Applying Universal Design Principles to Themes for Wearables

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Abstract. Wearable computing offers new opportunities for technology to help us in many different contexts. Yet, it is important that designers of wearable devices take into account Universal Design principles to ensure that as many people as possible can benefit. We discuss the possible advantages of applying universal design principles to different themes that wearable technologies address. We use six themes that are driving wearable enhancements. These themes cut across industry and use cases; most wearable technologies will use at least one of these themes. We take each of the universal design principles and see how they apply to each theme and what advantages can be expected from such an application. The study shows that a balance needs to be achieved to the accessibility, usability, and general use of a wearable device.

Keywords: Wearables · Wearable computing · Design · Universal design

1 Introduction

Wearables, also known as wearable computers, became widely known because of the popularity of activity trackers. A wearable is a fully functional, self-powered, self-contained computer that is worn on the body, providing access to and interaction with information anywhere and at anytime [1]. Wearables are not a new trend: experiments from the 1960 s [2] helped pave the way for wearables. According to BI Intelligence, the market of wearables has grown by 50 millions of units from 2010 to 2015 [3].

While wearable tracking devices are becoming popular, the problem of technology acceptance is still remains. According to Moti & Caine [4], more than half of U.S. consumers who have owned an activity tracker no longer use it. A third of U.S. consumers who have owned one stopped using the device within six months of receiving it. Moti & Caine argue that human factors need to be addressed during the early design stage of wearable applications. To accomplish this, we need to identify principles that are relevant for designing a human-centered wearable application. Moti & Caine propose a set of principles; other authors proposed their own design principles for wearables with different focus and degree of granularity [5–8].

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Instead of proposing our own framework, we examine the well-known and mature Universal Design (UD) principles, which were approved by community of designers during the last 17 years. We aim to understand what impact does Universal Design have to designing wearables?

We apply UD principles to themes that drive wearable enhancements instead of dividing the area of research to sectors, products, applications and functions [9]. First, the themes are general: they can drive design of wearables that do not exist today. Themes are good triggers that include the main motivation for a design. A theme is not limited to a specific application domain and one wearable device can be driven by several themes at once. For example, the same wearable may be used by someone to track their accuracy in performing an action, while another may use it to test the progression of rehabilitation. Since themes represent more general concepts, they can be separately examined on compliance with specific design approaches. The results of such examination can be then emphasized in the inherited domains and applications.

2 From the Internet of Everything to Wearables

The Internet of Everything (IoE) has its beginning in the Internet of Things (IoT). The Internet of Things was originally introduced as a concept for describing a world where RFID chips would be used for tracking different objects [10]. Though these chips were not on the Internet, their movement and exchanging of information among themselves mimicked exchange of data. It was a literal network of things. Yet, other definitions exist [11], and a more common understanding now is to think of an object or thing that is on the Internet, but not a traditional computer. For example, Busch et al. [12] present an idea for a medicine cabinet that can help people remember to take their medicine; it accomplishes this by keeping track of the pill boxes and knowing the medicine schedule for the person. Over time, radios and sensors have become smaller, and more things can contain them. It is now possible for a home to have many different devices that are using the Internet. The addition of objects and services using the Internet brings its own set of trust and UD issues [13].

As the popularity of the idea of the Internet of Things moved from beyond research into consumer consciousness, Cisco [14] introduced the idea of the IoE to highlight that only a small subset of things are connected to the Internet, and adding more objects would result in better use of data and connections. If wearable computing devices (or wearables) have some sort of connection and are able to talk to each different object, we have wearables as good candidates for making better use of data and connections.

Wearables allow people to do different types of computing in new contexts, basically wherever the person is, without having to involve the person's hands or another device. The idea behind wearables is to make making computers small enough and energy efficient enough so they can be used in different articles of clothing or other accessories. The most popular forms are items that can be put around your wrist, worn around the body, worn as eyeglasses, or something small that can fit into a pocket. Many of the current devices help in recording fitness data. Most of these devices do not offer a traditional interface as found on a PC. Many require little or no input from the wearer at all; all information is gathered automatically. The collected data is sent to servers where it is analyzed and interpreted by semantic engines. Others provide a voice-driven interface. Some of these devices do not have a direct connection to the Internet, but instead piggyback off another device (for example, connecting to a smartphone through Bluetooth and pushing heavy processing off to the phone).

Since wearables (like clothes) can be with us in multiple contexts, it makes sense to not categorize wearables by industry or product type, but to look at themes driving wearable enhancements. That is, what sort of goals or uses a person may have for a wearable. A wearable may also be composed of different themes, so it we don't have to be strict about where a wearable belongs. PSFK Labs [15] defines six themes:

- **Bio-Tech Fusion**: technologies quickly evolve by creating a closer relationship between wearable devices and the human body. Examples include wearable devices that a person will seldom remove such as medical devices or activity tracking.
- **Synced Lifestyle**: ability to sync with a broader ecosystem of connected technologies. Many of the current fitness tracking devices aim to make it easier to keep track of activity done during the day and synchronize it with different cloud services.
- **Organic Computing**: opening the door for a more natural form of communication and computing by introducing wider range of human inputs from gestures to biometrics; for example using touches and hugs to transmit affection and care between people, especially when they are separated by a great distance.
- **Human Enhancement**: appearance of assistive technologies that are capable of both restoring and augmenting existing senses and abilities. This can work for security and safety, for example, detecting hazardous substances to indicating security levels to being assistive technology for helping someone with a disability to be more independent.
- **Health Empowerment**: empowering people to take a more active role in the management of their personal well-being. This goes beyond your typical fitness tracking to also include helping keep track of a medical condition or helping someone regulate a disease.
- **Personalized Context**: situated within a given context, self-aware devices and platforms can facilitate connected experiences that deliver greater meaning and relevancy into people's lives. For example, devices and wearables communicating to reduce lighting and play calming music at the end of a stressful day.

3 Principles of Universal Design

There are several terms that are simultaneously used for description of design that intended to include as much as possible wide target audience: Universal Design, Exclusive Design, and Design for All. While all three have different origins and different ways of individual evolution, they have similar goals and concepts and often are used as interchangeable ones [16, 17].

The term *Universal Design* comes from U.S., where the moving force for design for disabled influenced by the demographic change of the aging population. The huge population of veterans from several wars increased this need. The origin of the

Universal Design concept was proposed by Ronald L. Mace [18], program director of The Center for Universal Design in Carolina University. As a wheelchair user himself, Mace was focused on issues of accessibility in buildings. In his book, Mace outlined distinction of universal design to other types of design for people with special needs: "While accessible or adaptable design requirements are specified by codes or standards for only some buildings and are aimed at benefiting only some people (those with mobility limitations), the universal design concept targets all people of all ages, sizes, and abilities and is applied to all buildings" [19, p. 3].

While Mace was the first researcher who defined UD concept, his works were influenced by early ideas of UK researcher Goldsmith, which were published in his book Designing for the Disabled [20]. Also a wheelchair user, Goldsmith had professional roots in architecture. His attention was focused on accessible buildings, e.g., public toilets for users with special needs, steps and stairs, and tactile pavings [17].

In 1998, Mace with his colleagues extended definitions and described in detail UD guidelines in book, *The Universal Design File*, where they first time defined seven principles applicable to environmental accessibility [21]. UD was defined in the book as the design of products and environments to be usable to the greatest extent possible by people of all ages and abilities. Titles and descriptions of seven UD principles are as shown in Table 1.

Table 1. Principles for Universal Design and their definitions

Principle	Description
Equitable Use	The design is useful and marketable to people with diverse abilities
Flexibility in Use	The design accommodates a wide range of individual preferences and abilities
Simple and Intuitive Use	Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level
Perceptible Information	The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities
Tolerance for Error	The design minimizes hazards and the adverse consequences of accidental or unintended actions
Low Physical Effort	The design can be used efficiently and comfortably and with a minimum of fatigue
Size and Space for Approach and Use	Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility

4 Applying UD Principles to Wearable Technologies

As Story et al. [22] suggested, besides educating designers and consumers about the characteristics of more usable products and environments, UD principles could be applied to *evaluate* existing designs and *guide* the design process.

Universal Design principles can be applied in different ways and to the different domains. There are three examples of applying of Simple and Intuitive principle proposed by Story:

- For architecture — methods of creating clear environmental way-finding features;
- For products — methods of applying the concepts of correspondence and cognitive mapping to user interfaces;
- For software — methods of supporting broadly accessible user interaction modes [23].

For the study where wearables are a subject of research both the second and third methods are relevant.

Why it is important to use UD principles? Developing countries have advantages over industrialized countries, as they can avoid mistakes that the industrialized countries have committed. For these countries, Balaram proposed four areas of design intervention, where UD principles can be applied [24]:

- *Educating for the future*: as fostering positive attitudes toward people with different abilities as part of their regular education in schools, colleges, and universities;
- *Positive thinking by user groups*: people with disabilities should be seen as people with *different* capabilities rather than people with lesser capabilities;
- ***Increasing the usability range***: universally designed products and environments can foster equality by adding universal features into usual products;
- *Bridging the gap between people*: there is a need for products that act as a bridge between different people and their needs, whether that difference is cultural or physical.

How do UD principles influence assistive technology? Designers who use UD principles [21] attempt to create solutions that are usable by as many people as possible instead of trying to create special solutions for a specific disability. As more services are being offered as digital-only, universal access and quality of use for the broadest possible user population is a requirement for citizens of an information society [25]. In this case, non-traditional interfaces can help people with disabilities live more independent and better lives or they can exclude them from any benefit and leave them as second-class citizens.

The importance of UD principles becomes apparent when taking a look at the flipside of things. Design can potentially become subject of abuse. According to Clarkson and Coleman, “we live in a world increasingly shaped by human intervention where design can enable or disable people” [17].

It is important to mention that the *Human Enhancement* theme has the same roots in accessibility as UD: UD and its close cousin, Accessible Design continue to gain popularity and their influence spreads; this causes society to change its collective conceptions about human functioning [26]. Therefore we can talk about two directions: applying UD principles to assistive design (which always will be relevant) and to other kinds of design, which do not aim improving accessibility.

In the following subsections we apply UD principles to different themes, and speculate on these applications.

4.1 Equitable Use

Equitable Use principle is transcending, integrating principle. Equitability imposes constraints on the other design principles and forces the integration of the other universal design principles [26].

For that principle, the following recommendations are defined: to provide the same means of use for all users, to avoid segregating or stigmatizing any users, to make provisions for privacy, security, and safety equally available to all users; make the design appealing to all users.

It seems natural that wearables can help in multiple contexts, but wearables also can be a way forward for achieving equality by including people with different abilities into use of modern services that improve quality of life. For example, the same heart rate sensors could be used by athletes for tracking their training and the elderly or infants for tracking their health. It is hard to imagine any area of use of the wearables, which does not aim the equality or the safety. Recommendation to test any wearables idea to *Equitable Use* principle could be considered as the first and essential activity when design process starts. Such testing could be useful for understanding that the idea does not contradict to equality and at the same time may provide prompts for use of the same wearables by diverse groups of people. Each theme that is introduced in the Sect. 2 is affected by *Equitable Use* principle.

The *Equitable Use* principle promotes such aspects as privacy, security, and safety, which can make designers examine ethical questions. *Human Enhancement*, *Health Empowerment*, *Personalized Context* themes seem as the most sensible for testing these aspects. The themes of *Human Enhancement* and *Health Empowerment* are all about *Equitable Use* assuming that they are helping to bridge gaps in human capacity or make it so someone can be more independent. The *Personalized Context* theme is also about *Equitable Use* since the idea is that the wearable fits a person (perhaps literally) and can be used in the context a person chooses.

Bio-Tech Fusion allows more people to participate in society. An automated syncing implied in the *Synched Lifestyle* allows information to be synced to multiple devices or presented on a device that works better for a particular person. *Organic Computing* implies new ways of interaction open up possibilities for others that cannot use other forms of communication. Of course, if they are dependent on average human skills, they may still limit their use.

4.2 Flexibility in Use

In contrast to the *Equitable Use* principle, the *Flexibility in Use* is the process-related principle. According to this principle, the design should accommodate a wide range of individual preferences and abilities. The principle can be applied to the design of wearables to provide choice in methods of use, facilitate the user's accuracy and precision, and provide adaptability to the user's pace. Flexibility is the common principle. Following it can hypothetically enhance user experience with any known wearable device. However, at first it could be considered for application to the themes that are the most rich by user-interactions like *Human Enhancement*. This theme aims restoring and augmenting existing senses and abilities that exactly requires taking into account the wide range of individual preferences and abilities. Adaptability looks like a challenging issue when it is applied to a body. Glasses, 3D printed exoskeletons, and embedded sensors should provide greater amount of flexibility and help users to adapt for different tasks and situations.

Another way to think of flexibility is the environments where it will be used. Like clothes, wearables may be used in a variety of conditions (e.g., rain, snow, extreme heat, extreme cold). They could also be under differing levels of stress and atmospheric pressure. The different wearable themes imply that a wearable will likely be used in multiple places in different conditions, indicating a need for flexibility.

4.3 Tolerance for Error

Tolerance for Error principle implies the design that minimizes hazards and the adverse consequences of accidental or unintended actions. While purely recreational wearable technology is less critical with respect to error-tolerance, assistive technology puts forth a higher requirement in this aspect. Assistive devices need to be dependable and reliable, especially during use in potentially hazardous situations, such as public transit. These qualities are the most important for *Human Enhancement* theme as it is mainly focused on the assistive technologies.

The second theme that is important for application of *Tolerance for Error* principle is *Bio-Tech Fusion*. As this theme aims for creating a closer relationship between the wearable and the human body, errors in such bio-tech products like implants can be risky for one's life.

When looking at the themes for wearables, one can hope that the wearable itself has some tolerance for error. For example, putting the device on backwards should not cause the wearable to suffer a catastrophic malfunction. It likely should be able to give some sort of indication about which ways is correct, but it might be possible to use it while worn incorrectly.

The more difficult issue is dealing with the computing the wearable does. If the wearable is part of the *Synced Lifestyle*, then the solution should allow for synchronization errors and corrections. If the wearable is providing *Health Empowerment* or a *Personalized Context*, it should avoid presenting data in a way that could cause the user to make a bad decision. *Organic Computing* wearables should tolerate errors in their input, especially since organic input is likely to be fuzzier than digital input. Finally, if the wearable is part of *Human Enhancement*, it should allow for human errors and corrections in daily use.

4.4 Simple and Intuitive Use

Simple and intuitive use principle is the third process-related principle. It promotes usability and simplicity of use. Design that follows this principle is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level. Applying this idea to wearables is quite natural: one does not notice one's clothes, footwear, or glasses after dressing. The distinction of the wearables to other smart things is that the wearables, in many cases, should be imperceptible by the user. Often wearables have very simple user interfaces, sometimes with very small or even no screens at all. Designing of such interfaces requires use of non-standard design approaches [27]. Wearable that requires a lot of attention from the user will produce negative user experience and finally will be dropped.

If we examine the themes, the need for interfaces that are simple and easy to learn is almost baked into the themes themselves. *Bio-Tech Fusion, Organic Computing, Human Enhancement,* and *Health Empowerment* all require the wearable to work seamlessly with the wearer. This can only be accomplished if the wearable is easy to learn and simple to use. If the wearable is communicating with other devices as part of the *Synced Lifestyle*, this communication should be seamless and easy to set up. Alternatively, if the user wishes not allow communication, it should be possible to easily disable the communication. A *Personalized Context* implies that the interface should be tailored to the wearer and the context the wearer is in. Having an easy to learn and simple to use wearable would help in making this experience personal.

4.5 Perceptible Information

The aim of this principle is to communicate necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.

Wearables that are addressing the themes of *Bio-Tech Fusion, Organic Computing, Human Enhancement,* or *Health Empowerment* may need to be in a form or worn in a location that makes using a display impractical, but other modalities are available. For example, the texture of the wearable could change resulting in different information based on the touch. Vibration could also be an effective way of providing information via touch. One could even examine creating different smells based on different situations. If the wearable is part of the *Synchronized Lifestyle*, it should be possible to export the information to a device or system that can present the information in the most accessible way for a person. Perceptible information is also a feature of personalization that would be needed for a wear's *Personalized Context*.

4.6 Low Physical Effort

The design can be used efficiently and comfortably and with a minimum of fatigue.

This is especially important when dealing with devices that have high requirements on ergonomics, such as custom-molded prosthetics or other gear that is in constant physical contact to the user.

Since most of the current wearables, such as sports trackers are designed to be worn for extended periods of time, they need to have a low amount of physical effort involved in their use. Any wearable that is addressing the themes in § 2 should not require much physical effort. If a wearable will be in everyday activities, it should not cause extra strain or be tiring itself. Wearables addressing the theme of *Human Enhancement*, *Health Empowerment*, or *Bio-Tech Fusion* may be worn by people who may have limited physical strength. A feature of the *Organic Computing* theme may be that it requires less effort than other forms of interaction. Looking at the theme of a *Synced Lifestyle*, synchronization with other devices should not cause great physical effort.

4.7 Size and Space for Approach and Use

This principle promotes an appropriate size and space, which should be provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.

This concept relates to the spatial dimensions of an appliance that typically should be adapting to the user's characteristics. We differentiate between the "one size fits all" and the "one size fits one" approach [28]. While the first approach is typically cheaper and simpler to achieve it yields a margin of users that are excluded, steepening the cost at a later point of time when they have to be included anyway. Using adaptive design patterns, the latter approach can be targeted at additional cost and effort with the cost curve flattening over time, e.g. during the maintenance phase.

In most cases, wearables abide by this principle regardless of the themes from Sect. 2. Wearables are on the person and eliminate their need for approach and use. If wearables are abiding by the other principles, then they are normally not getting in the way of the wearer. Even if a wearable is big and bulky, it's more an issue that the environment needs to be universally designed to accommodate the person wearing the wearable.

5 Discussion

This study shows that applying UD principles to the themes that drive wearable enhancements can provide interesting ideas that can be discussed in a framework of design process. The themes help generate concepts for wearables. At the same time, examining design concepts against UD principles offer designers constraints for equality, inclusion, and accessibility.

UD principles can be applied to products and architectures in a wide scope. If a product or a building meets all or some of the associated requirements, it is considered to be universally designed. One condition for success is mutual benefit—the design should benefit both users and the manufacturers [29]. On the other hand, universal design is not only a result (e.g. the wearable), but also a process. If a designer wants to know if something is universally designed, including people with disabilities is an important way to evaluate the wearable [30].

Overall, the question of balance between accessibility, usability and wearability of devices remains a complex problem, which we tried to soften by illuminating different dimensions and themes that are related to the issues at hand. On the one hand, a wearable device can be empowering, providing assistive technology to a user where and when needed. On the other hand, certain additional risks of failure emerge proportionally with the technical complexity of such devices.

An interesting point that puts emphasis on a critical viewpoint [4] is the observation that, ironically, wearables often have a low wearability, that is, they are not worn long periods of time. An example for this could be Google's Glass, which had two main reasons for failure. First, the battery life was too short—a problem that remains yet to be solved due to weight and size restrictions. The second factor was social acceptance; people were concerned about their privacy upon encountering a Glass wearer, because of the Glass's built-in camera. The latter effect sheds insight on the potential for wearables to cause unexpected effects that are not directly related to inherent design features — a challenge that hints at the assumption that Universal Design should not just focus on a single individual in user-centered design, but also consider wider environmental factors, e.g. social context.

This study shows that the application of UD principles to the themes that drive wearable enhancements may provide additional ideas that can have impact on design of the wearables. Such the application can be recommended on the earliest phases of wearables design process to discuss possible features, opportunities, restrictions, and risk. Also, the application can improve accessibility and adaptability of wearables that could broaden the base of potential users of the product.

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