Facilitating Accessibility and Digital Inclusion Using Gaze-Aware Wearable Computing

Andrew T. N. Kurauchi, Antonio Diaz Tula, and Carlos H. Morimoto
Department of Computer Science
University of Sao Paulo
São Paulo, SP, Brazil
{kurauchi, diaztula, hitoshi}@ime.usp.br

ABSTRACT
Gaze interaction has been helping people with physical disabilities for many years but its use is still limited, in part because it has been designed for desktop platforms. In this paper we discuss how gaze-aware wearable computing can be used to create new applications that can significantly enhance the quality of life of people with disabilities, including the elderly, and also be used to promote digital inclusion for illiterate people.

Author Keywords
Accessibility; digital inclusion; gaze tracking; wearable computing; gaze interaction; augmented cognition;

INTRODUCTION
> *"For persons without disabilities, technology makes things easier. For persons with disabilities, technology makes things possible."* – Radabaugh, 1988.

Accessibility and digital inclusion are listed as part of the Great Research Challenges for Human Computer Interaction in Brazil [4]. The concept of accessibility often focuses on people with disabilities or special needs, such as the United Nations Convention on the Rights of Persons with Disabilities [15], to guarantee their right to live independently and participate fully in all aspects of life.

The term "disability" has been defined by the World Health Organization as an umbrella term with several components, that includes [6]:

(i) impairments (a problem in body function or structure);

(ii) activity limitations (a difficulty encountered by a person in executing a task or action); and

(iii) participation restrictions (a problem experienced by a person in involvement in life situations).

For those people with disabilities, it is important to construct interfaces that are accessible, flexible, and adjustable, taking into account the different contexts and diversity of the Brazilian culture [4]. Considering the presented definitions, Human Computer Interaction research on accessibility should take into account how to improve the independence of people with disabilities in all places, even when they are not interacting with their desktop computers.

In recent years, the COGAIN community (`http://www.cogain.org`) has shown that eye movements are an important mean of interaction and communication for people with disabilities, though, despite many recent advancements, gaze-based applications are still limited to simple tasks such as eye typing.

Another emerging technology that has great potential to help people in their everyday activities (not only people with disabilities) is wearable computing. In this paper we describe a few ways of how gaze-aware wearable computing can significantly improve the life of people with disabilities and facilitate digital inclusion. Our position is that these two emerging technologies complement each other, so that their combination will overcome most of their current difficulties. Thus, allowing wearable applications to assist both users with and without disabilities in different aspects of life, even when away from their desktop computers.

In the rest of this paper, we further describe the current state of the art of gaze-based interaction and wearable computing, and describe scenarios where people with disabilities will become more independent and have access to digital media using this new technology.

GAZE-BASED INTERACTION
Gaze interaction represents an alternative of communication for people with disabilities. In this modality of interaction, the user can control an interface with his or her eyes using an eye gaze tracker. Modern eye gaze trackers use video cameras and computer vision algorithms to detect and track facial and eye features such as the pupil, sclera, iris, and eyelids. On a typical remote setup using a desktop computer, the eye camera is positioned under the computer monitor that is used to present the visual stimulus (or visual targets). A calibration process is performed to estimate a mapping function to transform eye features computed from the eye images to the point-of-regard on the computer monitor. More recently,

head mounted gaze trackers have been introduced. In a head mounted setup, two cameras are used, one pointed at the eye and a second looking at the scene. Gaze is computed using a calibration function that maps the eye features on scene image [7].

People with disabilities, such as lateral amyotrophic sclerosis and locked-in syndrome, that cannot use standard interaction devices, can benefit from gaze interaction as a mean of social reinsertion. An example of the current efforts to advance gaze interaction is the Communication by Gaze Interaction (COGAIN), association that aims to promote research and development in the field of gaze-based interaction in computer-aided communication and control (`http://www.cogain.org`).

Despite recent advances in gaze interaction, there are several limitations with this interaction modality [7]. Some limitations are technological, for example, the use of current eye gaze trackers is limited to indoor spaces, with controlled illumination; the calibration drifts requiring system recalibration; and limited spatial accuracy in point-of-regard estimation (which is about 0.5^o in commercial eye gaze trackers, going up to 1.5^o in low cost solutions).

Though gaze has been long proposed for interaction purposes, the development of gaze-based applications is still a challenge. Because it is natural to look at objects of interest, gaze can be used efficiently for pointing, but selection or "clicking" using gaze is not straightforward. Most current gaze interaction paradigms rely on dwell-time (the user has to fixate at the visual target during a dwell time, after which the target is selected), or gaze gestures (the user has to perform a particular sequence of eye movements or follow certain targets). These paradigms impose unnatural eye behaviors that make the interaction not appropriate for most people to use. Therefore, current gaze-based applications are limited to simple activities such as eye typing and command activation, and its use with head mounted eye gaze trackers remain mostly unexplored.

WEARABLE COMPUTING

Wearable computers have the characteristic of being always on and available. Current smartphones, though might be always on, are not always available, since it must the be picked up and manipulated. Therefore, they are considered mobile but not wearable computers yet. Based on the forthcoming Google Glass and the Vuzix M100 the next generation of smartphones is moving from mobile to wearable by using a head-up display (HUD) for "hands free" constant information and communication access. With the announcement of such commercial wearable devices and considering recent developments it is possible to say that this technology is maturing in equipment size and weight, price, battery life, and other aspects. However, applications must deal and take advantage of the unique characteristics of wearable devices.

Wearable Computing Usability Issues

Constancy is an important characteristic of wearable computers. Because the applications can be always on and available, having information popping up at any time may distract the user and even become a hazard in particular situations, such as competing for (or even obstructing) the user's attention when crossing a street.

Therefore, the design of wearable applications must consider different design issues than desktop applications. In particular, as pointed out by Rhodes [13], typical WIMP interfaces require fine motor control and eye-hand coordination on a large screen, while many typical wearable computing applications are secondary tasks (e.g. reminders) or support a complex primary task. Even when the wearable application is the primary task (such as text editing), the environment might intrude and, therefore, there is a need to design for low and divided attention.

With this in mind DeVaul [3] defined the following principles of low-attention interaction for wearable computing:

1. Avoid encumbering the user, both physically and perceptually, referring to the hardware, peripherals and interface.
2. Avoid unnecessary distractions, by minimizing the frequency and duration of the interactions, and using appropriate context information.
3. Design interfaces that are quick to evaluate, so the user, even when interrupted, is always in control.
4. Simplify the execution as much as possible, but no further. Easy things should be easy, hard things should be possible.
5. Avoid pointers, hidden interface states, non-salient interface changes, and never assume the wearable interface has the user's undivided attention.

Another problem with traditional wearable computing platforms is the limited input modalities to allow user communication and context estimation. For example, chord keyboards commonly used in wearable computing [3] require a long time to learn and use efficiently and, particularly during the learning period, the attention focus could lead to hazardous situations if the user wants to type while crossing a street for example. Voice commands would be better in this case, however in the presence of other people the user might feel uncomfortable talking about private issues.

Considering these issues, the following challenges in wearable computing still require further research:

- Interaction challenge: how can the user privately and comfortably interact with the wearable device in low or divided attention situations?
- Context estimation: how the wearable applications know when to interrupt the user and what information is most relevant?

In the next section, we discuss possible solutions for such challenges using gaze information.

GAZE-AWARE WEARABLE COMPUTING

Only a few works in the literature have suggested the use of gaze enhanced wearable applications. Bulling et al. [1] suggest the use of user's eye movement to determine contextual information for wearable applications, but does not use gaze information. Data input is carried out using a chord keyboard. A concrete example of a wearable augmented reality system using gaze interaction was described by Park et al. [12]. Their system relies on scene markers to position virtual objects. Gaze information is used to point and objects can be selected by dwell-time.

By enhancing wearable computing with head mounted eye trackers, wearable applications can use gaze information for both interaction and user context estimation. For example, current gaze interaction techniques could be used in wearable applications to interact with a computer or smart environments, while gaze and eye movement behaviors can be used to determine the context of interaction, where only the object being gazed, among several other possible objects in the scene, can be used to receive a command issued by voice, keyboard, or switch. Such context-aware ambient intelligence is very important to enable anyone, especially people with disabilities, to easily access information services and to support them in a wide range of daily activities [2].

Therefore, gaze interaction that is considered today to have limited benefits to desktop applications, will have significant impact to wearable computing applications, helping this technology to reach its full potential, and gaze-based interaction can finally be useful to all users, with and without disabilities.

Example Applications

In this section we discuss how combining wearable computing with gaze information can create new application scenarios to facilitate accessibility and digital inclusion.

Carbonell [2] shows how ambient intelligence can provide accessibility to people with physical disabilities while building applications for the general public with the use of multimodal input and output. Considering our argumentation, wearable computers could provide contextual information, such as heart rate and focus of attention, and gaze could be used to send simple signals to control the objects in the environment. Mardanbegi et al. have shown how to use head-gestures in combination with gaze pointing for interaction in smart environments [10].

Take a smart lamp as an example. Gaze information could be used to infer that the currently focused object is such lamp. A simple gaze-based interface could be provided on a head-up display to allow the user to turn on/off the lamp or control its brightness. Other more complex possibilities could follow the same principle to, for example, set ambient temperature, control a television, or call the caregiver. In such environments people with disabilities would be empowered with much more independence. It is important to note that even the low accuracy on low cost eye gaze trackers would be enough to control gaze-based interfaces on head-up displays with few buttons or regions of interest.

Accessibility also promotes digital inclusion, since accessible systems allow people with disabilities to use services such as online education, e-government, e-commerce among others [11]. Gaze-aware wearable devices could facilitate digital inclusion of the illiterate while also assisting their alphabetization. The application could, for example, read aloud the currently gazed word or syllable, or automatically search the dictionary definition of a word the user has trouble reading. The wearable system and applications would then be capable of acquiring much more information about the user's activity and state, and obtaining a better understanding of the surrounding environment. Note that similar applications could be used by people travelling in foreign countries, where signs in train or bus stations or even the restaurant menus are written in a unfamiliar language.

Also other groups could be favored by such gaze-aware wearable devices. By knowing where a person has not looked it is possible to emit warnings about approaching objects that have not been seen while walking or driving. This would be particularly useful, for example, for the elderly when crossing streets or distracted drivers.

Aging also is commonly followed by other signs such as degrading memory and diminished visual/auditory perception. Next we discuss augmented cognition applications that could be used to compensate for such aging signs.

Augmented Cognition

Augmented cognition is the field of study that seeks to enhance the cognitive performance of the user, such as memory or skills [14]. It is done by partially coding their cognitive process and context to design interfaces that assist in the decision making process or other mental tasks. Considering the user's cognitive process it is possible to adapt the interaction and interfaces to suit the needs and difficulties of each person.

Wearable computers can be used to support the user's primary, and possibly complex, task due to their ability to augment and mediate reality. In a similar way, augmented cognition applications aim at assisting the user to perform mental tasks. Thus using wearable computers to create augmented cognition applications is a direct consequence.

A concrete example is given by Mann and Fung [8]. They use an EyeTap [9], a device that combines a head-up display (HUD) with a scene camera, to present a diminished reality. They show how removing clutter, such as advertising and billboards, from the image can help the user by avoiding information overload. The EyeTap configuration allows the camera to capture the same image as it would be captured by the eye, providing very realistic visual effects and life logging data that can be shared and used as the user's extended memory [5].

Similar but simpler configurations such as the "Memory Glasses" created by DeVaul [3], may place a wearable HUD to (or instead of) the lens of the eye glasses. In such configuration, the useful display area covers just part of the visual field of view of one of the user's eyes, reducing the quality of the mediated reality experienced. The "Memory Glasses" provide just-in-time information based on the user's context. With the use of a chord keyboard the user can create reminders for delivery by time, location, social, and action context. As we previously argued gaze could be used both as a contextual information provider and as an input modality in all these examples.

CONCLUSION

We have discussed how gaze-aware wearable devices can be used to promote accessibility and digital inclusion when the user is not interacting with a desktop computer. We also have proposed how eye trackers can be combined with other wearable devices to overcome some usability issues, namely, gaze as an extra input-mode for wearable interaction and user context estimation.

Wearable applications must be developed for low or divided attention and should therefore consider different usability principles than desktop applications. The use of gaze information will facilitate the application of such principles, creating opportunities for several innovative applications. By moving the user away from desktop computers with the use of wearable devices, both the general public and users with disabilities can be given similar opportunities for interaction. Because the general public will be benefited as well, more and better applications will be developed faster, so that more people with different disabilities (such as impairments, activity limitations and participation restrictions), that includes the elderly with diminished cognitive and perceptual processes, and the illiterate, will also benefit.

Our group and collaborators are working to create low cost gaze-aware wearable platforms and applications, in particular, applications to help communication by gaze interaction for people with severe motor disabilities, and we hope that more people will be inspired by these ideas in helping advancing these two emerging technologies that might be, soon, considered one.

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