Design for Wearability

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ABSTRACT

Digital Technology is constantly improving as information becomes wireless. These advances demand more wearable and mobile form factors for products that access information. A product that is wearable should have wear-*ability*. This paper explores the concept of dynamic wearability through design research. Wearability is defined as the interaction between the human body and the wearable object. *Dynamic* wearability extends that definition to include the human body *in motion***.** Our research has been to locate, understand, and define the spaces on the human body where solid and flexible forms can rest – without interfering with fluid human movement. The result is a set of design guidelines embodied in a set of wearable forms. These wearable forms describe the three dimensional spaces on the body best suited for comfortable and unobtrusive wearability by design.

Keywords

dynamic wearability, design research, design guidelines, wearable computers, human body

WHY IS WEARABILITY IMPORTANT?

Current trends in computing tools are consistent with society's historical need to evolve its tools and products into more portable, mobile, and even wearable form factors. Time pieces, radios, and telephones are common examples of this trend. With advances in technology, miniaturization, and wireless communication, access to information is no longer limited to the static environment of the office desktop and personal computer. Well-designed mobile and wearable products can offer more portable and effective ways for people to relate to this information. However, simply shrinking down computing tools from the desktop paradigm to a more portable scale only makes them into mini PC's. It does not take advantage of the opportunities presented by a whole new context of use. It does not regard the human body as a context.

The word wearable implies the use of the human body as a support environment for the product. The human body is active, its form is diverse and changing. Wearable design that respects these dynamics results in product wearability. Existing static human anthropometric data provides a limited description of the body [1,2]. Beyond these simple dimensions, no resources describing how to design wearable forms for the human body have been found. These issues considered, there is an obvious need for a more in depth understanding of the role of human form in wearable product design.

Our study, *Design for Wearability*, evolves from over seven years of hands-on, interdisciplinary, in-the-field experience developing mobile and wearable computer systems for a variety of industrial, commercial, and military applications [3,4]. From this experience we have mapped the design space for developing wearable systems. Wearable computer design involves a great deal of compromise, inevitably encountered when integrating issues of human form and human-computer interaction with the constraints of technology and the context-of-use.

APPROACH

Design for wearability focuses on a specific and important issue within the design space for developing wearable computing systems; wear-*ability*, the physical shape of wearables and their active relationship with the human form**.** In the sections that follow we have outlined several design guidelines for the creation of wearable forms.

These design guidelines are based on codifying our past experiences building and testing systems in the field and extensive research in understanding the issues enveloped in addressing wearability. We study wearable objects, the human body, and individual experiences with wearables. In our study of wearable objects, we explore history and cultures regarding many topics including clothing, costume, protective wearables, and a variety of carried devices. [5,6]. Study of the human body focuses on form and dynamics. For this, we look to physiology and bio-mechanics, as well as the movements of modern dancers and athletes [7,8,9]. Interviews of people explaining their own wearables provide a valuable glimpse into the way humans prepare, compromise, and construct themselves with what they wear and carry. Much of this background research can be found on the Design for Wearability web site. The design guidelines below reflect this study and experience with wearability.

DESIGN GUIDELINES FOR WEARABILITY

The design guidelines below are intended to communicate the considerations and principles necessary for the design of wearable products. They are listed here in a predictable order from the simple to the more complex, understanding that in development, tradeoffs will exist between them.

Guidelines for Wearability:

1. Placement (where on the body it should go)
2. Form Language (defining the shape)
3. Human Movement (consider the dynamic structure)
4. Proxemics (human perception of space)
5. Sizing (for body size diversity)
6. Attachment (fixing forms to the body)

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7. Containment (considering what's inside the form)
8. Weight (as its spread across the human body)
9. Accessibility (physical access to the forms)
10. Sensory Interaction (for passive or active input)
11. Thermal (issues of heat next to the body)
12. Aesthetics (perceptual appropriateness)
13. Long-term Use (effects on the body and mind)

Our wearability study attempts to integrate these guidelines. While all are important, we will only focus on the first six guidelines in the physical manifestation of our study. We have found the latter seven are not easily generalizable since they are much more dependent on the context and constraints of a specific design problem

Design Guidelines for Wearability

1. Design for dynamic wearability requires unobtrusive **placement**. Placement is determined by editing the extensive human surface area with the use of criteria. Criteria for placement can vary with the needs of functionality and accessibility; however, it is important to work within the appropriate areas for the dynamic human body. The criteria we used for determining placement for dynamic wearability are:

- areas that are relatively the same size across adults,
- areas that have low movement/flexibility even when the body is in motion, and
- areas that are larger in surface area.

Applying these criteria results in the most unobtrusive locations for placement of wearable objects. These are depicted below.

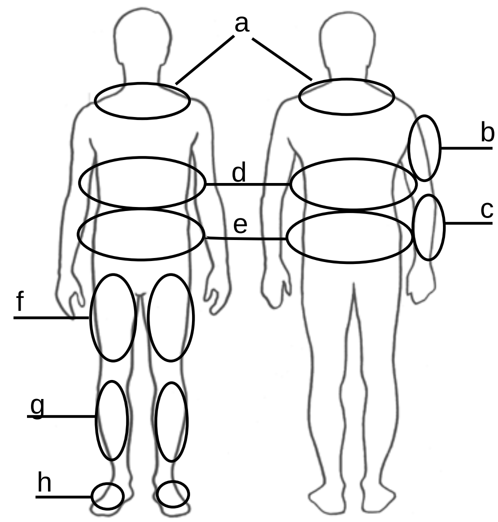


Fig. 1, The general areas we have found to be the most unobtrusive for wearable objects are: (a) collar area, (b) rear of the upper arm, (c) forearm, (d)rear, side, and front ribcage, (e) waist and hips, (f) thigh, (g) shin, and (h) top of the foot.

2. Design for the human body also requires a **humanistic form language**. This works with the dynamic human form to ensure a comfortable, stable fit. Humanistic form language includes forming a concavity on the inside surface touching the body, to accept human convexities. On the outside surface, convexity will deflect objects in the environment thereby avoiding bumps and snags. Tapering of the form's sides will stabilize the form on the body. Radiusing all edges and corners creates a safe, soft and wearable form. These steps are illustrated below, taking a simple block to a wearable form. The humanistic form language not only makes forms wearable, it adds structural ruggedness which is crucial in an active environment.

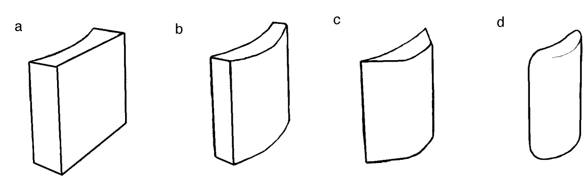


Fig. 2, Combining elements of concavity (a) against the body), convexity (b) on the outside surfaces of the form, tapering (c) as the form extends off the body, and radii (d) softening up the edges combine to create a humanistic form language

3. Human movement provides both a constraint and a resource in the design of dynamic wearable forms. Human movement is useful in determining a profile or footprint for wearable forms, as well as to shape the surface of forms. Consider the many elements that make up any single movement. Elements include the mechanics of joints, the shifting of flesh, and the flexing and extending of muscle and tendons beneath the skin. The photographs below illustrate how much the form of the body changes with simple motion. Allowing freedom for these movements can be accomplished in one of two ways: by designing around the more active areas of the joints or by creating spaces on the wearable form into which the body can move. For example; the torso is a good place to put a wearable, but the arms need to have full freedom to swing around the side and front of the torso. In addition, the torso needs the full ability to twist and bend. These movements can help sculpt the surface of the form.

Figure 3, Even through simply motions, our bodies change significantly.

4. Design for **human perception of size**. The brain perceives an aura around the body that should be considered to determine the distance a wearable form projects from the body. The understanding of these layers of perception around the body is referred to as proxemics [10] Forms should stay within the wearers intimate space, so that perceptually they become a part of the body. The intimate space is illustrated below and can be between 0 and 5 inches off the body. Compromises are often necessary but a general rule of thumb is to minimize thickness as much as possible. This increases safety and comfort, both physical and perceptual. A good example to observe is when a young American football player first dons shoulder pads, and immediately starts bumping into people and door ways because of the extra bulk.

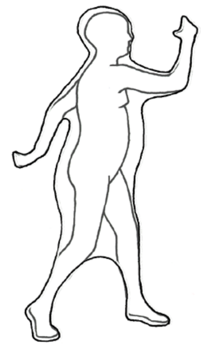


Figure 4, Aura around the human body that the brain will perceive as part of the body.

5. **Size variation** provides an interesting challenge when designing wearable forms. Both the build of a body and the ways in which it will gain and lose weight and muscle are important. Wearables must be designed to fit as many types of users as possible. Allowing for these size variations is achieved in two ways. The first is the use of static anthropometric data, which details point to point distances on different sized bodies [1,2]. The second is consideration of human muscle and fat growth in three dimensions. Fitting these changing circumferences can be achieved through the use of solid rigid areas coupled with flexible areas. The flexible areas should either be located between solid forms as joints or extending from the solid forms as wings.

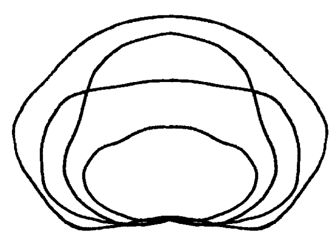


Figure 5. Torso cross sections of various sized bodies shows how sizes vary.

6. Comfortable **attachment** of forms can be created by wrapping the form around the body, rather than using single point fastening systems such as clips or shoulder straps. As in guideline 5, it is also important to have attachment systems that can accommodate various

physical sizes. Design for stable, solid, and comfortable attachment draws on the clothing and outdoor equipment industries. Design for size variations in attachment systems can be obtained in two simple ways. The first is through adjustability; e.g. straps that can be extended as seen on backpacking equipment. The second is through the use of standardized sizing systems from the clothing industry.

Figure 6, Single point attachment of a common pager or portable stereo is unstable and perceptually separate from the body.

7. Designing wearable objects generally requires the object to **contain** materials such as digital technology, water, food, etc. While some of these things are malleable in form, there are many constraints that these 'insides' bring to the outer form.

8. The **weight** of a wearable should not hinder the body's movement or balance. The human body bears its own extra weight on the stomach, waist and hip area. Placing the bulk of the load there, close to the center of gravity, and minimizing as it spreads to the extremities is the rule of thumb.

9. For any wearable it is important to consider the sort of **accessibility** necessary to render the product most usable. Extensive research exists in the areas of visual, tactile, auditory, or kinesthetic access on the human body. Simple testing should be conducted to verify the accessibility of specific wearables.

10. Sensory **interaction**, both passive and active, is a valuable aspect of any product. It is important to be sensitive to how one interacts with a wearable - something that exists on one's body. This interaction should be kept simple and intuitive.

11. There are three **thermal** aspects of designing objects for the body - functional, biological, and perceptual. The body needs to breathe and is very sensitive to products that create, focus, or trap heat.

12. An important aspect of the form and function of any wearable object is **aesthetics.** Culture and context will dictate shapes, materials, textures, and colors that perceptually fit the user and their environment. [11] For example, we created a wearable computer for an airplane repair situation, depicted below. Using the heavy leather of the traditional tool belt, it is possible to increase the comfort and acceptance by the repair technicians.

Figure 7. Navigator 2 wearable computer for aircraft maintenance engineers integrates a humanistic form language with attachment guidelines, placement guidelines (small off the back) and aesthetic, perceptual, and sensory informed use of materials.

13. The **long term use** of wearable computers has an unknown physiological effect on the human body. As wearable systems become more and more useful and are used for longer periods of time, it will be important to test their effect on the wearer's body.

The Design Guidelines alone can not convey all significant aspects of designing for wearability. They communicate a means to consider all the issues involved when creating wearable forms. The design guidelines for dynamic wearability were written in conjunction with the development of a family of wearable forms. These forms are a part of our study of design for dynamic wearability. The intent of this study is to thoroughly reflect design guidelines and define the ideal three-dimensional envelope where forms can exist on the human body in motion.

DYNAMIC WEARABLE FORMS

We have created a set of three dimensional forms for the human body that employ the Design Guidelines listed above. These forms outline the ideal envelope for dynamic wearability. The creation of these forms was an iterative process. We made both two dimensional drawings and three dimensional foam models and applied them to many bodies in the process. We also conducted two user studies, the first to better understand the complex curves of the body and the second to verify these forms are indeed wearable on the dynamic human form.

The object of the first study was to generate data defining the complex convex curves of the determined placement areas (see fig. 1). Our goal was to not only define but also to further understand those curves and how they changed with bodies of different size and shape. We developed a tool for this study, depicted in fig 8. With this flexible tool, we were able to map the arcs of several parts of the body: the collar area, triceps, forearm, ribcage, thigh, and shin. We were then able to both compare and measure the arcs from various bodies. This allowed us to determine an appropriate radius/spherical section for the concave inside of the forms, as well as the starting point and length of the flexible areas for each form.

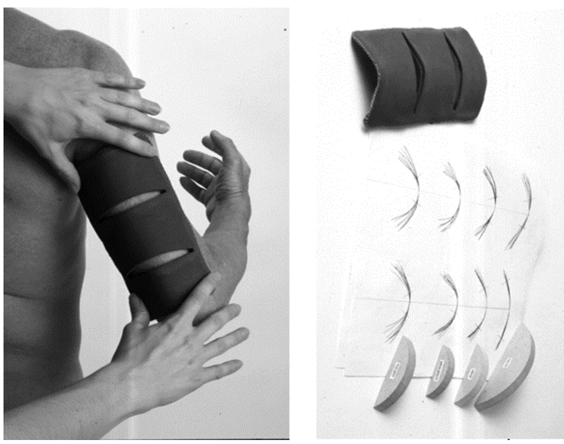


Figure 8, a shape-able tool used to map the arc of the triceps. Different peoples arcs are then mapped together to create an average concavity and width dimension to apply to wearable designs.

The second study is part of our on-going research. It is being performed to test the comfort level and freedom of movement allowed by the forms we design. So far we have had ten people test the wearability of these forms. Test subjects were chosen to represent extreme diversity in body shape and size. They performed a series of simple activities, once in their regular clothing and once with the full set of wearable forms on their bodies, over their clothing. The activities are walking, carrying a box, bending, squatting to lift a box, reaching, climbing, and sitting. Subjects are asked to rate their freedom of movement and comfort levels during each activity and for each area of their bodies. This study has thus far been successful and informative. Preliminary analysis of the data indicates that levels of comfort and freedom of movement appear nearly identical with or without the pods. More interesting than the data has been the subjects' comments; both from the standpoint of testing the wearability of these forms and from the standpoint of studying peoples' personal relationships with their wearables.

Below are some initial and final reaction quotes from test subjects wearing all 36 of the dynamic wearable forms:

"I feel pretty comfortable and secure, not hi–tech but sporty"

"feels like a bullet proof unit"

"I feel like a catcher"

"Football uniform, save the shoulder pads"

"Physically pretty comfortable, not very restrictive. I knew they were on"

"I feel more stable, like with a brace or support, this lends stability to the joints"

" Feels positively supportive, like the difference between awareness and constriction"

"Its not scary like blood pressure, it feels like a costume or sports gear, activity oriented"

"I can even cross my legs with these on"

"Everything that I am wearing I would consider very comfortable"

Each of the forms worn by the test subjects was developed by applying design guidelines and follows a simple pattern for ensuring wearability. Beginning with **placement** in acceptable areas and the humanistic **form language**, we then considered **human movement** in each individual area. Each area is unique and some study of the muscle and bone structure is required along with common movement. **Perception of size** was also studied for each individual area. The general principles for **size variations** were applied and customized for each unique area.

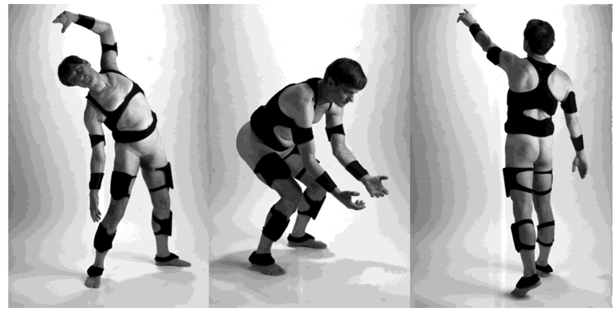
The **attachment** system designed for testing with the forms was minimal spandex that stretched around the body. Spandex pockets held each of the forms close to the body. The image below depicts the attachment system on our model.

One additional constraint we gave ourselves in developing these pods was that they must be able to house electronic componentry. As a result, all of the forms are between 3/8” and 1” thick and we anticipate that flexible circuits could fit comfortably into the 1/4” thick flex zones.

Descriptions of each of the dynamic wearable forms with photos, charts and maps of the body and the unique details of the individual areas are too extensive to list here. This paper will detail the neck area to illustrate the work. The full set of extended descriptions can be found on our web site, listed at the top of this paper.

Dynamic Wearable Forms Around the Neck

We refer to the three dimensional forms we developed as “pods”, a group of pods strung together are “pod sets”. Around the neck there is a pod set consisting of four pods. Two pods rest on the front of the body and two on the back. Each individual pod is made up of three parts: two thin solid forms with a flexible material sandwiched between them. The flexible material extends beyond the solid pod structure, serving as a flex zone. On the neck the flex zone creates a collar that encircles the neck and connects all four pods. The two pods on the front of the body sit just below the



collar bone, on the pectoral muscle and above the breast. The two pods on the back of the body sit on the large triangular muscle that connects the shoulders to the neck , the trapezius. Placement of

four neck pods allows for all movement of the shoulders arms and head . The flex zone connecting these four pods flexes to accommodate the various different torso depths and chest and trapezius arcs.

Pods on the chest follow the curves defined by the first and second ribs below the collar bone. The trapezius pods have a top profile determined by the curve where the neck meets the shoulders and a bottom profile determined by the movement space for the shoulder blades and the spine.

These pods on the shoulder area are designed to move and float over the movement of the trapezes (shrugged shoulders). The pods on the chest extend 1/2 inch off the body and are four by two inches. The pods on the shoulder extend 3/4 inch off the body and are 2.3 by 3.4 inches.
The neck and chest pods are contained in a collar that encircles the neck and holds them in place. These pods can also be attached by containing them in a minimal vest structure that supports pods on the rest of the torso.

Next Steps

We intend to continue refining these dynamic wearable forms through testing and create a dynamic human factors guide for designing comfortable, manageable, and unobtrusive wearable products that integrate with the body in motion. The initial results of our Design for Wearability Project, Design Guidelines and Wearable Forms begin to instruct and define wearability. We intend to use these as a tool and reference document and hope that others concerned with the creation of wearables will do the same. By making dynamic wearability constraints explicit, we hope designers will treat wearability requirements as concretely as technological constraints, and match them to users' functional requirements in the early stages of the design process.

We plan to extend our research to include accessibility for different activities, weight distribution, thermal concerns, interaction issues, material preferences, and long term effects to the body while using these wearables.

CONCLUSION

• Static, anthropometric data exists, however, dynamic understanding and measurements of the human body do not. We have collected information that has aided us in our development of wearable systems. This Design for Wearability Study represents a start at putting this information together, organized, in one place, to be useful as a set of guidelines and a resource for designers that need to integrate issues of wearability into a design.

• Our design guidelines illustrate steps to take into consideration when designing something to exist on the human body. This set of guidelines presents a method of thinking about and understanding a wearable and its' wear-ability.

• Wearable technology should not compromise but enhance people. It is possible to create a wearable piece of digital technology that feels good. Design for wearability and the wearable forms provide both proof and process for this.

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