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Interactive Technologies of Wearable Devices for Elderly: A Literature Review

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Abstract

Older people interacting with wearable devices have inspired many researchers to explore and contribute to a wide range of research threads. However, much of the research has focused on the technical aspects of wearable devices and there is a lack of user-centered research, and there are still many gaps in the literature on wearable device interaction for older people. In this literature review, interaction techniques for older people using wearable devices are summarized. The analysis of 115 research articles concludes that older people use smart wearables primarily to monitor health and exercise, The paper describes the development of wearable device technology, the value for older people, the types of wearable devices, interaction modes, and interaction design principles and guidelines to the elderly. It also shows the design requirements of older people for wearables and the directions designers need to take when designing for older people.

Subject Areas

Applications of Communication Systems

Keywords

Smart Wearable Devices, Interaction Design, Elderly, Interaction Pattern

1. Introduction

1.1. Development of Wearable Devices

In 1980, Steve Mann developed a line of embedded cameras and microphones to record people's daily activities [1], and after 2010, sales of wearable devices in the commercial market rose [2] to 8.9 billion by 2022 [3]. There are a wide range of wearable devices, with wristband (e.g. smartwatches, bracelets, etc.) and

headset (e.g. smart glasses and augmented reality headsets) wearable devices being the most popular. Wearable devices use sensors to capture the user's daily activity and behavior, location and also to collect information about the user's location. Wearable devices have been used in a variety of fields: environmental detection, healthcare, security and industrial applications [4].

1.2. Older Adults and Wearable Devices

In 2020, the United Nations reports that the world's aging population will be approximately 727 million people aged 65 years or older, and in addition, the older population is expected to increase to 1.5 billion by 2050 [3]. For older people, health is a primary concern. In recent years, an increasing number of older people have been affected by chronic diseases [5], and in the normal course of human aging, most people experience a reduction in the volume of grey matter in brain structures associated with coordination and control of movement, as well as a decline in cognitive functions related to attention and memory. The recent 2019 coronavirus epidemic has had a significant impact on older populations around the world, whose health conditions are in greater need of high levels of monitoring and care [6]. According to research, digital technology can improve the living conditions of older people, especially in terms of the quality and efficiency of disease prevention and healthcare [7]. Head-mounted devices can help them to enhance their cognitive function. Wearable devices not only help older people in terms of health convenience, but also make a difference to their lives in areas such as exercise and entertainment.

1.3. Current Status and Challenges of Wearable Devices for the Elderly

Some researchers have found that most older people age with little apparent impairment and even have a strong drive to remain independent [8], while the existing literature suggests that older people perceive themselves as younger than their actual age and that their behavior even appears younger than their actual age [9], so it is suggested that the design of the study should not be oriented towards the "age" factor, but should focus on physical and behavioral changes in older people [10].

Another challenge in designing wearable devices for older people is that "current commercially available wearable devices can only measure basic steps, the distance which can be called health assessments. However, the accuracy of relatively complex activity, sleep quality measurements remains poor" [11]. With regard to the design of wearable devices, there are no enhanced features designed for the elderly population, for example in the health management function, which should help the user to change healthy behaviors together with the monitoring process, wearables and smartphones currently rarely include personal barriers and subsequent solutions to problems [12]. Finally, the researcher found four areas where designers misunderstand older users when designing: "aesthetic preferences of older people, sensitive identity symbols, acceptability of

usage behavior and neglect of privacy" [13].

1.4. Article Chapter Structure

This article, in the introduction section, briefly describes the development of wearable device technology, and presents the current situation of older people. The value of wearable devices and their applicability, and presents the current state of use for older people. In the rest of the paper, Section 2 describes the methodology used in this literature review and the references. Section 3 is the core of the paper, Section 3.1 illustrates that wearable devices domains of elderly. Section 3.2 focus on the types of wearable devices for older people. In Section 3.3, the interaction modes of wearable devices for older people are described. In Section 3.4, interaction design principles and interaction design guidelines for the use of wearable devices by older people are described. In Section 3.5, a brief description what designers should do when evaluating wearable devices for older people is presented. At the end of the article, we also discuss the current limitations of wearable devices for the elderly and potential future directions.

2. Methodology

This study conducted a literature review on wearable device interaction technologies for older adults, using the search engine Google Scholar to search for academic articles from IEEE Xplore, Science Direct, Hindawi, MDPI and others, with possible combinations of keywords from all databases: "wearable devices" "wearable technology" "elderly " "older adult" "human-computer interaction" "interaction technology" and a literature review. The 115 articles were collected from the database and 20 duplicate articles were removed during an initial screening of the article titles, according to the inclusion criteria: academic articles in English; articles with a policy and standards perspective, finally, 73 articles met the inclusion criteria and were subjected to a thorough reading and scientific analysis.

3. Interactive Technologies Wearable Devices for Elderly

3.1. Wearable Devices Domains of Elderly

3.1.1. Fitness and Sports

According to the study, older people mostly accept wearable activity trackers [6], they clearly understand its value to their lives [14].

The fMOOC project is a wearable augmented fitness project for older people that combine fitness trackers with gamification elements. The aim of the project is to combine creativity, learning and insights from health theory to promote healthy ageing [15]. Additionally, wearable devices can improve quality of life by increasing an individual's physical activity [16], Can motivate older adults to be more physically active [17]. In addition, researchers studying habit formation regarding older adults' use of wearable activity trackers have found that long-term wearable users tend to initiate wearable activity trackers in a meaningful way

[18].

In another study of 92 older adults, four frustrating factors were identified: inaccuracy of reported data, challenges with instructions for use, device malfunction, and discomfort while wearing the device [19], and older users identified a need for enhanced interface design for data visualisation and provision of technical explanations [16]. Therefore, the four most important aspects for older adults are: the operation of the app, data comprehensibility, the graphical user interface of the app, and the operation of the wristband [20].

3.1.2. Health Care

Healthcare is increasingly used in wearable devices, for example, the use of Google Glass' head-mounted display has features in healthcare [21]. Older adults with osteoarthritis of the knee rated the smart watch app positively and were satisfied with the device.

Wearable technology in healthcare-related applications focuses on prevention, diagnosis and rehabilitation [22] [23]. The need for wearable technology in relation to ageing is described in the study of potential applications of smart multifunctional wearable materials in geriatrics, including devices for home rehabilitation, telemonitoring, social well-being, frailty monitoring, diabetes monitoring and wound healing, and fall detection (Armstrong *et al.*, 2017). Some researchers have also found that in the wearable device user community, common health-related data used by users include temperature, weight, daily steps and distance [19].

While health features have been utilized in wearable technology for older users, most commercial wearables in the current market are lifestyle and fitness products and are not as comprehensive and specific as medical grade devices [24]. Meanwhile, a lack of awareness of telemedicine services and wearable telemedicine device technology was found in the study of wearable medical devices providing telemedicine services targeting older people in Poland [25]. Results in understanding the ongoing wearable technology use behavior of middle-aged and older adults in fitness and self-health management also suggest that perceived enjoyment and attention have a positive impact on attitudes [22]. However, the loss of performance in activities of daily living is greater in people with physical impairments compared to cognitive functioning or sensorimotor control [26]. Therefore, differences between patients' health and digital skills should be considered when designing about medical wearables, which are important for the understanding and utilization of health-related information in wearable solutions.

3.1.3. Assistive Technologies

The use of wearables as assistive technology has become more practical and affordable with popularity of wearable devices [27]. Wearable applications have been used for sign language recognition and to support users with visual impairments, hearing impairments, mental impairments [3]. For example, to in-

crease users' awareness of their emotional state, MoodWing, a wearable device mounted on the user's wrist and foot can help those with poor emotional expression, such as sick children and elderly people in nursing homes [28]. Wearable devices are used as assistive technologies for the expansion of human senses, as well as prosthetics for organ or limb replacement and medical devices for monitoring specific diseases [3].

One researcher has developed a Google Glass-based virtual assistance system to support people with mild cognitive impairment and older adults in their daily lives. The aim is to allow the user to maintain a high degree of independence in different daily situations [19]. Supporting the wearable soft robot IronHand system as an assistive device or training tool is a promising approach to combat the decline in physical function associated with ageing [29]. A scalable, easily modifiable and on-site assistive technology system that detects walking behavior in comfortable smart shoes to prevent possible health problems in older people and promote their lives as independently and safely as possible [30].

3.1.4. Navigation

Navigation devices can help them to remain autonomous in their daily activities. Some researchers have studied the navigation experience of older pedestrians, whether using visual (augmented reality glasses) or auditory (bone conduction headphones) wearable devices, to help them find their way around. In one study, navigation performance was measured and explicit interview techniques were applied to obtain a detailed description of the user experience, highlighting three main phenomena that affect the quality of the user experience with both devices: a shift in peripheral awareness and the emergence of feelings along the way [31].

Meanwhile a study has highlighted that older pedestrians could benefit from the use of bone conduction headsets and smartwatches, which provide turn-by-turn directions to find their way around urban environments. Both inattention and the time required to navigate the route are less than with paper maps. In addition, the user experience and success rate is superior to that of AR glasses providing the same type of instructions. The problems faced by AR glasses may be due to the immaturity of such devices, being too heavy and the lack of contrast of the projected visual information to be perceived outdoors.

3.2. Types of Wearable Devices for Elderly

3.2.1. Wrist-Worn Devices

It was found that the most used wrist wear devices by older people include: smart bracelets and smart watches. Older users rated the way the wristband was attached and the synchronization between the wristband and the appropriate app poorly [17]. In addition to data security, older adults value comfort when wearing a bracelet and a clear screen. Due to reduced vision, it is difficult for older adults to see small screens. However, a clear limitation of the market is that the technology has not been developed to suit the needs of older users [32]. In based on Maslow's Hierarchy of Needs theory, it is important to study the dif-

ferent levels of needs of older people and use this to guide the design strategy of smart bracelets for older people [33].

Studies found positive attitudes toward smartwatch use among older people [34]. For most older people, smartwatches are useful, but these are not the main reason for adoption. Value and desirability play a key role in smartwatch appropriation, and as such, smartwatches and potentially other technological devices play a key role in expressing the user's identity [35]. Furthermore, design aesthetics were identified as an important factor influencing behavioral intentions across the user community, with screen size and uniqueness having a significant impact on current user usage behavior and potential users' willingness to purchase. Gender has an influence on current smartwatch user usage behavior, with female users being more likely to behave in this way than male users [36] [37]. A breakdown of usability issues for older adults using smartwatches reveals: user interface and hardware [38]. Furthermore, the study suggests that prior experience, emotional quality and technology-related anxiety affect older people's perceptions of ease of use.

3.2.2. Headset

Smart glasses are one of the more common devices. Researchers have found it difficult for users to set them up correctly and to connect the smart glasses to the internet. However, the use of head-mounted displays like Google Glass is becoming more popular, especially in the healthcare sector [21]. Smart glasses have the potential to enable learning content to be accessed by different groups of users, regardless of location and time [39]. Some researchers have also previously studied the suitability of Google Glass for older people, finding through the study that 60% of participants found the design attractive, reasonably good operability and low system complexity [39]. In addition, design principles for smart glasses were established in the context of vocational education and training [40]. In addition, wearable cameras can help older people with mild cognitive impairment can become qualified users of life records with good acceptance, with potential benefits for memory outweighing privacy concerns, while limitations, advantages and implications for future research are discussed [41].

3.2.3. Wearable Clothing

The researcher studied the effect of wearable robotic gloves on functional motor performance in older adults and found that participants were able to generate greater pinch force and rated usability very positively when wearing gloves compared to no gloves. However, this was not reflected in improved functional performance of the gloves. Further design adjustments are needed and more research to investigate whether glove performance can be improved [29]. Some researchers developed guidelines for the design of clothing-based soft wearable robots. They include function, design and actuators. Three stocking types and one trouser type were then designed. Wiring position measurements were carried out with the prototype to try a survey to modify the design based on the

survey's satisfaction with the design, similarity and intention to use [42].

In addition, one researcher described a user-centered design approach based on the assessment of user acceptance of smart clothing. It was also used to assess the general response of each garment type to different categories and to determine the propensity of older users to use the developed product. User-centered design plays an important role in the design process, it enables the understanding of users' needs, and guidance of positive attitudes in older people [43].

3.2.4. Wearable Shoes

Smart devices worn on the feet are not popular among older people and current findings are limited to studies in the literature. Some researchers have found that wearable shoe sensors can measure gait characteristics associated with Parkinson's disease. Such measurements could be used not only to detect symptoms but also to assess the effectiveness of treatment [44]. In addition, researchers have proposed a scalable, easily modifiable and on-site assistive technology system based on comfortable smart shoes capable of detecting walking behavior to prevent possible health problems in the elderly [30]. Researchers have also found insoles with an integrated fall prediction intelligence system that captures the physiological aspects of impaired minimal toe clearance variables risk factors, signaling imminent danger to the user and thus helping older people to prevent falls [45].

3.3. Interaction Pattern of Wearable Devices for Elderly

3.3.1. Vision

It is well documented that older adults have reduced sensitivity to information beyond central vision [35] [46]. Physiological changes in the eye reduce visual acuity, colour vision and effective visual field. Colour vision can also be affected, making it difficult for older people to distinguish between similar shades, particularly within the blue-green range [47] [48]. For example, as an object moves from central to peripheral vision, its detail becomes more difficult [49].

Graphical user interfaces are the most commonly used in wearable devices, with graphic design decisions including colour, icons, text, resolution and navigation paths [3]. Users find text feedback more credible than that sent by images. However, Icons are more intuitive and therefore easier for the wearer to read, however, in wearable devices, they usually have very limited screen space, so the visual display is easily confused by information and components [3].

Researchers have proposed visual design solutions for older people when using wearable devices, A visual display suitable for older people should be easily adjustable, consistent brightness is necessary and pop-ups may be allocated to specific parts of the screen to avoid overloading the user. Meaningful icons are provided to differentiate between categories, text-only lists may cause problems for those with poor eyesight. In general, keeping the visual presentation simple and clear is key when designing for older users [46]. Avoid visual clutter by showing or hiding information according to distance. Information should be

concentrated in the centre of the older person's field of vision. Colour schemes should avoid shorter wavelengths, such as blue and green, as older people are less sensitive to these wavelengths. For optimal contrast, text should be presented in black and white [46].

3.3.2. Audition

Auditory wearables such as earpieces and headphones, most of them are small and easily portable. Auditory feedback is key to hands-free interaction and can be achieved through bone conduction. Voice interaction is a way to help technology products become more accessible and convenient, and successful user interaction with technology products depends heavily on the user's ability to hear (Nunes *et al.*, 2010). In addition, voice interaction is the most natural way for humans to communicate, it does not require visual feedback [3] [50]. Speech interaction is recommended when the primary task is manual and requires visual attention or physical demands to be performed correctly [3] [50]. In addition, auditory frequency decreases with age. At the age of 65, approximately half of men and 30% of women suffer from varying degrees of hearing loss.

Some researchers have suggested auditory interaction with wearable devices for older people, where specific sounds can make human interaction meaningful. One researcher suggested that acoustic feedback could provide an auditory icon with a short and distinctive sound [50]. Older people receive adequate auditory information by controlling volume and rate of speech, making speech more understandable, and improving the effectiveness of the system state [46]. Empirically, a sound intensity of 85 decibels is close to the level appropriate for many older people and stimuli with high frequencies >4000 Hz should be avoided [50]. Auditory stimuli must last longer. Researchers have proposed increasing the amplitude of these frequencies when needed to counteract age-related decline. To accommodate this adaptive approach, devices can incorporate a "hearing test" to calibrate the output signal of a given device to a specific user [3] [51].

3.3.3. Body Sense

The benefits of haptic interfaces provide a more intimate and private experience for the wearer. Haptic devices provide feedback to the user's skin, including changes in intensity, magnitude, pressure, duration and pattern [52].

However, older people are less sensitive to haptic feedback, which is necessary to interact with technology. Touchscreen interaction modes are currently dominant in mobile devices, but it remains a challenge to apply them to very small wearable devices [50]. The main disadvantage of haptic response is that users are not used to using it and therefore conveying an intuitive response can be a challenge for designers [50]. Tactile-based systems are impractical for most users with disabilities. For example, users with visual impairments are not always able to use touchscreens, and they have a higher sensitivity to tactile feedback for output responses [53].

Some studies have mentioned, when providing assistance with haptic design

for older people, that when using vibration as a cue, higher frequencies of 60hz and above must be avoided as sensitivity decreases linearly with age from adolescence onwards. When delivering tactile information, upper body parts (e.g. hands) should be preferred over lower body parts (e.g. feet) because age-related sensitivity to the lower limbs decreases more [46].

3.3.4. Gesture

Gestures are used to input inputs, either through finger gestures on the smartwatch screen or through head gestures embedded in the headset [54], and although actual hand and body gestures are rarely used for input during movement, gestures are very beneficial for interaction as the wearer does not have to look at the screen to interact. Gestures can be performed while moving, facilitating the communication of wearable devices. Gestures can also be performed with the eyes, using eye gaze and sweep to control the input [55].

However, gestural interaction is considered unnatural as users are not always accustomed to communicating through gestures [54]. In addition, changes in motor control, including fine motor control, increased coordination, and the onset of illnesses such as arthritis, may affect the experience of physical interaction with technology for older people. Older users often have difficulty finding small targets and are less accurate in their movements. Continuous, rapid movements such as "drag and drop" and "double tap" are also difficult to accomplish. Indeed, fatigue is also present as a problem, especially when these gestures have to be performed for long periods of time [3].

It is important for designers to consider the decline in fine motor control with age [56]. In addition, larger buttons and longer click intervals are some ways to reduce user distress and eliminate unnecessary errors. Depending on the device, system or process, older people should have the opportunity to customise settings such as language, gestures, voice input, text size, color contrast, and the intensity and frequency of sounds [46].

3.4. Interaction Design Principles and Interaction Design Guidelines

In order to improve the design of wearable interactions for older adult users, researchers have defined a number of interaction design principles and guidelines that can help analyse and compare different design solutions. The design needs to be refined according to principles that can increase the usefulness and adoption rate of older adult users, while reducing frustration [57].

3.4.1. Design Principles

1) Aesthetics

Aesthetics is one aspect of wearable devices that attracts users to purchase them in terms of form and function. People are more concerned with shape, size, color and material when using wearable devices, and that gender moderates user behavior, with women being more influenced than men.

2) Comfort

Focusing on the location, fit, size, weight, and stability of the device [58], allow them to move naturally and ease the burden on the wrist without any additional restrictions [59], while smaller form factors and convenient sensors can also help ensure user comfort.

3) Highlight

Zoom in on key information, text, graphics, etc. and make it clear [60], greater spacing between different control elements, content arranged in order of importance, kept in the middle of the interface. Text should be presented in black and white, larger text and adjusted to the appropriate font size. Adequate feedback is another key feature [61].

4) Overload

Human processing power is still limited, and therefore there is a limit to all the operations that can be performed in a given amount of time, which presents a particular challenge to designers [3]. Avoid information overload, so that users may focus on the technology.

5) Privacy

Providing privacy, security and safety is an integral part of the system's functionality. Elderly users are very sensitive to sharing information about themselves [3]. The system should therefore follow the management of personal information security through encryption and identity verification [60].

6) Memorability

Reduce cognitive load by providing older people with tools to help them remember when using wearable devices. Digital information, such as instructions and system controls, must be displayed near the older user when necessary [60].

3.4.2. Design Guidelines

Guideline 1*: Appearance design of wearable devices for elderly*

1) Shape

For most older people, they mostly think that the form of a wearable product should be equivalent to the shape of a watch [62]. Therefore, wearable devices with a rounded appearance or with rounded curves are more popular with older people.

2) Color

In terms of color choice, older people prefer darker colors to brighter ones, but for female users, aesthetics are important, so the appearance of a variety of color wearable devices can increase the purchasing power of users.

3) Screen

Older people mainly prefer larger screens for better display of information, but prefer smaller devices for portability [19] [63].

4) Material

Older people preferred leather or rubber material materials [62]. Materials with elasticity are well suited to joint movements of older people. For example, soft straps of suitable material are used to avoid redness or sweating of the skin

[11].

Guideline 2: Interface design of wearable devices for elderly

1) Text

Minimum 12 pt font, avoid handwritten and decorative fonts [11], text is arranged in order of importance, kept in the middle of the interface, and for best contrast, text should be presented in black and white. In addition, plain text lists may cause problems for those with poor eyesight.

2) Icon

To accommodate a wide range of literacy and language skills, generic icons are used to easily convey information. In addition, they are accompanied by text descriptions to ensure that the icons are recognizable. The icons needed to be large enough to be seen at a comfortable viewing distance. Finally, highly saturated shades are used to maximize color contrast [3].

3) Layout

The design should reuse internal and external components to maintain consistency with the purpose, thus reducing the need for the user to rethink and remember. Make the menu area large enough and wide enough for light presses or clicks. Place essential UI elements in a visible area, preferably within the reach of the user's thumb [11].

3.5. Interaction Design Evaluation

Evaluation methods depend on their goals, objectives, stage of technological development, target audience, time, budget constraints. Qualitative or quantitative depending on the nature of the data collected [3]. The assessment of the end user helps to find the right solution for the user's needs. Of the expert-based usability methods, heuristic evaluation and cognitive rehearsal are the two most widely used in the field of human-computer interaction [11]. In general, usability testing can be divided into two categories: testing by users and testing by experts [64]. Based on the results of the evaluation, the technology is iteratively redesigned to solve the problems encountered, improve the level of quality, and improve it until an acceptable version is reached.

In order to determine whether the wearable interface is effective and satisfactory in the assessment, subjective ratings are collected by asking wearers about their perceptions of the device and allowing wearers to express their views on comfort and acceptability of the technology [3], Evaluation techniques for wearable devices focus on reducing human error and frustration.

In the comparative usability assessment, synchronisation and navigation of the app was quite difficult for older participants. In evaluating visual models, designers should perform usability testing, create audit reports, and identify improvements prior to final delivery. Khakurel also combines multiple methods using usability evaluation where data is collected through surveys, observations gathered during reflection, and information gathered from diaries to assess user perceptions of perceptions of self-tracking wearable technology [2].

4. Conclusions

4.1. Limitations

Real age is used as a measure of older people, which is not a reliable way of looking at older people as there is a great deal of variability between them, including physical fitness, personal experience and ability. For example, a 60 year old may have used a computer in the workplace, whereas an 80 year old may not. There are even older people who, as they age, have little apparent impairment and a strong drive to remain independent. But some older people's physical condition becomes physically weaker with age. Another is that the literature reviewed in this study was limited to the English language literature, in which other areas of research may be missing.

4.2. Future Research and Conclusion

This paper presents an extensive literature review on interaction technologies for older people using wearable devices. Wearable devices have faced significant growth in the last few years and can be valuable tools to help older people in their daily lives. However, wearables are still relatively new to older people. The literature review analyses and discusses the current development status of wearable devices and the attitudes of older people towards wearable devices, understands the barriers and frustrations that older people encounter when using wearable devices, and summarizes the specific requirements of older people for wearable product design in terms of the appearance, functionality and interaction of wearable devices. Finally, interaction design guidelines and interaction design assessments are summarized in terms of user experience and understanding of user behavior to guide designers in designing more appropriate wearable devices for the elderly population.

Despite the growing acceptance of wearable devices by older people, there is still room for improvement in terms of usability and durability of the devices. And keeping the interface simple are all factors that designers will need to consider in the future. In the study, it was also found that the health function and exercise function are the most used by the elderly population and the design of this function should be enhanced. At the same time, attention should be paid to their physical condition and ability to use them, and the visual, auditory and tactile senses of older people are factors that designers should consider when designing. The size, color, size and material of the device are all factors that older people will consider when purchasing. The end user should be involved at the final stage of the design process to evaluate the user and refine the design. There is still limited literature on the various areas of interaction with wearable devices for older people, such as those worn on the feet and head-mounted smart devices, which should be explored, and it is hoped that in the future more research experts will join in and provide more clues.

Conflicts of Interest

The author declares no conflicts of interest.

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