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Exploring the Role of Interaction Design in Wearable Devices: Challenges and Opportunities in Human-Computer Interaction, Interface Design, Application and Service Design

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Abstract: With the continuous development of technology, wearable devices are moving from the laboratory to the market, transitioning from independent use to multi-platform coordination, and from focusing on hardware-based product functions to focusing on user data-based applications and services. These changes make the role of interaction design increasingly important in the further development of wearable devices, while also posing many new challenges that are different from traditional devices. This article analyses and studies the interaction design of wearable devices from three main aspects: human-computer interaction, interface design, and application and service design, with the aim of providing a certain theoretical accumulation for the interaction design of this increasingly user-oriented new type of product.

1. Introduction

In the field of computing, there has been a quest to break through the limitations of desktop computers and make them more mobile. Since the first wearable computer was introduced in 1966 [1], wearable computing has been an important research direction. The field covers a wide range of technological directions from input-output interfaces and computational processing of continuous sensing data to behavior recognition, environmental context awareness and even materials and energy consumption. However, wearable devices really became a consumer product and entered the public eye recently with Nike's Nike+ platform-based sports digital products.

One of the key factors in this is the development of computer hardware. As core functions such as sensing, computing and wireless communication can be implemented in increasingly smaller and lighter modules, the biggest problems facing wearability have been solved. However, it is the shift in the positioning of wearable devices that is key to their growing prospects. Early wearable computing focused on expanding human functionality and developing cyborgs (cyborgs), with the ultimate goal of a relatively closed computer system for enhancing various human behavioral capabilities. Now, with the increasing maturity of big data, cloud computing, data mining and analysis, mobile computing, wireless communication and social networking, the positioning of wearable devices has expanded to the scale of network and society. There is a shift from localized behavioral empowerment to interconnected and network-dependent, data analytics-based services and collaboration. As a result, the design of wearable devices needs to focus not only on the physical product, but also on the design of applications and services, which are the most important part of bringing them to market[2-4].

Accordingly, technical research will not only be limited to solving hardware problems such as input and output and signal processing, but also data analysis, mining and application of interconnectivity will become a more central part. The shift in the positioning of wearable devices and the process of moving from the laboratory to the end user provide opportunities for interaction design. Therefore, this paper first analyzes the classification and characteristics of wearable devices, and then summarizes and discusses the interaction design characteristics and elements of wearable devices from three main aspects: human-computer interaction, interface design, and application and service design.

2. Wearable Device Classification and Characteristics

According to the wearing method, wearable devices can be divided into four categories: head-worn, bracelet, portable and body-applied. The characteristics and main interaction methods of these four types of devices are described next. Head-worn devices are usually worn on the head and can be used for virtual reality and augmented reality applications, such as smart glasses, some of which are equipped with touch screens for user interaction. Bracelets are usually worn on the wrist and are mainly used for health and exercise monitoring, such as smart bracelets, which are usually equipped with heart rate sensors, pedometers and other functions and can be connected to smartphones via Bluetooth. Portable devices generally refer to wearable devices that can be carried around, such as smart watches, smart glasses, etc. Body-applied devices are devices that can be attached to various parts of the body, such as heart rate monitors, breathing monitors, etc. Different categories of devices have different characteristics and main interaction methods, so consumers can choose the right device according to their needs [5-7].

Please see the following Table1-4, which classify wearable devices based on the way they are worn and their characteristics and interaction methods:

Table 1: Features of head-mounted devices and how they interact

Current Representatives	Characteristics	Interaction Methods
Google Glass, Melon Headband	1. Can display information in the user's natural field of view; 2. Can transmit private audio signals using bone conduction or headphones; 3. Highly related to the user's field of vision and head movement.	1. Headphones or bone conduction; 2. Micro-projection; 3. Voice control; 4. Traditional physical input (such as buttons and touchpads); 5. Limb motion sensing (such as a gyroscope); 6. Body information sensing (such as EEG).

Table 2: Features of wristband devices and how they interact

Current Representatives	Characteristics	Interaction Methods
Qualcomm Toq, Samsung Galaxy Gear, Pebble, Nike+ FuelBand	1. Screen is small or non-existent; 2. Can measure parameters such as pulse and blood pressure; 3. Highly related to the user's limb movement; 4. Generally uses low-power communication technology (such as Bluetooth 4.0) in conjunction with smartphone apps; 5. Serves as an auxiliary tool for traditional mobile smart devices (such as receiving notifications, setting shortcuts, etc.).	1. Vibration and indicator lights; 2. Micro-display screen; 3. Traditional physical input (such as buttons and touchpads); 4. Limb motion sensing (such as a gyroscope); 5. Body information sensing (such as blood pressure and pulse); 6. Environmental data collection (such as altitude, particulate matter, and environmental detection); 7. Matching applications.

Table 3: Features of portable devices and how they interact

Current Representatives	Characteristics	Interaction Methods
Qualcomm Toq, Samsung Galaxy Gear, Pebble, Nike+ FuelBand	1. Screen is small or non-existent; 2. Can measure parameters such as pulse and blood pressure; 3. Highly related to the user's limb movement; 4. Generally uses low-power communication technology (such as Bluetooth 4.0) in conjunction with smartphone apps; 5. Serves as an auxiliary tool for traditional mobile smart devices (such as receiving notifications, setting shortcuts, etc.).	1. Vibration and indicator lights; 2. Micro-display screen; 3. Traditional physical input (such as buttons and touchpads); 4. Limb motion sensing (such as a gyroscope); 5. Body information sensing (such as blood pressure and pulse); 6. Environmental data collection (such as altitude, particulate matter, and environmental detection); 7. Matching applications.

Table 4: Features of body-worn devices and how they interact

Current Representatives	Characteristics	Interaction Methods
Qualcomm Toq, Samsung Galaxy Gear, Pebble, Nike+ FuelBand	1. Screen is small or non-existent; 2. Can measure parameters such as pulse and blood pressure; 3. Highly related to the user's limb movement; 4. Generally uses low-power communication technology (such as Bluetooth 4.0) in conjunction with smartphone apps; 5. Serves as an auxiliary tool for traditional mobile smart devices (such as receiving notifications, setting shortcuts, etc.).	1. Vibration and indicator lights; 2. Micro-display screen; 3. Traditional physical input (such as buttons and touchpads); 4. Limb motion sensing (such as a gyroscope); 5. Body information sensing (such as blood pressure and pulse); 6. Environmental data collection (such as altitude, particulate matter, and environmental detection); 7. Matching applications.

When it comes to trends in the wearable devices market, platforming cannot be ignored. In the field of communication engineering, platforming can provide an open design and development environment through which more developers are attracted to create useful, innovative applications. This trend will also further promote the datafication and application of wearable devices, thus making them more popular and practical. In addition, platform-level devices like Google Glass and Pebble have fully independent operating systems and development frameworks, and support the development and extension of third-party applications, which makes them particularly valuable in the communications engineering space. Product-level devices, by contrast, are better suited to support certain specific features with relatively closed operating systems and software, with no official open SDKs or third-party applications. However, in the wearable device market, opening up the design and development of applications through a platform-based approach will be an important avenue for their development, especially with their new positioning as data and application-based.

3. Human-Computer Interaction for Wearable Devices

3.1. The Development of Wearable Devices

As wearable devices have unique wearable attributes, their design and manufacturing face many challenges, such as improving comfort, ensuring safety, extending service life, improving interaction convenience, improving information transmission efficiency, ensuring stability of electronic components, improving data collection accuracy, reducing energy consumption, and improving social acceptance. These requirements put forward very high demands on the human-computer interaction experience of wearable devices. In the field of communication engineering, many basic researches have been carried out to solve these problems, including the study of wearable device wearing position selection and product form design principles, the visual response timeliness of wearable devices worn on different body parts, the analysis of human-computer interaction characteristics in terms of supporting task completion and physical experience, and the study of wearable devices from the perspectives of appearance and perception, fit to the body, safety and reliability, etc. Comfort is studied. These research results can provide important reference values for optimizing the human-computer interaction experience of wearable devices and creating new interaction methods.

In terms of wearable device interaction, compared to Apple's historic introduction of touch interaction six or seven years ago, sensing-based interaction will be more widely used in the future. The use of sensing-based interaction not only takes advantage of wearable devices' easy access to body information, but also is a good solution to the problem of small visual interface and difficult touch control of wearable devices. Sensing-based interaction includes recognizing human manipulation input and collecting human body data through sensors, as well as collecting environmental data or receiving information from sensors in the environment, and analyzing and processing it for feedback to the human sensory system.

Since the interface size of wearable devices is small and not easy to touch when moving around, interaction methods such as voice recognition, gesture control and eye movement recognition become more suitable application scenarios and may therefore promote the development and application of these interaction methods to increase significantly. Wearable devices are often the devices that people need to assist in their daily activities. In order to be able to support the effective execution of tasks in different contexts, the interaction of wearable devices should be multimodal, i.e., using a combination of interaction methods. For example, a user wearing Google Glass can take a picture by blinking or voice control, and start the glasses displaying the time by tilting the head. Tapping the touchpad on the frame allows menu and content navigation, and private voice signals are sent via bone conduction technology. Timely information pushes for changes in the surrounding environment can help users with different functional operations such as map navigation and email sending and receiving.

It is important to note that although linking with cell phones and networks is not a direct operation for users, it is an important aspect of wearable device interaction that cannot be ignored. With the majority of devices having cell phone applications, the interaction with wearable devices is more like the interaction with input and output devices in many cases. Many of the functions behind the operation are done in the mobile application or cloud, and such a cognitive concept will largely affect people's interaction with the device itself.

3.2. Current Wearable Devices

Currently, the input methods of wearable devices mainly include body data sensing (such as brain waves, heartbeat, etc.), limb movement detection (such as face, fingers, wrist, body trunk, feet, etc.), eye tracking, physical interaction (such as hand tapping), voice command and selection, muscle bioelectricity, and environmental data detection (such as temperature, humidity, air cleanliness, location, etc.). Output methods mainly include sound, small displays (such as LCD, LED, OLED, AMOLED, ePaper, soft display, transparent panels), head-mounted micro-projection, ambient projection, built-in lights, vibration, temperature, and other limb-receptible signals, and the use of other platforms' interfaces to display data information. Behind these are a large number of potential interaction methods and technologies being researched and tested.

Some researchers have also explored new interaction methods, such as Manabe et al [8], who studied the optimization of headphone-based eye-movement input with conductive plastic. Amft [9,10], Yatani [11] and others have tried to recognize different oral movements such as eating, drinking, chewing, swallowing, speaking, laughing, coughing, etc. through electromyography (EMG) as well as microphones and other acoustic sensors attached to headphones and worn on the neck. Deyle et al [12] developed a limb movement recognition input using piezoelectric sensors to detect movement sounds conducted through bones. Loclair et al. [13] focused on how to allow users to complete primary tasks while easily and quickly performing secondary tasks through micro-interactions (interactions that require only brief attention from the eyes). They invented a system for one-handed interaction, where different operations are performed through overall gestures or thumb presses on fingers or palms, swiping and turning on the palm of the hand. Kim et al [14] focused on exploring the possibility of using the upper peripheral space for gesture manipulation in response to the increasingly small manipulable interface of wearable devices, and specifically introduced a prototype system using an infrared distance sensor. The wearable interface WUW by Mistry et al [15] allows people to interact directly with information projected in the environment or surrounding objects through gesture-based input and augmented reality information presentation. Akiyama et al [16] developed a thermal media system that allows people to feel dynamic hot and cold changes in response to the music they listen to, thus providing users with an unprecedented emotional experience.

4. Wearable Device Interface Design Concept

A number of design concepts and principles can guide the design of an interface. First, the interface should be task-driven and focus on the task that the user is currently performing. Second, the interaction methods should be diverse, including voice commands, gesture control, eye tracking, and other options to accommodate different usage scenarios and user preferences. In addition, the interface elements should be as simple and easy to understand as possible, intuitive and actionable. Finally, the interface should also take into account the user's interaction with the surrounding environment, for example, through environmental data detection to achieve active adjustment of device functions or through micro-interaction to accomplish secondary tasks.

These design principles need to be followed in the design of wearable devices, as well as constant testing and feedback to ensure the validity and reliability of the design.

4.1. Scene Fusion

In wearable devices with graphical interface display capability, the screen is often a complement to the real-life context, rather than a screen space independent of the real world as in the case of traditional device screens, so it is important to create a connection between the interface and real life in interface design.

On the other hand, a large part of user input to wearable devices comes from everyday actions and behaviors, which is an important difference from traditional input, that is, the reusability of input behaviors. In traditional devices, the user's command to the device or system is often specific and single, but for wearable systems, the user's input may be a reuse of another action, or the user's input behavior is not only the intention to operate the device. For example, the user's action of looking around can be used as a behavioral input to a head-mounted wearable device, such as moving the viewfinder when recording a scene or changing the focus of augmented reality information. The recent emergence of mobile devices equipped with "co-processors" can also use user behavior as input, but in this state the mobile device can also be considered a portable wearable at another level. It follows that the interaction design of wearable devices should be sufficiently connected to the user's real-world context (environment, actions, and goals) so that user commands and environmental information can be obtained in a more convenient and natural way, and the coherence between device services and real-life experiences can be further enhanced.

4.2. Scene Fusion

Due to the limitations of wearable devices in terms of frame size and input, a more linear interaction logic will improve the efficiency and usability of the entire application or system. This design philosophy was widely and deeply used in the early days of mobile devices, and even with the proliferation of large-screen, high-performance mobile devices today, linear, repetitive interaction design is still important for shifting user perceptions and lowering the learning threshold. The use of hierarchical advancement is not only a matter of separating functions into processes, but it is also critical that the different functions are planned and segmented in a logical way to ensure that they can interact with the user according to a set of framework processes and interaction logics in the process of use.

As a quick entry point for smartphones on Pebble watches, the first problem Smartwatch+ had to solve was how to transfer the complex functionality and logic of a smartphone to a smartwatch. The main menu is highlighted.

4.3. Scene Fusion

Compared with traditional mobile devices, wearable smart devices seem to be closer to the user, not only in terms of wearing characteristics, but also in terms of interaction design. Combined with the above-mentioned concept of choice reduction, when the complexity of a single interface is reduced to a certain level, certain functions and information can be directly "tiled" on top of the menu. By presenting key features and information at the first level, it helps improve user efficiency and brings the product closer to the user: the dynamic tiles introduced by Microsoft in Windows 8 and Windows Phone/RT have also been used to improve the efficiency of the main menu.

Although the main menu is weaker than the feature list, it can be used in conjunction with a list of supplementary menus, where the main information and functions are at the first level, and more actions and detailed options can still be accessed by calling out the menu. In essence, this design helps users to pre-select the functions and organize the most important (or most needed) functions and information.

5. Conclusion

With the rapid development of technologies such as microprocessors, sensors, mobile Internet, social networks and new materials, wearable devices have gradually entered the market and become part of the larger O2O online and offline ecosystem. However, for wearable devices to be successful, they need to make rational use of the data collected by the devices, design and develop diverse and effective applications, and establish organic connections with social networks. All of these offer a lot of room for interaction design. Due to the limitations of long material and hardware development cycles, high human factors engineering requirements and social acceptance, it will take some time for wearable devices to proliferate and be marketed. However, the interaction design field can start to explore the characteristics and design elements of wearable devices in terms of their own interface and interaction, multi-device and multi-platform interconnection, and the design of application ecosystem, so as to prepare for the popularity of wearable devices in terms of interaction. At the same time, it can also take advantage of interaction design's focus on user usage patterns and service system design to promote the further development of wearable devices based on existing technologies through innovative applications and ecosystem design.

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