‘placing’ layer (Figure 3b) which drops the bookmark on the cobweb. (If there is an existing one on that location, the new bookmark will replace it).

Discussion. Both *Body Viewer* and *Body Cobweb* are similar as they use the body and its surroundings as a mobile canvas to extend the mobile device’s file storage/access mechanism. They differ in that they appropriate different proximal spaces of the body. *Body Viewer* associates images to discrete marked locations directly on the body’s surface. *Body Cobweb* goes beyond the body’s surface, where it senses the device’s continuous distance and orientation in relation to the space around the entire body, and uses that information to dynamically anchor or retrieve bookmarks from that space. Spatial memory, augmented by visual feedback presented on the mobile device, is a key factor in enabling both interactions [2]. It helps people recall which body part they have associated an image to, or which part of the cobweb holds a bookmark of interest. As well, people’s associative experience of how a real cobweb functions helps them understand concepts such as ‘layers’ and ‘sticking a web page on the cobweb’.

Body-Centric Digital Shortcuts

The next two prototypes consider triggering digital actions.

Body Shortcuts, inspired by Guerreiro et al. [7], follows the same interaction style as *Body Viewer* except that we developed associated meanings of body parts to trigger programmable digital actions. For example, in Figure 4a a person has associated a calendar application with the wrist, and holding the device close to the wrist opens the calendar. Similarly, a person can also associate his stomach to finding the nearby restaurants (Figure 4b), his knees to searching for walking routes to nearby amenities (Figure 4c), and so on.

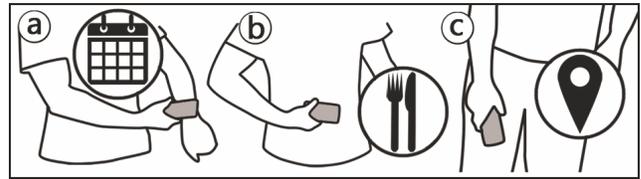


Figure 4. *Body Shortcuts* use body parts to trigger digital actions.

Whereables, inspired by [27], is also designed for triggering programmable actions, but it does this by having a person wear the device at particular locations on the body, which changes to the foreground application mapped to that location. Figure 5a illustrates how the device’s currently running application switches to a phone when held close to the ear, while in Figure 5b it automatically switches to a music player when attached to the upper arm (e.g., via a band). This implicit application switching is in sharp contrast to the application juggling that occurs when a person is using on-screen touch controls.

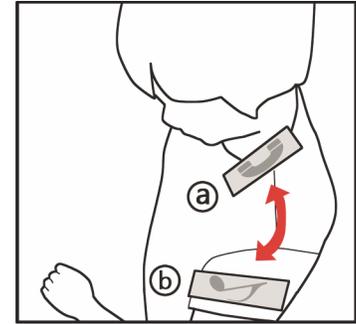


Figure 5. *Whereable* is a device whose functions are triggered by wearing it on different body locations.

Discussion. Both *Body Shortcuts* and *Whereable* use body locations to trigger programmable digital actions, which would otherwise require a sequence of screen navigations. Technically, both perform in quite similar ways, yet they are perceived by a person quite differently: one by temporarily moving to a location to activate an action, the other by making the device’s function location-dependent.

One important aspect revealed by our examples in this section is that people can apply their associative experience to semantically relate their body parts to certain digital actions. Unlike the cobweb model, body parts are visible and full of meaning. They provide visual cues that help people recall what digital actions are readily available from their body. The wristwatch on the wrist relates to time and thus calendars, the stomach to food and thus restaurants, the ear to listening and thus phones, and so on. People’s kinesthetic sense also adds to such interactions [25]. It allows a person to reach their body parts with reduced visual attention. However, physical constraints must be considered. For instance, placing a shortcut on one’s back makes it almost impossible (and at times inappropriate) to reach and trigger.

Body-Centric Controls

The next two prototypes concern using the device’s location relative to the body as input to control a running application.

Body Toolbar, inspired by Shoemaker et al. [23], allows a person to access virtual tools associated with body

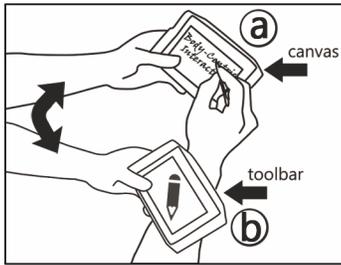


Figure 6. *Body Toolbar* lets one view and select from a palette of tools located on the body

the device along her right arm (Figure 6b), where the screen responds by showing available tools associated with locations along the arm. A person selects the tool by touching the screen. The previously active tool is kept if a person moves the device away without touching the screen. To pick a color, a person would move the device along the left arm instead, which reveals a palette of colors that can be picked as drawing colors.

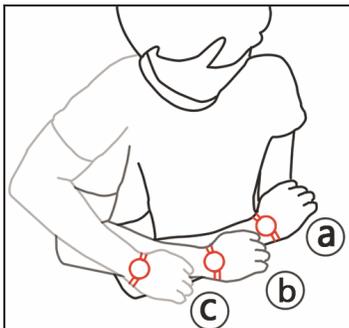


Figure 7. *Rotating Watch* is moved around the body to display scheduled events in a sequence corresponding to particular positions

(Figure 7a) while future times appear as the arm is rotated to the right (Figure 7b, c), and likewise past events are shown when rotating leftward. The resolution of interaction is decided by a pre-defined arm rotating range, while the time of the calendar is calculated by interpolating between the leftmost and the rightmost orientations.

Discussion. Both *Body Toolbar* and *Rotating Watch* track device-body relationships as input to control a running application. They both reduce the need for conventional on-screen widgets that compete for the limited screen real estate, as well as reducing navigation through hierarchical on-screen menus. Yet both realize this goal differently. *Body Toolbar* extends the canvas of a sketching program naturally to its nearest body parts – people’s arms. In contrast, *Rotating Watch* casts the interaction to the arm’s rotating range around the body. *Body Toolbar* lets people position the device to specify discrete tools on the body while *Rotating Watch* measures the device’s continuous orientation with regards to the entire body. Both leverage a person’s associative experience, but do so differently: *Body Toolbar* somewhat mimics a GUI toolbar as a pallet affixed

locations. People select a tool by moving the device close to a particular body part. Figure 6 shows our sketch application. The screen only displays the drawing canvas when held in a normal viewing position (Figure 6a). To select different painting tools, a person positions

the device along her right arm (Figure 6b), where the screen responds by showing available tools associated with locations along the arm. A person selects the tool by touching the screen. The previously active tool is kept if a person moves the device away without touching the screen. To pick a color, a person would move the device along the left arm instead, which reveals a palette of colors that can be picked as drawing colors.

Rotating Watch is a wristwatch mobile device that shows a person’s daily schedule one event at a time. People move the watch around their body to go through their scheduled events (Figure 7). The watch measures its orientation relative to a person’s body and maps it to the change of time. The present time is immediately in front

(Figure 7a) while future times appear as the arm is rotated to the right (Figure 7b, c), and likewise past events are shown when rotating leftward. The resolution of interaction is decided by a pre-defined arm rotating range, while the time of the calendar is calculated by interpolating between the leftmost and the rightmost orientations.

to an arm, while *Rotating Watch* maps orientation to scheduled events in a way that conforms to people’s notion of time units (i.e., the hours of a day sweeping from left to right). Further, people’s spatial memory and kinesthetic sense also help them understand and make use of these two interaction techniques, e.g., recalling which arm part a tool is associated with (*Body Toolbar*), and guiding the arm to rotate to a specific event (*Rotating Watch*).

REVEALING RECURRING DESIGN THEMES

Having presented a series of prototype systems, we now reflected on the design of each of these prototypes, as well as the literature, to identify three recurring themes that encapsulate how *Body-Centric Interactions with Mobile Devices* can be realized. First, proximal spaces on and around the body are identified and delimited to situate interactions. Second, within these spaces, the spatial relationship between the body and the device serves as ‘raw input’. Third, given such ‘raw input’, various considerations should be incorporated when designing interactions of navigating and manipulating the device’s on-screen content. We consider these three themes as important lessons learnt from our bottom-up prototyping practice. We now articulate them in more detail as well as their implications.

Situating Interactions in the Body’s Proximal Spaces

We surveyed neuropsychology theories in order to deepen our understanding of people’s perception of the space centered on their bodies. As a result, we found that within the personal space (defined by Hall [10]), most neuropsychologists suggest that our brain builds up multiple representations of space [12] centered on one’s corporeal body [5,12] (see Figure 8):

- *Pericutaneous space*: the space immediately outside the body;
- *Peripersonal space*: the space surrounding the body and within easy reach of the hands;
- *Extrapersonal space*: the space far from the body and outside of one’s reach.

This neuropsychological understanding of the body has contributed to HCI research as various spatial models, such as Benford and Fahlén’s model for mediating interaction between persons and objects inhabiting a virtual space [3], or Shoemaker’s model for leveraging the body to interacting with large wall displays [23]. With *Body-Centric Interaction with Mobile Devices*, we specifically focus on and refine two proximal spaces of the body.

- *On-body* space, corresponding to pericutaneous space, hosts interaction where people’s actions specify particular body parts (e.g., in *Body Shortcuts*, referring to the wrist to trigger a calendar app).
- *Around-body* space, corresponding to peripersonal space, supports interaction where the people’s actions specify a location at an arm-reachable distance from her entire body (e.g., in *Body Cobweb*, pointing to



Figure 8. The perceived proximal spaces on and around the body.

bookmarks and passing through different layers to place or retrieve web pages).

We also realize design possibilities exist in the space far from the body (corresponding to extrapersonal space) [23]. While this is beyond our scope – our focus is the space within immediate reach by the hand holding the device – we recognize extrapersonal space offers fertile grounds for interaction.

Tracking the Device-to-Body Spatial Relationships

The interaction techniques for all our prototypes – on or around the body – are driven by the spatial relationships between the device and the body. However, they differ in how they exploit these spatial relationships.

In the *on-body* proximal space, our prototypes’ basic approach is to detect whether the mobile device is spatially located within certain range of a body part. For example, *Body Viewer*, *Body Shortcuts*, ‘*Whereables*’, and *Body Toolbar* develop and track this spatial relationship between the device and the person’s wrists, forearms, abdomen, knees, etc. To further explore the richness of interacting

with body parts, we can categorize these spatial relationships into the following dimensions: *discrete/continuous position* and *orientation* (captured as the angle of the device relative to the normal of a particular body location). We can alternate these dimensions to expand the richness of interactions. For example, we can extend the original *Body Viewer* to incorporate the continuous changes of position between the device and a body part, thus enabling more interaction possibilities. For example, once an image is retrieved, moving the device up and down over that location zooms in/out that image. Similarly, we can consider *orientation* changes to drive the interaction. For instance, as an extension to *Body Toolbar*, a person can *rotate* the mobile device around the forearm to customize a parameter of the currently selected tool (e.g., adjusting the thickness of the brush).

In the *around-body* proximal space, our prototypes consider the position and orientation relative to the *entire body of a person*. For example, the *Body Cobweb* prototype exploits orientation of the device relative to the body’s center to allow a person to navigate across the cobweb for viewing/placing bookmarks, while *Rotating Watch* uses changes in orientation of the device (attached to the arm but still relative to the center of the body) to cycle through calendar events. Similar to the on-body proximal space, other metrics can be extracted, such as device’s *position* along a given orientation (i.e., distance to the body). *Body Cobweb* identifies two discrete distance values to demark the retrieving/placing operations of bookmarks. Further, monitoring *continuous* changes of distance allow more interaction possibilities, such as transitioning from an overview of all bookmarks, to gradually ‘zooming in’ to, and eventually focusing on a particular one.

In short, the device-body spatial relationship can be represented as the device’s *position* and *orientation* – measured *discretely* or *continuously* – in relationship either to particular body parts, or to the entire body in the environment. Table 1 compiles examples where these two relationships between a device and the body are driving the types of interaction.

Table 1. Examples for applying discrete or continuous measurements of a device’s on-/around-body position and orientation.

Spatial metric Proximal space	Position		Orientation	
	Discrete	Continuous	Discrete	Continuous
On-body	Moving the device close to the shoulder to trigger an application (see <i>Body Shortcuts</i>)	Hovering the device over a forearm location to zoom in/out a retrieved image (see <i>Body Viewer</i>)	Rotating the device along the circumference of the forearm to switch between viewing either an image or its properties (see <i>Body Viewer</i>)	Rotating the device along the circumference of an arm location to adjust the thickness of the brush tool (see <i>Body Toolbar</i>)
Around-body	Placing the device at distinct distances from the body to perform different bookmark operations (see <i>Body Cobweb</i>)	Moving the device along a direction from the body to transition between overview and focus of bookmarks (see <i>Body Cobweb</i>)	Pointing the device at distinct orientations to place/retrieve a bookmark (see <i>Body Cobweb</i>)	Rotating the device around the body to shift the time line of a video (see <i>Rotating Watch</i>)

Considerations for Mapping the Interactions

Our prototypes and prior work illustrate a range of different kinds of mappings between the device-body relationship and actual interaction. A number of factors should be considered in deciding on these mappings. For instance, while designers may be limited by physical constraints, they can take advantage of people's kinesthetic sense, visual cues, and even associative experience to create mappings that will be easy to execute (kinesthetic sense), understand (visual cues), or remember (associative experience).

Physical constraints of people's bodies restrict the possible design options (cf. [17] where 'physical constraint' describes situations where some actions are impossible on a GUI). Consider *Body Toolbar*. While it is reasonable to place a tool shortcut on the arm, the interaction becomes cumbersome when placing it, say, under one's knees, where the hand can hardly reach (and where the device would be out of view). Similarly, when mapping the arm to a slider, it is more reasonable to place the control along the arm's length rather than its width as the latter provides very limited sliding range.

Kinesthetic sense is our awareness of body parts' relative positions [19,25], while *spatial memory* is our ability to memorably associate space with information [2]. Through both, it enables people to 'remember' where they have previously placed the digital content. In *Body Viewer*, people can associate an image with an arbitrary body part (say, the arm) as a short-term bookmark.

Visual cues of the body (also combined with kinesthetic sense) further strengthen the association between its space and information [26]. In the *Body Shortcuts* prototype, the visual cues of one's wrists, abdomen, and knees inform people of the digital shortcuts that are readily available from their bodies, while kinesthetic sense allows them to accurately locate these body parts in order to trigger the associated shortcuts. Further, clothes and items worn on the body also serve as visual cues.

Associative experience associates prior experiences, metaphors, uses of the body, and uses of space to the mapping process. One approach builds associations based on conventions [17] developed from the GUI paradigm, where people would use the interface on and around their body in a manner that is similar to using a GUI. For example, people can transfer their knowledge of using a digital calendar to using the *Rotating Watch* where the arm's rotating range maps to how one scrolls the day-view of a calendar application. Another approach creates meaningful, sometimes personalized, body-information association. For example, in '*Whereables*', one can switch the device from 'phone' to 'music player' by moving it from ears to the upper arm. The knowledge of how to make a phone call and the experience of wearing a music player during workout are the underlying motivation for customizing such association.

USING DESIGN THEMES TO REFLECT ON PAST WORK

We now discuss the three recurring themes in relationship to previous related work. For the purpose of illustration, we organize this discussion by the three proximal spaces centered on the body (percutaneous, peripersonal, and extrapersonal [5]). In each category, we begin with a broader overview of interactions in this body's proximal space; we then narrow to a specific focus on *Body-Centric Interactions with Mobile Devices*. Our goal here is to use reflection to see how others have (perhaps tacitly) considered our design themes, as well as to further understand the interplays between interactions and the body.

Space on the Body

Ishii & Ullmer envisioned that the locus of computation would shift into two directions, one of which was to people's skins and bodies [13]. This vision pointed to the development of wearable computing where the boundaries blurred between everyday clothing and computing devices [18]. Sharing the same interest of the body, physiological interactions exploits the body's biological properties to enable direct interaction with the skin [11], muscle [21], or the entire body [4]. Shoemaker et al. appropriated a person's body as data storage and control surface [23]. Gustafson et al. appropriated the human palm as a phone interface [9].

On-Body Interaction with a Mobile Device

Our work differs from above, as we focus on positioning and orienting a *mobile device* to specific locations on the body, which are then mapped to various digital objects and the interaction with them. Several projects are related to this approach. In *Body Mnemonics* [1], people were asked to describe what kind of information and applications they would associate to particular body locations. A follow-up study generated associative maps of the information associated to the body. *BodySpace* applied this idea to a music player which is controlled by placing the device close to different parts of the body [24]. Similarly, *Mnemonic Body Shortcuts* enabled quick access to applications by moving the device from one's chest to a number of designated body parts [7]; *Snaplet* provided a wearable flexible E-Ink display with varied functions decided by how people hold or wear it [27].

As a whole, this work chose the space on a person's body as the input area. The interactions are primarily driven by the device's *discrete* on-body *positions* where people's associative experience of their body plays an important role in enabling the mapping between pointing to a body part and retrieving a piece of associated digital content.

When considering our identified design themes we find new design opportunities that could extend this prior work. For example, while most projects considered binary body-device relationships, one can add more expressive actions by considering continuous measurements of distance. Orientation, while mostly overlooked in previous work, can

be also leveraged to enrich interaction design. To illustrate this, we will shortly showcase a prototype where a location on the arm carries an ‘armband’ of buttons, reachable by rotating the device and the arm relative to each other.

Space Around and Far From the Body

Interactions can also be extended outward from the body. Shoemaker realized people’s ability to manipulate far-away UI objects using a shadow metaphor [22]. *SixthSense* demonstrated a type of gestural input by positioning and moving hands in front of the body [16]. *Imaginary Interface* let people create a virtual interface and point and draw on it in mid-air [8].

Around-Body Interaction with a Mobile Device

Our work differs from above, as we focus on the closer-to-body peripersonal space reachable by the device held in a person’s hands. Two projects presented similar focus. Yee’s *Peephole Displays* imagined an invisible information space in front of a person who used a handheld device to ‘peep’ into this space [28]. For example, one can move the device on a horizontal plane in front of her where the screen consistently reveals parts of a subway map. Li et al’s *Virtual Shelves* developed a similar idea where they enabled people to trigger programmable shortcuts by spatially orienting their devices within a circular hemisphere in front of them [14]. The interaction carried the metaphor of a ‘shelf’ wherein one could organize and retrieve the many mobile apps with reduced visual attention.

These two projects both situated interactions *around* a person’s body. *Peephole Displays* tracked the device’s *continuous positions* and mapped it to the movement of a shifting window over the underlying information space. *Virtual Shelves* tracked the device’s *orientation* based on a Spherical coordinate system and mapped it to a number of spatially distributed (*discrete*) shortcuts. Both systems made use of people’s spatial memory to maintain a model of the virtual information space (*Peephole Displays*) or the shelves of content in their mind (*Virtual Shelves*).

By again considering our design themes, we can think of their design approaches as complementary. First, *discrete orientation* around the body is useful for sorting many digital objects and retrieving them with reduced visual attention. Once an object is retrieved, tracking the device’s *continuous position* on a virtual canvas enables finer-grained manipulation with that object.

The two broad categories above – using space on vs. around the body, are not mutually exclusive. Neither are the use of both position and orientation for spatial tracking, and the various mapping considerations. Yet the prior work we are aware of typically considers only a few of the ‘parameters’ suggested by our themes. By articulating these ‘parameters’, we can now contemplate how interaction design could benefit from a more holistic view and a spectrum of interaction possibilities suggested by the design themes. As a first step to apply and reflect on these themes,

below we showcase a design wherein a body-centric approach leads to new ways of using a mobile application.

DESIGNING THE BODY-CENTRIC BROWSER

While the earlier-mentioned prototypes have developed the fundamental concepts of *Body-Centric Interactions with Mobile Devices*, they only demonstrated parts of the underlying design themes. In this section, we illustrate how to apply these themes as a whole to the design and implementation of a mobile browser application. In particular, we show how a *body-centric* approach has led us to a novel design direction: in a mobile browser, one can manipulate multiple tabs, bookmarks and controls on and around her body.

Interaction Scenario

The following scenario (as well as our video) introduces the kinds of expressive interactions possible with our body-centric browser. Larry is browsing the web on his smart phone where he holds the device in the *viewing zone* – the space with a comfortable eye-reading distance in front of his upper body (Figure 9a, 10a). He has opened a number of tabs, each of which is maintained in a queue located in the *navigating zone* – a virtual circular tab bar around his lower body (Figure 9d). In Figure 10d, Larry is retrieving an earlier-opened tab by simply orienting the device along the navigating zone: the screen reveals the tabs consistent with the device’s orientation. To bookmark the page on this tab, Larry goes to the *bookmark zone* – a virtual cylindrical canvas sitting behind the viewing zone – where one can pin or unpin a web page for future reference (Figure 9c). In Figure 10c, we see Larry positioning the device at his eye level, orienting it to the 1 o’clock direction and tapping to pin the page on the canvas. Later Larry wants to share this information with his friend Sally. He goes back to the bookmark zone, positions and orients the device to locate the web page and taps to select it from the canvas. He then orients the device to the *control zone* – an array of virtual buttons aligned on his right wrist (Figure 9b). Figure 10b shows Larry *positions* the device on the wrist, and *orients* them relative to each other (where in this case ‘orientation’ is done by moving the device around the wrist) to go through a number of buttons until he locates the ‘email’ option.

Design Details

Tabbed browsing – a useful feature in most desktop browsers – is more difficult to perform in the mobile setting. In designing this prototype, we apply a body-centric approach to enhance the manipulation and navigation of browser tabs. Specifically, our designed body-centric browser has three requirements: displaying and managing opened tabs, bookmarking web pages, and providing controls to work with them. We now describe how our three design themes brought *Body-Centric Interactions* to the implementation of these functional requirements.

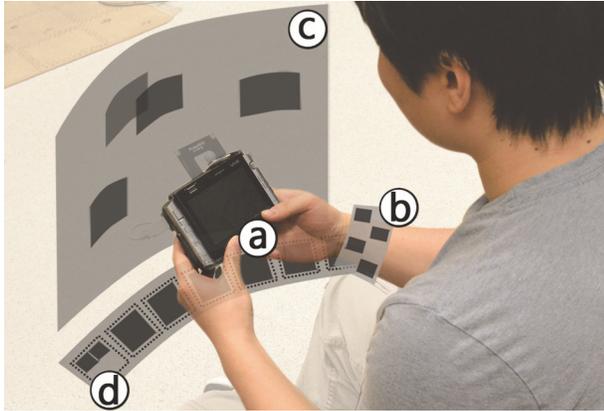


Figure 9. Body-centric browser's interactive zones allow users to (a) view, (b) control, (c) bookmark, and (d) retrieve browser tabs.

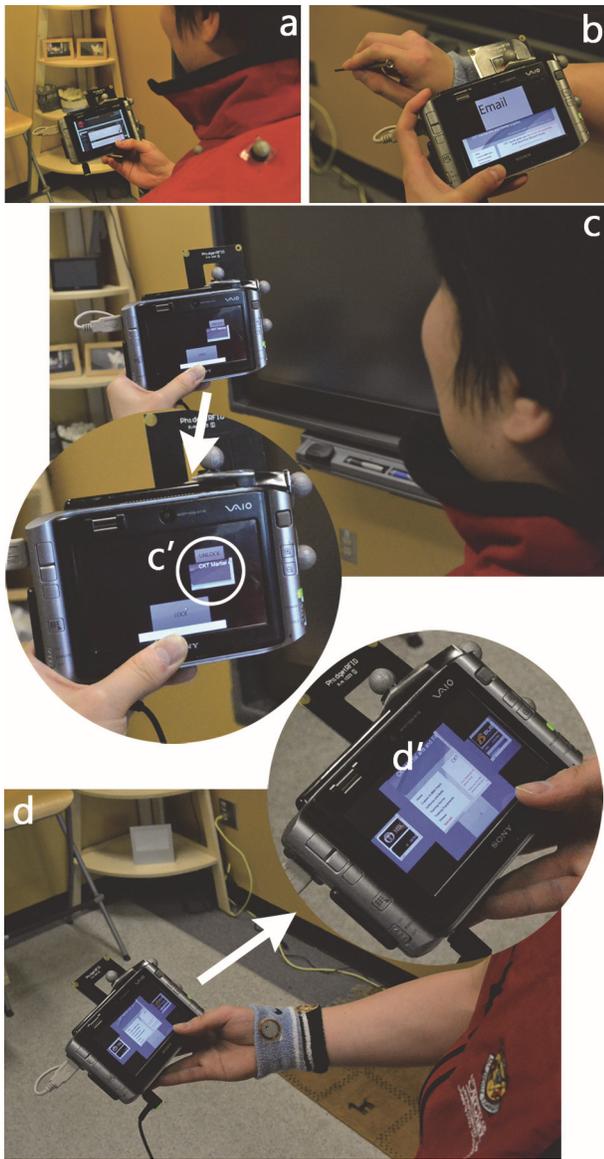


Figure 10. Interaction scenarios of body-centric browser: the user positions/orients the device on and around his body to navigate and manipulate browser tabs.

Displaying and managing opened tabs: the tab navigating zone. To fulfill this requirement, we learned from the browser's design of tab bar where it can be easily seen (usually just atop the web pages) and retrieved by a person. When thinking of potential design ideas, we found people normally hold and view the device in their field of view (i.e., a 'viewing zone' at an eye reading distance in front of their upper body). First, it made sense that our tab navigating zone should be close to this position while not interfering with it. Thus we placed the tabs in front of a person's waist, which is immediately below this 'viewing zone'. One could easily lower the device to reach and switch between these two zones (Figure 10a, d).

Essentially, this layout exploits people's associative experience of the 'tab bar' widget in desktop browsers. Furthermore, we situate this zone *around* the body, where the semi-circular queue of tabs is shaped to match the motor characteristics of the arm (*physical constraints*). Thus the *orientation* of the device maps to parts of the queue that are then displayed on the screen (Figure 10d'). This leverages ideas found in *Rotating Watch*, as the tabs are normally in time-order, and panning around them essentially navigates across time. A further design challenge is how to adapt the layout to an increasing number of tabs. Currently, we fix the number of (discrete) slots in the queue to seven. We allow for more than seven tabs by collecting older tabs within a hierarchy (e.g., as a collage or pile within a slot). Figure 9d shows the two oldest tabs squeezed in the leftmost slot so that the other six newer tabs can have their individual ones. However, this adds interface complexity. Still, as we will talk about shortly, making a modest number of tabs available for rapid access is still valuable.

Bookmarking tabbed web pages: the bookmark zone. We needed to allow people to 'casually' bookmark a tab by 'pinning' it somewhere for future reference. Similar to how we considered tab navigation (and leveraging the *Body Cobweb* design), we chose the space behind the viewing zone (i.e., further in front of one's upper body), as we wanted people to be able to easily bookmark a page immediately after viewing it, where they could freely pin, move, and unpin a web page anywhere within it. Our space is modeled as a cylindrical canvas, matching a cylindrical coordinate system. We measure the device's *continuous orientation* and height (*y-axis position*) to keep track of its location on the canvas (e.g., somewhat similar to [14]). Upon 'touching' the web page when in this bookmark zone, the web page displayed in the device (which perhaps had been previously selected from the tab navigating zone) can be pinned on it by a single tap. It is then anchored to that location and shown as a web page thumbnail (Figure 10c') during navigation. Tapping an existing bookmark (i.e., a web page thumbnail) selects it, after which one can pin it somewhere else or return to the viewing zone to browse the page. Because these bookmarks stay at the same location, interaction with this bookmark zone exploits people's

spatial memory to recall the spatial mapping between the canvas and the bookmarks.

Providing control options with tabs: control zone. Our last requirement is to provide basic control options, such as those that operate on the currently web page (e.g., ‘email’, ‘refresh’, etc). These controls are used intermittently, so we decided to place them somewhat off the body’s main viewing axis, just as a palette of tools in a GUI are typically at the edges of the window rather than its center. As a result (which also leverages ideas in *Body Toolbar*), we designed a band of ‘control buttons’ that is virtually worn on a person’s wrist. To choose a control, a person *positions* the device on the wrist, and *orients* them relative to each other. The changing orientation leads to different control options seen on the screen. A single tap then selects and executes that option.

DESIGN ISSUES AND CHALLENGES

Body-Centric Interactions with Mobile Devices addresses the small screen real-estate problem with a variety of design strategies. Yet this interaction – in and of itself – also raises several issues and challenges, which we briefly outline below.

Scalability

The resolution of *Body-Centric Interaction* is limited by the number of digital items that need to be displayed. For example, in the body-centric browser, as the number of tabs increases, it will become more and more difficult to locate or retrieve a particular tab from the navigating zone. Of course, larger zones can fit more items, but the space for these zones is fairly limited. Consequently, the greatest benefit of *Body-Centric Interaction* comes from reserving that space for a modest number of important items and actions. Examples include quickly placing content for later retrieval, accessing frequently done actions, navigating to favored places, repeating recently done actions or viewing recently visited content (i.e. a history list), and a place to customize favored actions as shortcuts.

Search and Find

Another challenge occurs when a person cannot quite remember where something was placed – how do they search and find digital content on and around the body? Our current designs require them, for instance, to ‘scan’ the virtual canvas with the device in order to visually locate an item (e.g., a web page thumbnail in the bookmark zone). We can improve this by standard information visualization mechanisms – although we recognize that we are still limited by the small screen of the device. For example, consider an overview mechanism. When moving the device towards the bookmark zone (of the body-centric browser), the screen first shows an overview of the entire canvas, perhaps with items altered to best represent them at their small size (i.e., semantic zoom). As the device gets closer, it gradually zooms in the overview until finally focusing on a particular area.

Social and Cultural Concerns

Finally, *Body-Centric Interaction* should take into account social and cultural concerns. For example, can the body-centric browser be used in public? It might not be socially appropriate to wave the device around one’s body (cf. [20]). It may look odd, and might even invade others’ personal spaces (e.g., when used in a crowded elevator or a restaurant with cramped seats).

CONCLUSION AND FUTURE WORK

Body-Centric Interaction with Mobile Devices contributes a class of mobile input techniques, where the focus of interaction has shifted from the device’s screen to include a person’s body. Our goal is to mitigate the ‘small screen’ problem by enabling beyond-screen interactions mapped from one’s actions of holding and moving the device on and around her body.

A bottom-up path of prototypes explored how such interactions can be realized, which in turn revealed several recurring themes reusable for new designs. We showcased one such new design in the body-centric browser prototype. By taking a body-centric approach, we create new experience of using a mobile browser where one can manipulate multiple tabs, bookmarks and controls on and around her body.

This work is just the beginning. As usual in any new interaction paradigm, much is left to do. While our prototypes and techniques seem intuitively appealing, their actual usefulness and usability in practice are yet to be determined: much iterative redesign is likely. Similarly, we need to see how effective our recurring design themes will influence actual designs in terms of inspiring novel mobile interactions. Finally, we need robust and reliable enabling technologies if we are to move beyond proof-of-concept prototypes to actual systems that people can use and enjoy in their daily lives.

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