Understanding the Wearability of Head-Mounted Devices from a Human-Centered Perspective

Vivian Genaro Motti, Kelly Caine
School of Computing – Clemson University
McAdams Hall - Clemson, SC – United States
{vgenaro,caine}@clemson.edu

ABSTRACT

Extensive efforts have been dedicated to developing wearables, but existing solutions focus mainly on feasibility and innovation. Thus, although many devices are named 'wearable', users face some wearability issues. Previously adopted trial and error approaches have effectively produced wearables, but not focusing on human factors. Through an extensive analysis of online comments about head-mounted devices, this paper presents their problem space from a human perspective. The analysis of online comments from existing and potential users enabled us to identify key aspects of the wearability of head-mounted devices, bridging the gap between design decisions and users' requirements.

Author Keywords

Wearable Devices; Head-Mounted Devices; Wearability

ACM Classification Keywords

H.5.2 [Information Interfaces and Presentation]: User Interfaces: Miscellaneous.

INTRODUCTION

Available in many form factors, wearable devices are applied to support human activities in several domains, especially: health care [1,3,6,10], activity recognition [4], fitness [6,7], elder care [1,9] and entertainment [5,14]. Wearables are promising [3], and their improvements have been boosted by the quick evolution to smaller devices, more efficient batteries, and optimized components. Much progress has been made in wearable computing, but room for improvement still remains, since the solutions proposed so far focus on technical feasibility and rapid innovation, rather than on users' perspectives and wearability concerns [8,11,13].

Identifying, understanding, and considering human factors in the early stages of design results in devices with better wearability, users acceptance, satisfaction, and engagement [8,14]. To define key factors of wearability, we analyzed online comments about head-mounted devices from a large sample of potential and existing users. From their comments, we extracted key aspects to design successful wearables. The main contribution of this work is a set of key principles to be considered in the design of head-mounted devices (HMD). This work frames wearability from a human-centered perspective, aiding to understand the preferences, wishes, interests of users, improving their acceptance of and engagement and satisfaction with wearables.

Wearable devices are aligned with two technological trends: the *Internet of Things* (IoT) and the *Quantifiable Self* (QS). In the IoT, users are constantly connected, interacting with small devices (gadgets), accessing and producing online content; in the QS, sensors attached to the users' body continuously track their biometric data and daily activities. By tracking habits, such as sleeping or eating, recording data such as calories and steps, and monitoring vital signs such as respiration, and pulse, users can improve their habits, treatments, and even prevent or detect diseases. The IoT and the QS use gadgets to access and produce content, enabling users to record and analyze their lives based on data and statistics. Optimistically, being aware of these data empowers users to improve their behavior and quality of life. While both IoT and QS have the potential to enhance users' lives, this depends on the success of the device: its usefulness, acceptance, adoption, and satisfaction.

Industrial reports show [6,12] that while wearables are growing in amount, variety, features, designs, activities and domains supported, they suffer short life spans, low user engagement, and are met with barriers such as privacy [6].

A great potential exists for small wearable devices that fit well in conventional outfits. So much so that currently wearables are applied to fashion, entertainment, and healthcare, e.g., digital jewelry, technological clothing [2], gaming, sports [7], and medical emergencies [1,3,6,10]. To support these applications, wearables have been designed as many form factors: head mounted (glasses, headsets, earpieces), wrist and hand mounted (watches, gloves, rings), and chest and back mounted (belts, bands, shirts). Choosing a form factor depends on the data of interest, as certain biometric inputs can be sensed from a few or a unique part. Sensors can be *in* or *on* the human body or *near* it [14].

This work focuses on *head mounted* devices (HMD): wearables worn as helmets, glasses, goggles, lenses, earpieces, and headphones. HMD aims depend on their computational features. Helmets, glasses and goggles often support augmented or virtual reality, using the environment as background for the interaction, or simulating a new virtual environment. Contact lenses have been explored for healthcare,

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unobtrusively monitoring health data (glucose). These form factors are promising but are still in the early development phase; progress is needed before they are made practical, safe, available in the market, and widely adopted. Earpieces and headphones aid communication as hands-free devices that integrate microphones and speakers, often being employed with other devices. Headphones are popular and widely adopted by teenagers, adolescents and young adults. Because of the variety in device maturity we are interested in understanding the wearability of prospective/prototype devices in addition to devices that are already available.

Achievements in wearable computing focus on the feasibility of the solutions, so the usability of the wearable, its *wearability*, is often neglected. To understand key aspects of the wearability of HMD, we systematically gathered and analyzed online comments of existing and potential users.

METHODOLOGY

We selected a representative set of 33 HMDs, and 59 online sources to search for comments about each device. From the sources, which included social media outlets and IT websites, we extracted key sentences and main quality factors. We sought to keep sources broad so we could ensure coverage of less popular devices (K-Glass, EmoPulse NanoGlass). Users' comments were captured directly from the source by the researcher team (2 assistants, 1 postdoc, 1 advisor). After extraction, the contents were analyzed to identify, filter, and mark key aspects and qualities of HMD. A color scheme was used to mark the contents: key aspects were marked in blue (e.g., quality, comfort), their positive and negatives reviews were marked in green and pink (e.g., easy, heavy). We annotated the contents with tags, and quantified them for analysis. Word trees helped us interpret the results and to understand the wearability of HMD from a human-centered perspective. All work is IRB approved.

Reviewers (technical journalists) and actual and potential users created the comments posted them online. Reviewers focus on users as target audience, so the concerns of their critical analysis match with users' interests. Comments from users focus on similar aspects, but differ in comprehensiveness, extension, balance, and quality. Compared with reviewers, users are more focused and informal.

We analyzed thirty three HMDs representing four form factors (Table 1): 14 glasses, 13 headbands, 4 earpieces, and 2 headphones. They provide different, but complementary features. Because we are interested in current and future HMDs, we gathered data on 26 HMDs that launched between 2011 and 2014 and 7 that are prototype systems or proposals yet to be commercially launched (marked with an asterisk in Table 1). The comments about the devices were collected from 59 online sources: 15 forums (Reddit, ThinkDigit, Wearable Computing), 34 technical sites (PopularScience, CNET, Engadget, Geek, PC Advisor, TechCrunch), 6 e-commerce sites (Amazon, eBay, Newegg, Overstock, Tiger Direct, Best buy), and 4 social medias (LinkedIn, Twitter, Facebook, GooglePlus).

Glasses	N
Sony HMz-T1: personal 3D viewer headset video glasses	713
Oculus Rift (dev): virtual reality headset for games and virtual worlds	484
Google Glass: displays smartphone content in a hands-free format	477
Vuzix Smart Sunglass: hands free access to content, data collection	216
Smart Contact Lens*: monitors glucose levels in tears	153
Meta Pro: offers fully immersive virtual reality	146
ICIS*: prescription eyewear displays notifications from a smartphone	72
Epson Moverio BT100/200: see-through display for apps, gaming	69
Second Sight Argus II: restores functional vision for the blind	53
Atheer One: offers immersive 3D display	53
Olympus MEG4*: connected to glasses displays smartphone content	51
Laster SeeThru: wireless augmented reality eyewear	31
EmoPulse NanoGlass: displays a color signal on short messages, incoming calls, of a smart phone to the lenses of the glasses	3
K-Glass*: offers an augmented reality (AR) experience	3
Headbands	**N**
Voyager Legend: mobile Bluetooth headset	30
iRiver On: stereo Bluetooth headphones with a heart-rate monitor	16
iWinks Aurora: plays lights and sounds for lucid dreaming with a smart alarm clock to help one sleep better	15
Recon's Snow2: heads-up display for alpine sports with the onboard processing power	11
Avegant glyph: virtual retinal display	9
Emotiv Insight: wireless headset, records and translates brainwaves into meaningful data	9
Cynaps Enhance: hands-Free, ears-Free, Bluetooth bone conduction headset in a hat	8
Axio EEG: EEG headband that taps into brain's inner workings to show how well one maintains mental focus	6
Vigo*: tracks patterns in blinks and moves to quantify alert levels	5
NeuroOn: brainwave - monitoring sleep mask allows to switch from monophasic to polyphasic sleep	5
Life Beams: tracks heart rate based on skin temperature and pulse	5
InteraXon Muse: reads the brain activity	4
Immersion*: measures biometrics as heart rates as one plays games, alerting when the user turns from annoyed to rage-filled hate	3
Earpieces	**N**
Looxcie Camcorder: futuristic wearable Bluetooth camcorder	53
Intel Smart Earbuds: headphones with sensors in the earpiece to monitor heart rates	7
LG Lifeband Earphones: Bluetooth 4.0 peripherals track steps and calorific burn, movement over the course of the day, and heart-rate	2
Microsoft Septimu: ear buds to gauge mood and create a playlist	0
Headphones	**N**
Muzik: headphones enable flipping through tracks and adjusting volume by tapping on the right ear cup	50
Neurowear Zen tunes*: detects mood with a EEG brainwave sensor to play a matching song	10

Table 1: Head-mounted devices per form factor, their brief description, and total number of comments. Devices marked (*) are prototypes proposed, dev. means developer versions.

%	Top 10 Factors	%	Top 20 Factors	%	Top 30 Factors
12	**Design:** look and feel, weight, size, balance, symmetry, comfort, fashion, shape	3	**Interaction:** how easy it is to control, access and navigate, alternative inputs,	2	**Compatibility:** to other devices (earplugs, chargers), platforms (e.g. OS)
10	**Purpose:** functionalities, applications, features, and contents available, useful-	3	**Accuracy:** how precisely the device responds to interaction, sensor precision	2	**Novelty:** ability to surprise users, with new experiences, contents and features
8	**UX/UI & Usability***:* how handy, intuitive, simple and easy to use a device is	3	**Comfort:** no pain, harm, pleasant feel, ease with having device on	1	**Resistance:** sturdy device, resists humidity, sweat, rain, temperature pressure
8	**Quality:** audio, video and image, resolution, sharpness, contrast, details, depth	3	**Accessibility:** how universal the design is, regardless of impairments	1	**Personalization:** how configurable the device settings and UIs
6	**Contextual awareness:** external factors such as light, brightness and noise	3	**Customization:** adaptability, changing colors, fit, modes, by calibration	1	**Simplicity***:* how easy, fast and intuitive is to understand, use, interact with
5	**Battery:** time to charge, how long it lasts, power sources, compatible chargers	3	**Fit:** how comfortable, adjustable and flexible the device is, device dimensions	1	**SN-integration:** ability to post in social media, share contents with friends
5	**Privacy:** access control prevent illegal use, criminal abuse, piracy	3	**Responsiveness:** how the device performs, prompt, accurate, right response	1	**Availability:** if the device continuously works without crashing, or interruptions
4	**Ease of use:** how intuitive and simple the device is to understand, to interact	2	**Safety:** how harmful a device is, causing e.g., headache, nausea, or eyestrain	1	**Portability:** ability to move and to transport the device
3	**Price:** overall costs given the benefits provided by the device	2	**Self-containment:** device use as portable, autonomous, stand-alone	1	**Reliability:** how trustful the interaction is, responding properly, accurately
3	**Obtrusiveness:** how intrusive the device is, standing out, in the users' way	2	**Control:** ability to interact with the device and change desired settings	1	**Adaptation:** ability to properly react to the context of the user

Table 2: The 30 categories identified representing the key wearability concerns for HMDs, ordered by percentage of occurrence.

QUANTITATIVE AND QUALITATIVE RESULTS

Table 1 presents the HMD and the comments retrieved. While some HMD had many comments (Sony HMzT: 713, Oculus Rift: 484, Google Glass: 477), others received fewer (Microsoft Septimu: 0, LG Lifeband: 2), likely due to marketing, their popularity, success and period for sale.

After marking the comments, they were classified in 30 categories (Table 2). Comments were screened and the categories were identified in a bottom up approach, until a comprehensive set was reached. To minimize bias, the team agreed on the protocol and set of categories. The number of comments was extensive (2772); so their classification allowed us to synthesize and abstract key concerns. Quantifying the occurrence of each category allowed us to prioritize key factors according to occurrence. Table 2 shows the occurrence by percentage of each category, considering all form factors. The top 5 concerns are design, purpose, usability, quality and contextual-awareness. These factors may warrant special attention in the design of future HMDs.

Although the quantitative analysis tells us that users often talk about these factors, it does not tell us why these factors are important. To add qualitative aspects to this analysis, we created 13 word trees that represent users' views, thoughts, and feelings about the wearability of a HMD.

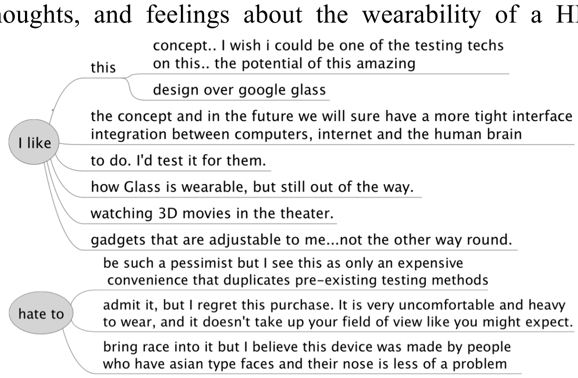

Figure 1. What users like (top) and hate (bottom) in HMD

These trees help us understand users, what they like, love, dislike, hate, wish, expect and hope. The key words of the tree roots were set after an exploratory phase, resulting in expressive terms. Figure 1 shows 2 word trees, with 7 aspects that users like in their devices: i) potential, ii) design, iii) concepts, iv) novelty, v) unobtrusiveness, vi) user experience, vii) adjusts; and 3 aspects that users hate (bottom): i) price for a device that provides existing features, ii) uncomfortable and heavy devices, and iii) accessibility issues. Further word trees permitted the analysis of 11 sentiments, framing users' thoughts about HMD. Focusing on glasses, which had the most comments, users:

***Love* to.** try or test the device before buying it (as pioneers), have certain features available (wireless communication, positional tracking, 3D movies and games), more polished final versions of the device (instead of prototypes), new concepts (futuristic ideas, novelties), conventional looks (nice designs, small devices), useful aim (healthcare).

***Expect*.** accessible navigation, improved final versions (better products in the future, success of the devices), integration between physical and virtual worlds, gaming, ubiquitous devices, proper feedbacks, high quality (camera, audio, video, image, sensors), conventional looks, style, and affordable prices (fair balance between costs and benefits).

***Wish*.** to test the devices first (pioneers), luck (for developers to reach successful versions), to properly adjust the devices (image focus), compatibility, extensibility (further applications to extend the original features).

***Hope* the devices to have.** good notifications, alerts, and feedback (useful, discreet), the necessary approvals, design quality (image), contextual awareness, iterations, improved future versions (due to successful teams, large adoption, more competition), compatibility (with accessories, applications, devices), small versions (discreet), reliable specifications (trustful advertisements), useful aims (healthcare), accessibility (for users' impairments), comfort, personalization (to adjust the UI), fair privacy policies, standalone use (self-containment), satisfactory UX (user experiences).

Consider that devices are *still.* in early development stages (infancy, first iterations, prototypes, conceptual versions, work in progress), targeting specific users (minorities, very niche), lacking in quality (resolution) and legal policies (piracy, DRM), looking futuristic, expensive for the consumer, confusing (social implications, use norms).

Don't know. the actual safety of the device (headaches), if the devices' specifications are realistic (perception depth), the motivations of design decisions (discomfort).

Don't think. it will take a long time to reach sound improvements, it is enough to have available more features or applications (as UX must also be addressed), prices are always not affordable (depends on their enthusiasm, worth perception), that the devices will be widely adopted (niche).

***Don't* want to.** look weird, watch movies or play games with glasses (small screens, discomfort), be isolated.

Don't see. current versions as successful, final, the replacement of current devices (traditional entertainment, TV, games, smart phones), always an issue with built-in camera.

***Don't get* why.** some devices are not self contained, depending on cables, some features, sensors are (un)available (camera), using gesture (tiring, painful in long interactions).

***Don't like* to.** blindfold themselves to the physical world, accept some device just because of novelty.

***Doubt* that:** sound improvements and smaller versions can be reached (safety), devices will be largely adopted.

Feel that they *look like.* creepy, dork, science fiction, geek, Cyclops, idiot, retired, cyborg, funny, weird, droids.

This analysis complements the categories set and confirms their relevance. For quality, users expect high standards, accepting extra costs for them. For design, users expect discreetness, safety, and comfort. Prices should be affordable, or at least fair (costs vs. benefits). For usability, users expect intuitiveness, and ease of use. Users tend to be happier with useful purposes, but not only the features make a great device, as the user experience is important too. These concerns reflect the users' perception about the HMD, but since they are not unanimous, they must be carefully interpreted. While these concerns cover key factors, a balance must be met to ensure that opposite preferences are considered, or at least that most users' concerns are addressed. Meeting general requirements is more realistic than pleasing every user. Flexibility, ensured with customization, adaptation and personalization, can satisfy more users, but more complexity or cost must be avoided.

The comments emphasized universal design importance for wearability, raising phenotypic and technical issues (nose profile, voltages). To design for a global market, specificities of target users must be known and considered. Due to the individuality of each user experience, it is impossible to please each user in the design of new technologies. While features, comfort, and price vary by user, general trends suggest decisions that are more or less acceptable, for users as a whole, a group, or individually.

CONCLUSION

Matching users to decisions is challenging but key to reach a successful design. *One size does not fit all*, so ensuring the best design efforts can aid to reach great and customizable results. *Customization* should also be *intuitive* and *easy*, as enthusiastic users skip instructions, and misuse their devices, realizing later why they had bad experiences: a user complained of discomfort of his Sony HMz-T1, discussing online he noted that it was due to the misplaced head straps.

Analyzing online contents expressed voluntarily by users with varied profiles enabled us to gather several comments from a representative sample: existing wearable users and those who would like to use wearables in the future. Despite these benefits, online comments have drawbacks: users expertise and their demographic data are unknown since contents are anonymous. Still we do know that this user profile is often interested in technology, follows new trends, expresses their views, and accesses the Internet often. Users who comment online may be early adopters, which limits this work to a users' niche, but focuses on potential HMD users. Users who are negative about a device tend to be skeptical about novelties, considering those scary, weird or difficult. Still, the benefits of novelty can overweight the familiarity and comfort ensured with known technologies. Designers can deal with this tradeoff emphasizing the benefits of novelty, creating new paradigms, enabling new trials, and acceptance. This work focuses on human perspectives about HMD, aiding to understand what users want and would like to have in HMDs. Better understanding the wearability for HMDs aids to provide what users do need.

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