WEARABLE TECHNOLOGY DESIGNER’S WEB TOOL DESIGN AND ACCESSIBILITY CONSIDERATIONS

GPS Clothing

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[178, 179]

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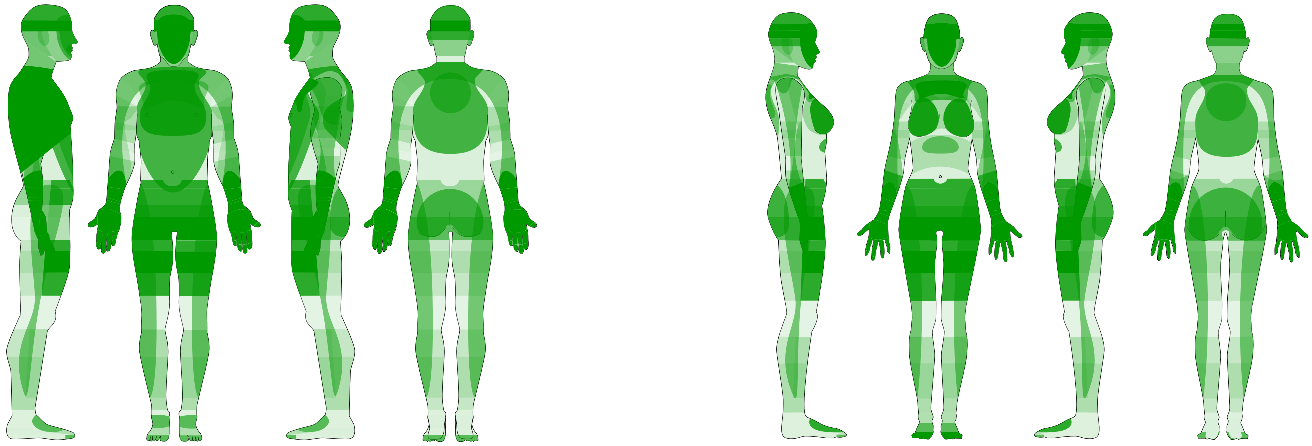
Contents

1 BODY MAP

This Body Map was created from your responses to the questions asked about your project idea. The stronger the green the more appropriate it would be to place your wearable on these areas of the body. Of course this does not mean that these are the only places you could place your wearable device.



2 DESIGN AND ACCESSIBILITY CONSIDERATIONS

Design Considerations are key points a designer should think about at the beginning of their project to point them towards a successful outcome. The considerations listed here are broken down by category. The Design Considerations listed here directly correlate to your answers to the questions in the web tool. Many of these considerations are derived from human factors and physiology.

Accessibility Considerations are also listed by category, any designer should think about the diversity of people who will use or wear their product. It is paramount that accessibility be considered at the outset of a project and kept in mind during all design and engineering decisions.

3 SENSING AND INPUT

3.1 MOVEMENT SENSING

Capturing the movement of the body through space and the movement of specific body parts relative to the rest of the body is the driving motivation behind many wearable technology devices [14, 79]. The general public's interest in fitness tracking by means of body movement and step counting launched companies like Fitbit into household names. While complex algorithms have made it possible to capture some body movement information without respect to the location of the sensor on the body, more precise readings can come from planning on-body sensor location, placement, and attachment.

In their "Review of accelerometry-based wearable motion detectors," Yang and Hsu also discuss placement of devices [173].

"Wearable activity sensors can be placed on different parts of a human body whose movements are being studied. In many cases, it is necessary to measure the whole-body movement. Therefore, the sensors are commonly placed on the sternum [108], lower back [98], and waist [75]. Most studies adopted waist-placement for motion sensors because of the fact that the waist is close to the center of mass of a whole human body, and the torso occupies the most mass of a human body. This implies that the accelerations measured by a single sensor at this location can better represent the major human motion." [173]

This approach to sensor placement to capture movement seems logical. Sensors placed near the center of mass will be able to tell whole-body acceleration, walking/steps/running, and even posture [42, 75, 138, 172], while sensors placed on the arms and legs will be able to tell movement of the limbs. Accelerometers and Gyroscopes placed on the head might be able to tell balance, head tilt or head turning. Magnetometers placed at the chest can tell the direction a person is moving relative to the earth North/South/East/West.

3.1.1 MOVEMENT SENSOR TYPES

- Accelerometer sensor– A sensor that measures acceleration [3]
- Gyroscope sensor- A sensor that measures rotation [8]
- Bend/Flex Sensor – "The resistance of the flex sensor increases as the body of the component bends" [6]

- Stretch Sensor - “Measuring stretch forces isn’t easy - unless you have some conductive rubber cord! This cord is 2mm diameter, and 1 meter long, made of carbon-black impregnated rubber. Usually this material is used for EMF gasketing, but it is also very fun to play with.” [5]
- Force Sensor – “Force-sensitive resistor’s (FSR) are easy-to-use sensors designed for measuring the presence and relative magnitude of localized physical pressure.” [7]
- Magnetometer – “This sensor allows you to quickly detect surrounding magnetic fields. This data can be used to create a digital compass or even sense strong magnetic fields from transformers.” [9]
- Barometric Pressure Sensor – “Barometric pressure sensors measure the absolute pressure of the air around them. This pressure varies with both the weather and altitude. Depending on how you interpret the data, you can monitor changes in the weather, measure altitude, or any other tasks that require an accurate pressure reading.” [4]

3.1.6 SENSOR ATTACHMENT TO BODY

Yang and Hsu also discuss types of attachment of devices to the body.

“Another consideration for sensor placement is how to attach sensors to the human body. Wearable sensors can be directly attached to the skin [75, 108], or with some form of indirect attachment by using straps, pant belts and wristbands, or other accessories [86, 100, 101, 116]. Sensors and wearable devices can also be integrated into clothing [113]. In principal, the accelerometers or motion sensors should be securely fitted and attached to the human body in order to prevent relative motion between the sensors and the parts of the human body. Loose attachment or unsecured fit causes vibration and displacement of the wearable systems, and this is liable to produce extraneous signal artifacts and to degrade sensing accuracy.” [172, 174]

3.1.7 MOVEMENT SENSING CONSIDERATIONS

DESIGN CONSIDERATIONS

- If trying to capture whole body motion, accelerometers, gyroscopes, and magnetometers should be placed close to the center of gravity on the chest.
- If trying to capture motion of limbs, accelerometers and gyroscopes can be placed on the limbs. Combinations of sensors in lower and upper limb configurations can aid in more defined movement capture (such as bending of joints, and gate).
- If trying to capture motion with respect to the environment, magnetometers (for direction) and barometric pressure sensors (for elevation change) may be used.

- Bend / Flex sensors can be used to determine joint bends and degree of bending. These sensors should be placed across the joint so the movement of the joint cause the sensor to bend. Bend / Flex sensors are often used in gloves to detect finger movement as well as in sleeves to detect elbow movement.
- Stretch sensors can be used in the same way as bend sensors. When sewn into form fitting garments properly, stretch sensors can give most of the same information bend sensors can, without the added rigidity from the sensor housing.
- Force sensors are often used in shoe applications to detect steps and also a number of other movements by detecting the force placed on different parts of the foot. Force sensors placed in glove fingertips can tell tapping and pressing. This information combined with other sensing information can give a very complete picture of body movement.

ACCESSIBILITY CONSIDERATIONS

- On-body motion/movement sensors can be a great noninvasive way to monitor someone who has a disability or is "aging in place." Because the movement sensing can be complete and complex, but also can be done without respect to location there is a level of privacy.
- Depending on body-placement of the movement sensors whole body motion, or specific body motion can be obtained. If monitoring someone for mobility a whole body movement sensor placed at the chest might be used to see if an aging person is "getting around". If a person is in rehabilitation from knee surgery, perhaps a movement sensor might be used to see if they are complying with their exercises.

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4 DISPLAY AND OUTPUT

4.1 HAPTIC OR VIBRATION OUTPUT

Many wearable devices use tangible feedback, or haptic feedback through the use of vibration motors, and sometimes other means such at electrical stimulation [48]. "Active touch refers to the exploratory action of touching, whereas passive touch describes a stimulation of the skin brought about by some outside agent [53]."[117] This vibration can be felt better on some locations on the body than others. If more than one tactor (or haptic stimulator) is used to create a pattern, it is also helpful to understand the body's sensitivity to "just noticeable difference" or how close stimuli can be to each other and still be detected as separate stimuli. A popular test to determine each individual's level of skin sensitivity to passive touch is the "two point discrimination test” [110]. Knowing the level of sensitivity local to each area of the body can help designers develop meaningful haptic stimulations.

Mancini et al. [92] have a great overview of whole body two point discrimination data. Understanding the body’s level of sensation can have major impact on the choice of body-location for wearable devices using haptic feedback, or haptic displays. Schiffman’s text book “Sensation and Perception” also does a great job of explaining skin sensations [132]

Aside from sensitivity with regards to on-body location there are other factors to consider when designing wearable devices with haptic feedback. Vibration stimuli have “extra parameters” including rhythm, roughness, intensity, and frequency that can all be altered to aid in correct vibro-tactile display designs [24]. Pasquero outlines some of these factors in his “Survey on Communication Through Touch” [117].

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- Masking is a phenomenon by which the performance at identifying a target stimulus is decreased by the prior or subsequent presentation of a masker stimulus [33, 35, 36, 37]. To reduce the undesirable effects of temporal masking, Craig suggests increasing the interval between two successive stimuli. On the other hand, he also notes that this can only result in lower rates of tactile communication since masking is related to the time interval between the onsets of the target and masker. Similarly, increasing the spatial distance between the masker and the target, such as displaying them on two different fingers, will likely decrease the effects of masking; however, it will also introduce undesired outcomes due to the extra attentional load imposed by having to concentrate on both stimulation sites simultaneously.
- Vibro-tactile adaptation, or the tendency for sensitivity to decline with prior exposure to a vibratory stimulation above threshold, is yet another example of tactile interaction. Adaptation is clearly reported by a handful of psychophysical experiments that either found an increase of the sensitivity threshold or a decrease of the perceived intensity following the exposure to a conditioning vibro-tactile stimulus [21, 160, 161]. Fortunately, the effect is not permanent and proper time gaps between the conditioning stimulus and the target can avoid it all together. Accumulated evidence suggests that neural adaptation takes place both at the mechanoreceptors level (i.e., expressed by a decrease in firing rates), and at higher perceptual levels [21].
- Vibro-tactile enhancement is well-reported time interaction with an effect that is opposite to that of adaptation [52, 160]. It is expressed by an increase in the magnitude estimation

of a vibro-tactile target stimulus following the presentation of a conditioning stimulus with significantly higher magnitude.
- The tactile equivalent of visual change blindness has also been recently observed with vibro-tactile stimuli [47, 46]. Change blindness is manifested by the failure to detect change in a tactile

” [117]

The Contextual Computing Group at the Georgia Institute of Technology has shown how the use of vibro-tactile motors through a combination of body placement (on the hand) and vibration styles and techniques and work quite effectively as a passive haptic learning tool [68, 94]. This is akin to haptic guidance for training motor skill, but is completed passively rather than actively [44]. Markow found that through the use of the wearable vibro-tactile passive learning piano gloves in the Mobile Music Touch project, spinal injury patients were able to advance their rehabilitation (gaining more feeling and dexterity after they otherwise would have stopped improving). Seim picked up the Mobile Music Touch project and began researching the best way to use the technique for teach braille typing [137, 134, 135, 136]. Seim describes the process for determining where to place the vibrating tactors and how to display multiple vibrations near each other on the hand through a wave pattern of vibration [136]. She also describes what she found as the usefulness of LRA to ERM vibration motors.

Haptics are also beneficial in proprioceptive display to make touch based interfaces more useful without visual attention [181].

4.1.1 TYPES OF HAPTIC STIMULATORS

- ERM Eccentric Rotating Mass Vibration Motors – The intensity of vibration is tied to the frequency of vibration. [1]
- LRA Linear Resonant Actuator ‘Vibration Motor’ – The intensity of vibration is not tied to the frequency, but intensity can be controlled more precisely and thus LRAs are very useful for haptic applications. [2]
- Electro-tactile / Electrical Stimulation – Electricity can also be used in low voltage to create the sensation of vibration by activating the muscles under the stimulator. This requires very good conductive connection with the skin, as the voltage needed from a resistive connection can cause the pain threshold to be met before the electricity is felt as a vibration.[80, 82]

In many vibrotactile displays the forearm seems to be a desired location, but the sensitivity of the forearm does not allow for very precise display [112]. Designs and evaluations have also been conducted for vibro-tactile displays placed on the shoulders [157].

4.1.2 HAPTIC OR VIBRATION OUTPUT CONSIDERATIONS

DESIGN CONSIDERATIONS

- When designing haptic displays for wearable devices, the sensitivity of the on-body location where the wearable is placed is very important.
- Vibrotactile displays should be programed to account for masking and vibrotactile adaptation.

ACCESSIBILITY CONSIDERATIONS

- Tangible/Haptic Feedback is an important part of a multimodal display system. Multimodal feedback is important; designers need to create wearable devices that can prompt users with a variety of different abilities. Vibration and haptic alerts can aid those with visual impairments when acoustic feedback is inappropriate.
- Vibration and haptic feedback have been seen to provide added benefit in rehabilitation of injuries (such as spinal injuries) where sensation has been degraded. Mobile Music Touch has shown that rehabilitation with the vibrating piano gloves not only taught participants to play piano, but also improved their sensation and dexterity [94].

4.2 AUDIO OUTPUT

Audio Output in wearable technology can be very important. In fact some of the most used wearable systems are for and enabled by audio output (smart headphones and in ear speakers for music).

Wearable projects like System for Wearable Audio Navigation SWAN explore a deeper understanding of how audio output might be used for more robust real time information display [169].

One type of hardware to consider are Bone Conducting Headphones. These types of audio displays are used in the SAWN system, but are also used in Google Glass. The advantage of such systems is that when used they do not occlude the ear and thus allow users to still hear their surroundings [162].

4.2.1 AUDIO OUTPUT CONSIDERATIONS

DESIGN CONSIDERATIONS

- Consider Bone Conducting Headphones for audio output when creating head mounted displays or other devices meant to be worn for extended periods during daily activities.

ACCESSIBILITY CONSIDERATIONS

- Consider that some people may have difficulty hearing audio output. There is literature pointing to frequencies and volumes which might aid in those with hearing loss to be able to better hear an interface [66, 123].

ADA Guidelines for Assistive Listening Systems Include [12] :

- Assistive listening systems shall be capable of providing a sound pressure level of 110 dB minimum and 118 dB maximum with a dynamic range on the volume control of 50 dB.
- The signal-to-noise ratio for internally generated noise in assistive listening systems shall be 18 dB minimum.
- Peak clipping shall not exceed 18 dB of clipping relative to the peaks of speech.

4.3 VISUAL OUTPUT

When designing a wearable device with a visual display, it is important to consider where a person can see visual feedback emitting from the body most effectively.

Chris Harrison developed such a study to find out where to locate wearable displays [62]. Participants wore devices with LED lights and were asked to press the button on the device when the LED blinked. The devices were placed in seven different body locations to see if reaction time would change depending on where the light was signaled.

Harrison furthered his work in on-body visual displays with OmniTouch [61] and other projects [63], using the body as a projection surface. The projection surface he uses is the hand and wrist, which seems obvious given his findings in on-body visual cue reaction time.

The body map for visible body areas from a first person perspective also takes into account Harrison's reaction times; therefore, the map is more representative of where a designer should locate a wearable visual display rather than just locations where a user can see it.

For individuals who may be losing vision it is important to provide a range of font sizes within interface displays. It is also important to follow design guidelines for color choices within interfaces that are easier to read and see for individuals with color blindness.

4.3.1 VISUAL OUTPUT CONSIDERATIONS

DESIGN CONSIDERATIONS

- When designing a wearable device with a display or visual signal, it is important that the device be placed on a part of the body where the display can be seen, and also a place on the body where it will be noticed easily.

ACCESSIBILITY CONSIDERATIONS

- Visual displays should be accompanied by non-visual signals for those with visual impairments.
- The visibility of on-body locations might change from person to person depending on their mobility and means of mobility. Wheelchairs or other mobility devices might occlude some on-body locations which would otherwise be acceptable for a visual display.
- Font size within interfaces should have an accessibly large font choice for those with vision impairment.
- Color choices and contrasts within interfaces should be chosen to work well for individuals with color blindness.

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5 HUMAN FACTORS AND BODY MECHANICS

5.1 PROXEMICS & PERSONAL SPACE

Proxemics becomes important for the on-body location of wearable technology when the size of the items being placed on the body exceed the body's natural understanding of its perceived size. Humans naturally have a slightly enlarged sense of their size to help them navigate the world without bumping into obstacles around them. When a young football player first puts on shoulder pads and bumps into the door on the way out to practice, this is a great example of a wearable object's size reaching beyond the body's perceived size. The distance from our actual skin we still perceive to be our size differs on different parts of the body. A designer might be able to place a larger object on the waist than on the wrist and it still feel natural to the wearer.

The concept of self-size awareness might not be as important as other design guidelines because from casual observation it seems that humans can adjust their self-size awareness. A person with a huge diamond ring might snag the ring as they reach into pockets or bags at first, but over time they account for it. The value of the ring is more important than the initial change in self-size awareness. The same might be true for a person who needs the use of a wheel chair, navigating the world incorporating the extension of the chair into ones self-size. However, if designers are to create wearable technology for the general public striving for Weiser's [167] idea of seamless, or invisible computing, then containing the shape of wearable tech within the aura of self-awareness might be a good start.

Figure 6: Symbol Ring Scanner (photo by Maria Wong Sala)

A great example of proxemics becoming a design issue is the development process for the Symbol Ring Scanner [149] used to scan boxes in a shipping hub. Because the device (see figure 4) extended beyond the self-perceived size of wrist / lower arm the key pad housing constantly rubbed against corrugated boxes during trial use in a shipping center. Constant abrasion caused the softer abs plastic to rub away and expose the internal electronics. Because of this, the whole system had to be 'ruggedized' for normal wear and tear. This could have been avoided if the device were smaller and within the user's proxemics (at the time this device was built, technology would have prevented this).

Gemperle talks about proxemics as a consideration for "Design for Wearability" [51], and Edward T. Hall discusses large aspect of humans' relationship to the space around them in The Hidden Dimension [58]. Gemperle uses Hall's definition of intimate space at 0-5 inches to develop an aura around the body of self-perceived size. Here we use the clothing corrections guide from Henry Dreyfuss Associates "The Measure Of Man and Woman" as a proxemics minimum guide as most humans wear clothing [156].

5.1.1 PROXEMICS AND PERSONAL SPACE CONSIDERATIONS

DESIGN CONSIDERATIONS

- If a wearable device or garment extends beyond the wearer's self-perceived body size, then the device or garment will obstruct natural movement within the environment. There will be a period of adjustment (through continued use) before the wearable device is incorporated into a person's perceived size of self.
- Some parts of the body can accommodate larger wearable devices without the protrusion from the body extending beyond a person's perceived size of self.

ACCESSIBILITY CONSIDERATIONS

- Someone with a body limitation that requires the use of a wheel chair (or other assistive device) may have a much different self-perceived size that would include their assistive device and normal posture.
- Attachments to a required assistive device will also affect proxemics, and should be viewed as a "wearable."

5.2 WEIGHT DISTRIBUTION

Today most wearable devices can be made very lightweight; however, the amount of weight we can wear, the balance of that weight, and the comfort of carrying the weight will surely affect the success of any wearable device.

As a general rule we can start with Gemperle's advice: "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." [51]

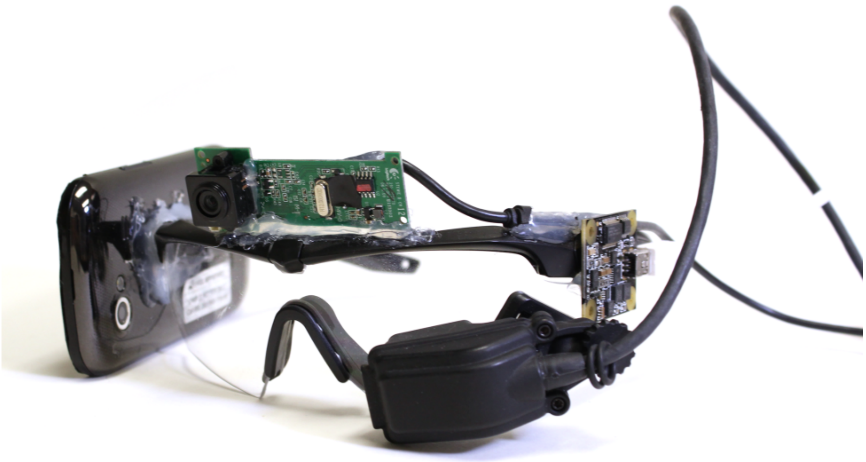

Figure 7: Google Glass Pack Prototype (photo by Maria Wong Sala)

When designing the original beta Google Glass (a head mounted display /wearable computer), designers and engineers focused first on what types of features would make the device useful [182]. Early prototypes rapidly created were somewhat heavy (figure 5) and hard to wear all day [153]. As the team worked and because of the importance of weight and comfort a separate but parallel prototype called 'Lennon' developed (figure X). The Lennon prototype started with a set maximum weight that the team believed a user would wear comfortably all day (45 grams), and only added features up to that weight. Lennon was the first Google Glass prototype that could be worn on the head all day without undue fatigue.

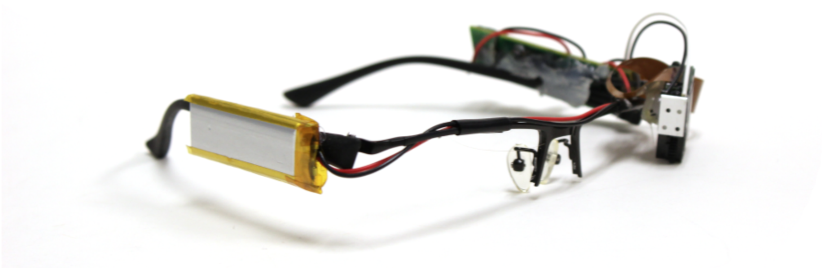

Figure 8: Google Glass Lennon Prototype. (photo by Maria Wong Sala)

Weight of wearable objects matters, and heavier items can be carried by the body better in some locations than others. Watkins details how Scribano, Burns, and Baron were tasked with developing a system in the 1970's for finding load thresholds for discomfort in aiding to design body armor for the US Army [133, 165]. In doing so, they also described the weight thresholds for discomfort for the torso of a male.

"In general, the army found that the fleshy parts of the body were more able to tolerate the pressure of weight than the bony ones, and that pressure on major nerves, arteries, and veins, particularly those that supply the brain, can affect coordination, and produce fatigue." [165]

5.2.1 WEIGHT DISTRIBUTION CONSIDERATIONS

DESIGN CONSIDERATIONS

- Weight, load, or the pressure of weight should be placed on the fleshy but non-sensitive parts of the body, avoiding boney areas.
- The lower waist is a good area for heavy loads.
- Weight should be balanced across the body evenly, and aligned to the center of gravity is possible.
- Heavy items should not be placed on the body's extremities for long periods of time.
- Batteries for a wearable device tend to be the source of most of the weight. If a device needs a large battery (to last a long time or because it needs large amounts of power to function), place the large battery on the waist. If the wearable needs to be located on a different part of the body for use then consider distributing the power from the area of use. Finally consider distributing battery cells instead of using one large battery.
- From a design perspective, weight also has a visceral quality. Density or heaviness compared to size in combination with other material aspects such as metallic textures are perceived to be luxurious. Donald Norman explains, "Physical objects have weight, texture, and surface. Physical feel matters. We are after all, biological creatures, with physical bodies, arms, and legs." [111] Use weight where appropriate to create a positive experience with the wearable technology object or garment.

ACCESSIBILITY CONSIDERATIONS

- Watkins states: "One aspect of Load Analysis to consider is that even though these tests provide data on pressure levels, not all individuals or areas of the body respond in the same way to pressure. Age, sex, medical conditions and other factors may affect the way in which pressure affects mobility." [165]
- Of course it is easy to assume that designers want the most light weight wearable technology anyway, but it is also good to remember that being light weight can make the wearable technology useful to broader communities (elderly, arthritic patients, children, etc.)

5.5 NETWORKING ON AND FROM THE BODY

In 2001 Thad Starner listed Networking as one of the major challenges for Wearable Computing: "For wearable computers, networking involves communication off body to the fixed network, on body among devices, and near body with objects near the user. Each of these three network types requires different design decisions. Designers must also consider possible interference between the networks.” [146]

When considering on-body location, designers need to consider the location of the antenna that communicates with the off-body fixed network. The mass (water/muscle/tissue) of the body can block many of the lower powered high frequency wireless network signals we use for communication [59]. At a higher power, such frequencies could have the potential to cause tissue damage, which is unacceptable for wearable devices. “Wireless Body Area Networks WBANs experience high path loss due to body absorption that must be minimized through heterogeneous and multi-hop links with different types of sensors at various locations. Additionally, change in operational conditions may lead to error-prone and incomplete sensor data relative to inherent sensor limitation, human postures and motions, sensor breakdown and interference” [106]. There is a balance, and many people have researched the application of WBANs for medical and other wearable sensing systems [60, 118, 158].

The following tables (Table 2 and Table 3) from Patel et al’s 2010 work can be very useful in understanding wireless network options with respect to wearable technology.

“Properties of potential frequency bands for BAN” from [118]

Frequency (MHz)	Acronym	Suitability to BAN applications	
		Merits	**Demerits**
401-406	MedRadio	Worldwide availability, good propagation characteristics, quiet channel, medical only	Secondary usage, body-worn applications not allowed in 402-405MHz core band, large antenna size, limited bandwidth, stringent rules.
433.05-434.79	General Telemetry	Good Propagation characteristics	EU/AU/NZ/SA only, crowded spectrum, large antenna, limited bandwidth
608-614 1395-1400 1427-1432	WMTS	Good Propagation characteristics, medical only	Licensed secondary use limited to healthcare providers inside healthcare facilities in US, limited spectrum, heavily used
868-870	General Telemetry	Good Propagation characteristics	EU only, limited spectrum, heavily used
901-928	ISM	Good Propagation	US/Canada only, crowded spectrum

		characteristics	
2400-2483.5 (2400-2500)	ISM	Worldwide availability, small antenna, large bandwidth	Crowded spectrum, many standards and technologies
5725-5850	ISM	Worldwide availability, small antenna, large bandwidth	Existing standard and technologies, severe attenuation
4200-4800 7250-8500	UWB	Worldwide availability, short range, low power, huge bandwidth	Coexistence with high data rate multimedia applications, severe attenuation

“Characteristics of candidate technologies for BAN” from [118]

Technology	Spectrum	Modulation	Channels	Data Rate	Operating space	Peak power	nj/b	Topology	Join time
Bluetooth classic	2.4 GHz	GFSK	79	1-3Mb/s	1-10 m on-body only	45mA @3.3V	50	Scatternet	3 s
Bluetooth Low Energy	2.4 GHz	GFSK	3	1Mb/s	1-10 m on-body only	28mA @3.3V	92	Piconet star	¡ 100 ms
ZigBee	2.4 GHz	O-QPSK	16	250kb/s	1-100 m on-body only	16.5mA @1.8V	119	Star, Mesh	30 ms
ANT	2.4 GHz	GFSK	125	1Mb/s	1-30 m on-body only	22mA @3.3V	73	Star, tree, or Mesh	
Sensium	868 MHz 915 MHz	BFSK	16	50kb/s	1-5 m on-body only	3mA @1.2V	72	Star	¡ 3 s
Zarlink ZL70101	402-405 MHz 433-434 MHz	2FSK/4FSK	10 MedRadio, 2 ISM	200-800 kb/s	2 m in-body only	5mA @3.3V	21	P2P	¡ 2 s

5.5.1 NETWORKING ON AND FROM THE BODY CONSIDERATIONS

DESIGN CONSIDERATIONS

- Antennas for wearable devices should be placed on the periphery of the body to have the best chance of having an unobstructed (by the body) connection to the fixed off-body network. This could mean the outer arms, shoulders or the head. Because of the strength and abundance of fixed off-body wireless network signal, this is not as much of a problem as it would have been in 2001.

- Body Area Networked devices using low powered wireless connections between devices on the body should also try to avoid obstruction by the body between devices. If one device on the front torso for example needs to wirelessly communicate via low powered signal to a device on the back, a third relay might be needed on the side of the body.
- All body mass compositions are unique. Outside of the general guidelines, wearable systems using wireless communication should be tested thoroughly on a variety of people and in a variety of settings.

ACCESSIBILITY CONSIDERATIONS

- Health monitors or wearable sensing devices use Body Area Networks. Some people might have many different monitors all using different frequencies. It is important when designing a new device that it does not interfere with wearable health devices such as heart monitors or pace makers. It is also important that it does not interfere with wireless hearing aids and other assistive devices. Adding a new signal to a series of signals requires some standards, research, and testing.

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6 SOCIAL ACCEPTABILITY

6.1 SOCIAL ACCEPTABILITY OF ON-BODY INTERACTION

A Wearable product can function perfectly, but if a wearer feels socially awkward using the device, then the technology will become a failure. This is even true among health and medical devices. Wearable technology has to be socially acceptable. How people present themselves to society is a huge part of a person's identity, and is also how others are able to relate to them. Goffman would say that it is the presentation of ourselves that gives others cues as to how to interact with us [56]. He goes on to explain that most people take this inferential information as a fact of whom one is and act accordingly: "The others find, then, that the individual has informed them as to what is and as to what they ought to see as the 'is'," [56]. In 1999, Starner et al. found that wearable computers or wearable technology in general was viewed by others (interpreted by others) to be medical devices [148].

Use of wearable technology and body placement has a great deal to do with the social acceptability of a wearable system [77]. Google Glass had an issue with its beta release because of public misunderstanding about the forward facing HUD camera [182]. This lead to a difficult release even though designers had factored in privacy by design, and there are a number of features on the device which alert the user to active filming. Other devices on the market can video and film with much more discretion, but the location of the camera on the face of the wearer (visible and noticeable during face to face social interactions) made the camera of Google Glass a touch point for discussions related to privacy [40].

The gestures and touches users make with wearable technology to interact and control devices can also cause uncomfortable situations. The placement of interactive textiles, interfaces, and the types of gestures used to control interfaces sensed through motion detection can make a wearer/user as well as bystanders feel awkward. "For wearable devices, the social perception and comfort of worn artifacts often extends beyond the "static" aesthetic variables of the artifact (worn on the body, but not interacted with) into the social aesthetics of interacting with a body-worn device," [41]. Profita et al. look specifically at body placement of interactive electronic textiles, and how third-party viewers deem interactions socially acceptable when placed on different parts of the body [124]. Given the information collected in these studies, I have developed a body map with regions of socially acceptable locations for wearable technology interaction and forward facing displays of technology.

6.1.1 SOCIAL ACCEPTABILITY CONSIDERATIONS

DESIGN CONSIDERATIONS

- Body placement of wearable technology can drastically affect the social acceptability of the wearable device. In general, avoid touch-based interactions and displays within regions of the body associated with sex or elimination of body waste. An exception would be if the wearable device is specifically designed to aid in sexual stimulation.
- In general, it is also advisable to avoid the breast and an interaction location for wearable technology (except for wearable devices specific to cis-gender males, but there are still more socially acceptable places on the body which could work better). An exception would be products designed to work with the breast (e.g. a breast milk pump).

ACCESSIBILITY CONSIDERATIONS

- Sometimes users want assistive technology to be conspicuous so that others know about their needs. Other times users want assistive technology to be inconspicuous so they can go about their daily life without a disability being the focus. Designers should work with

users to allow for wearing technology in ways that can throttle the visibility of wearable assistive technology.
- Wearable assistive technology should conform to the same social acceptability standards as other wearable technology. Assistive devices do not have to look like medical devices.

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7 CONSTRUCTION MATERIALS AND METHODS

7.1 GARMENT CONSTRUCTION

Understanding just a little bit about how garments are designed and constructed can aid tremendously in designing wearable technology, especially if it is to be integrated into clothing. This knowledge can help in making decisions about sensor location and the location of wired connections to a component placed across the body. Conversely, if a sensor needs to be placed on a specific body part, the clothing pattern can be designed to accommodate for that [73, 74, 165, 166].

While most wired connections do not stretch, most fabric does extend. Wires for connections can also be heavier than the fabric that supports them (this is especially true for light weight fabrics). These characteristics, along with the addition of rigid components, cause the hand of the fabric and the drape of a garment to alter in unwanted ways. If a garment has stretch, it is usually around the body horizontally. Designers should avoid horizontal wires connecting components and instead opt for vertical or diagonal traces. Seams are where fabric panels are sewn together to create a garment. Because seams are an edge condition and have double fabric, they are the perfect place to incorporate leads and wires if necessary. Some seams are sewn horizontal across the body and these are a better place to put horizontal traces. However, some seams are sewn in a specific way to allow stretch, so a designer should pay attention to if the fabric is a knit (stretchy) or woven (tend to not stretch) and if elastic is used to create a stretch seam. Fabric holds its own weight when cut and sewn into a garment. If components are to be sewn onto the fabric, its important to pick a fabric which can hold these components appropriately, both for function and for the aesthetic appeal and drape of the garment. Sometimes wires and leads can be used to support the weight of components if drape is considered during the garment design process.

Some textile manipulation techniques can lend themselves to fabric interfaces [171], and some couture sewing techniques might sometimes be used for the hand work necessary in creating some wearable technology [140]. Many times the type of fabric manipulation used in creating an interface might work better on some parts of the body than others.

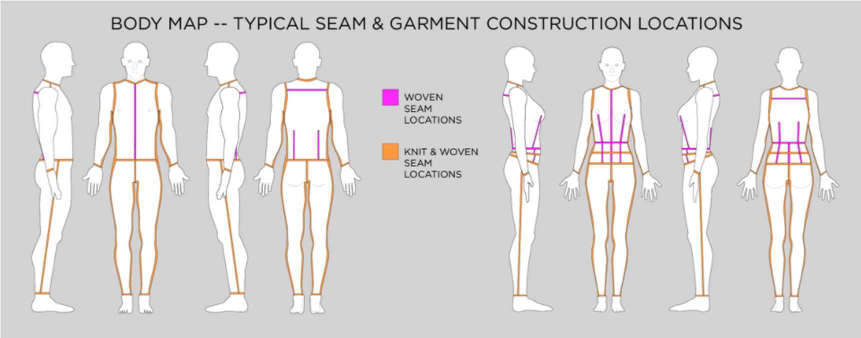

Figure 9: Typical Seam Locations and Other Garment Construction Locations

7.1.1 GARMENT CONSTRUCTION CONSIDERATIONS

DESIGN CONSIDERATIONS

- Wires and leads should be incorporated into seams when possible.
- Wires and leads should almost always run vertical (up and down) the body and not horizontal (around) the body.
- Look to fabric manipulation, old world textile techniques, and couture sewing techniques as inspiration for designing electronic textile fabric interfaces and sensors.

ACCESSIBILITY CONSIDERATIONS

- Some garments are specifically designed to be donned and doffed by people with mobility issues [165, 166]. Designing wearable systems for incorporation with these garments should follow the same strategies as any other garment. However, if redesigning seams and closures to afford the wearable technology incorporation, it is important not to impede the donning and doffing functionality of the accessible garment.

RESOURCES

- Coming Soon

7.2 ELECTRONIC TEXTILES

Incorporating electronics into textiles can happen on many different levels. Many who work in wearable technology endeavor towards creating fabrics that have technology and sensing woven or knitted into the textile. Currently this may take the form of applying sensors and electronics to a fabric in a way to cause the least amount of change in the drape and texture of the textile [25, 26, 104]. It might also mean designing wearable technology sensing systems utilizing conductive and insulative properties of the materials used to create certain textiles [23, 54, 121, 128, 180]. Some material scientists work on creating new materials that might enable more interactive and technology enabled fabrics [122].

7.2.1 ELECTRONIC TEXTILE CONSIDERATIONS

DESIGN CONSIDERATIONS

- When designing embroideries take care to make sure conductive thread leads do not cross and short.
- Tensioning on sewing machine and embroidery machines may need constant adjustments.
- Keep conductive thread in sealed bags with silver saver paper to prevent oxidization which can cause problems with machine tension and conductivity.
- Any elements (sensor displays) attached to the fabric via conductive thread will cause a change in the drape of the fabric, be strategic about placement so the finished product moves and wears well.

ACCESSIBILITY CONSIDERATIONS

- Use nonconductive thread to create textures that make feeling the interface easy. Nonconductive tread and yarn are can create shapes and non-visual aids to guide users to correct use of interfaces.
- Some users might have dryer skin than others or the same user may have dryer skin at some points of the day. Systems should be able to recalibrate capacitive sensitivity to accommodate for changes in weather and skin dryness.

RESOURCES

- **How To Get What You Want** by Hannah Perner-Wilson
- **High – Low Tech** by Leah Beuchley
- **Sparkfun e-textile tutorials**
- **Circuit Playground Express** for easy microcontroller and tutorials

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