Designing Eyes-Free Interaction

Ian Oakley and Junseok Park

Smart Interface Research Team, Electronics and Telecommunications Research Institute
161 Gajeong Dong, Yuseonggu, Daejeon, 305-700, Korea
{ian, parkjs}@etri.re.kr

Abstract. As the form factors of computational devices diversify, the concept of eyes-free interaction is becoming increasingly relevant: it is no longer hard to imagine use scenarios in which screens are inappropriate. However, there is currently little consensus about this term. It is regularly employed in different contexts and with different intents. One key consequence of this multiplicity of meanings is a lack of easily accessible insights into how to best build an eyes-free system. This paper seeks to address this issue by thoroughly reviewing the literature, proposing a concise definition and presenting a set of design principles. The application of these principles is then elaborated through a case study of the design of an eyes-free motion input system for a wearable device.

Keywords: Eyes-free interaction, design principles, motion input

1 Introduction

Modern user interfaces come in a vast range of shapes and sizes, an inevitable consequence of the spread of complex computational functionality from the office computers where it first evolved to the living rooms, cars, sofas, pockets and even clothes of everyday users. The rich graphical interaction paradigm developed for desktop personal computers is clearly inappropriate for an ultra-portable music player intended for joggers, and arguably a poor fit for even a sophisticated smart phone [13]. Indeed, there is a growing realization that the design of an interface needs to be tightly coupled to the context in which it is intended to be used, and an acknowledgement that the range of use contexts is growing rapidly wider.

This paper seeks to define, review, and explore the literature on one such class of new interface, termed eyes-free. This terminology has been in use for several decades as a descriptive phrase denoting a UI with little or no graphical component, but we argue that it is now emerging as a specialized interaction design area in and of itself, with unique features and qualities. Historically, the literature that has employed this term is distinctly heterogeneous: it originates from divergent motivations, addresses different domains, adopts different interaction paradigms and leverages different modalities. Authors have tacitly acknowledged this lack of accord by treating the term cautiously (typically using it italicized or wrapped in quotations). In this way, no unifying consensus has emerged regarding what exactly makes an interface eyes-free and, more importantly, what qualities makes one effective. Creating an interface that operates effectively without vision is a challenging task, but there are currently few general-purpose and easily accessible insights into how this might be achieved.

By offering a thorough review of the eyes-free literature, drawing out the themes that underlie it, this paper hopes to dispel the confusion surrounding this term and offer a set of principles against which future eyes-free system designers can position their work and understand the options available to them and the issues they will face. Less formal than a full theoretical explanation, this kind of framework has been widely applied in the HCI literature to systemize the design process, providing a focus and common language to facilitate discussions [18]. The review commences with an overview of the use of the term eyes-free in the HCI literature in order to delineate the scope of the research considered here. It then moves on to discuss the motivations that underlie the development of eyes-free systems and the properties of the different input and output modalities that have been employed to produce them. It culminates with a working definition and a set of principles for the design of eyes-free interfaces. This paper concludes by describing the design of an eyes-free interface for a wearable computing system which illustrates how these principles might be applied.

2 Eyes-Free Literature Review

2.1 History, Domains and Scope

Three domains which regularly reference the term eyes-free are voice recognition, gesture recognition and access technologies for the visually impaired. In the first, it is often coupled with the term hands-free and serves to describe two of the key features of voice input technology: it requires no mouse and no screen. In the second, it alludes to the fact that once learnt, users can perform gestures in the absence of graphical feedback; indeed as most systems do not feature any interactive feedback on the state of gestures, eyes-free use is the default mode. In both these domains, research tends to focus on improving recognition algorithms or the development, refinement and pedagogy of the semantically rich commands sets they support. In this way, we argue that the term eyes-free is peripheral, rather than central, to these research areas, and exclude them from the mandate of this paper. We make a similar distinction with access technologies for visually impaired users. The term eyes-free is an appropriate adjective, but the focus of this research area substantially differs from that which considers the wider population. An article from the former might focus on mathematical visualization techniques, while one from the latter, the interface to a personal music player. This paper is interested in this latter approach, and so excludes work conducted under the more established banner of access technologies.

Eyes free-interaction has been approached as an extension of work to reduce the amount of screen real estate taken up by a UI. With its roots in efforts to shrink graphical user interfaces through the presentation of audio or haptic feedback, this research has tended to focus on creating non-visual versions of user interface elements such as progress bars [4]. One important trend within this work is that it tends to focus on notification events, such as the completion of a file download or page load in a web browser page [16]. The simplicity of this scenario (where a single sporadically delivered bit of information may be sufficient) places light demands on the level and quantity of interaction required.

Work on audio (and less commonly haptic [17]) visualization has also used the term eyes-free, referring to the fact that the state of some system can be monitored without visual attention. Representative audio visualization work includes Gaver's [6] classic study of collaborative control of machines in a virtual factory and applied studies such as Watson and Sanderson's evaluations of structured sounds from a pulse monitor in a hospital scenario [21]. Finally, the term-eyes free is now also appearing in domains such as mobile [11], wearable [1], and pervasive computing. The typical approach in these systems is the design of a new input technique which enables interaction without visual attention. In particular it is this design process, in these emerging and demanding domains, that this paper seeks to shed light on.

2.2 Motivations

The fundamental motivation for eyes-free interaction is that as it leaves visual attention unoccupied, users are free to perform additional tasks [1], [17], [27]. Authors cite this motivation both in contexts where users are expected to be engaged in tasks in the real world (walking, driving) and tasks on their device (talking, typing). Underlying this proposition is the assumption that the cognitive resources consumed by the eyes-free interface will be sufficiently modest as to enable this. Essentially, an eyes-free interface is one that need operate not only without vision, but also without consuming an appreciable amount of thought or attention. An audio or haptic interface which requires focus to operate is unlikely to support even trivial multi-tasking. This places an additional challenge to eyes-free interface design that is arguably as central and demanding as the exclusion of visual cues.

The majority of other motivations are domain focused. Researchers in mobile interaction highlight the problems with screens on handheld devices: they consume power (reducing battery life), can be hard to see in bright conditions and it may simply be inconvenient to fetch the device from wherever it is kept just to look at its screen [27]. There is also a trend for mobile devices to feature larger screens and fewer buttons. One of the key ergonomic properties of buttons is that they can be identified and operated by touch alone, and the fact they are diminishing in numbers is likely to raise the importance of alternative forms of eyes-free interaction [11]. These same issues tend to be exacerbated in wearable computing scenarios, where researchers have also highlighted the inherent mobility and privacy [5] of interacting without looking as motivating factors for their systems.

2.3 Input modalities

Eyes-free input is characterized by simple gestural interactions which can be classified by conditional logic. Researchers have studied movements of styli [8], the finger [13], the hand [11], head [1] and even purely muscular gestures [5]. In each case, the movements themselves are closely coupled to the constraints of chosen bodily part. For example, marking menus [8], a well studied stylus based interaction technique, typically features straight strokes in all four cardinal directions as these can be performed (and distinguished) easily, comfortably and rapidly. In contrast, when studying head gestures, Brewster *et al.* [1] proposed a system that relied on turning of the head to highlight specific items and nods forward to select them. Nods backwards were not included as they were found to cause some discomfort and awkwardness. Similarly Zhao *et al.* [27] studied circular motions of the thumb against a handheld touchpad, as these fall within a comfortable and discrete range of motion.

A second common characteristic of eyes-free input is that it involves movements which are kinesthetically identifiable. The stylus strokes, turns and nods of the head or translations of the thumb mentioned above can all be monitored by users through their awareness of the state of their own body. It is trivial to distinguish between stroking downwards with a pen and stroking upwards. Equally, we are kinesthetically, albeit usually sub-consciously, aware of the orientations of our head with respect to our body at all times. The kinesthetic sense is often cited as the only bi-directional sense, in which motor output (in the form of some movement, muscular tension or strain) is tightly coupled to sensory input from the muscles, joints and skin informing us about this activity [20]. Taking advantage of this closed feedback loop is an implicit but important aspect of an eyes-free interface.

Although, as described in the next section, eyes-free interfaces are typically supported by explicitly generated audio or haptic cues, we argue that these messages are used to reinforce and augment the fundamental and inherent kinesthetic awareness that underpins eyes-free interaction. Kinesthetic input is the key factor that enables an eyes-free system to be operated fluidly and with confidence; explicitly generated additional cues add semantic content and beneficial redundancy to this basic property.

2.4 Output modalities

Eyes-free feedback has appeared as audio icons (semantically meaningful sampled sounds) [1], earcons (structured audio messages composed of variations in the fundamental properties of sounds such pitch and rhythm) [4] and speech [27]. In some cases the audio is also spatialized. Haptic systems have used both tactile [11] and force-feedback [17] output. These output channels vary considerably as to the richness of the feedback they support. For example, all three forms of audio output can arguably convey richer semantic content than haptic feedback, and of these, speech more than either audio icons or earcons. However, several other qualities influence the suitability of output modalities to eyes-free interaction.

The speed with which information can be displayed and absorbed is an important quality for an eyes-free interface. For example, a system based on user input, followed by several seconds attending to spoken output message, followed by additional input is unlikely to yield a rapid, satisfying or low workload experience. Indeed, such a paradigm, in the form of the automatic telephone menu systems commonly adopted by the call-centers of large companies, is widely acknowledged to be both frustrating and laborious [26]. This issue is exacerbated by the fact that a common eyes-free design technique is to segment some input space into discrete targets and provide feedback on transitions between these. Such transitions are usually designed to take place extremely rapidly; similarly immediate feedback is required to support them. This constraint can be satisfied at the cost of sacrificing the amount of information transferred in each message; a short cue signifying that an event has occurred is simply crafted, but it is considerably more difficult to convey an easily understood description of a command. The multi-dimensional trade off between the amount of information contained within user interface feedback, the speed with which this can be achieved and the amount of effort and attention required to interpret it is especially important in the eyes-free domain.

Eyes-free interfaces have also relied on continually (or ambiently) displayed background information. Inspired by every-day occurrences such as monitoring the performance of car's engine through the variations in its sound, this paradigm is arguably best suited to non-speech audio interfaces, and in particular to tasks which involve casually observing background events as opposed to issuing commands. It has a history in sonification [6], [21] where it has been shown that it can be informative, unobtrusive and effective.

The choice of feedback modality for eyes-free output is also mediated by the characteristics of the domain considered. Audio output is ideal for controlling a personal music player, where the clear perception of sounds through headphones is almost guaranteed. Its suitability may be in more doubt in other situations, where feedback from a device might be obscured by ambient noise or, alternatively, disturb other users. Equally, the use of tactile cues requires users to wear or hold an actuator of some sort and recent research has suggested [10] that perceptual abilities may be impaired when users are engaged in other tasks. It is also worth noting that some events may not require explicit feedback; the changes to the system state may be sufficient to indicate the action has taken place. Representative examples include actions such as terminating an alarm or answering an incoming call.

2.5 Learning Issues

One significant issue for eyes-free interfaces is how they are explored and learnt by a novice user. One reason for the considerable success of current graphical interfaces is that they support an exploratory mode of learning in which functionality can be explored and discovered – buttons can be clicked, menus scanned and mistakes undone from the offset. Given the constraints on the amount of information that can be displayed in an eyes-free interface, achieving a similar flexibility can be a challenge. The basic approach to solving this problem has been to introduce feedback which naturally scales; a novice can attend to it in detail, while an expert can ignore or skip over it. The concept is rooted in marking menus [8]. Typically, these systems feature four item graphical pie menus which users operate by making stylus strokes in cardinal directions. A typical example might involve tapping the screen to summon the menu, followed by visually scanning the items to identify an edit command at the base. Stroking downwards invokes the relevant sub-menu, in which a copy command is displayed on the right. It can then be selected by a rightwards motion. Through nothing more than repeated operation, users become able to dispense with the graphical feedback and simply draw an L shape when they wish to issue a copy command.

Zhao *et al.* [27] present a system which applies this concept to the speech output domain. In their list-like interface, all output is composed of brief transition clicks followed by short utterances describing the contents. These are truncated if a user performs additional input. Therefore, if a user interacts slowly, they hear the full description of the interface, while if they move rapidly then simply hear a sequence of clicks and aborted speech. Their approach appears to re-enable fluid, continuous, eyes-free interactions with the richness of speech output, something which has proven elusive in the past. Audio icon systems which present relatively long and informative snippets of sound, which are halted upon further user input have also been devised [1]. These examples suggest that rapid and low workload eyes-free interaction can only be achieved by experienced users of a system, and that incorporating a technique which enables novices to graduate to this status is an important aspect of eyes-free design.

3 Definition and Design Principles

This paper defines an eyes-free system as an interactive system with which experts can interact confidently in the absence of graphical feedback. The system should be aimed towards the general public, should feature an UI which enables a novice user to pick it up and use it immediately and should not rely on complex recognition technologies. We extend this definition with the following design principles:

1. Self monitored input: eyes-free input relies on the measurement of kinesthetic actions of the body: muscle tensions or the positions, orientations and movements of limbs. The bi-directional quality of the kinesthetic sense is what allows an expert user to monitor and mediate their input automatically and with confidence.

2. Input reflects bodily constraints: the control motions for an eyes-free interface should reflect the inherent characteristics of the motions of the body part being considered. The magnitude and stability of the motions, and the ease, and comfort with which they can be performed should be considered from the outset.

3. Minimal interaction models: eyes-free interaction models involve a simple, understandable mapping between a kinesthetic state and a system state. Metaphors (such as controlling the state of some virtual object like a cursor) should be kept to a minimum. The use of complex metaphors will detract from the correspondence between bodily and system states and will increase user reliance on the explicit cues generated by the system. This in turn will demand the deployment of more complex cues, which are likely to require additional cognitive resources to interpret.

4. Immediate output: eyes-free output is either immediate and short-lived or continually presented (and updated) as unobtrusive background information. Feedback needs to be displayed, and be capable of being absorbed, extremely rapidly. In cases where some external state immediately and noticeably changes as a result of the interaction, explicit feedback may not be necessary.

5. Seamless transition from novice to expert: fluid eyes-free interaction is the province of expert users of a system. It is important to provide a (possibly graphical) interface which enables novices to use the system straight away, but which also encourages them to seamlessly become experts who eventually no longer require it

4 System Design: Eyes-free input with a wearable motion sensor

Creating input devices for wearable computing systems is a challenging task. Input techniques need to be expressive, easy to learn and difficult to trigger accidentally, while input devices have to be small, lightweight and tough. High resolution graphical displays are unpractical in many scenarios while systems need to be expressive and easily understandable. Eyes-free interfaces are a natural fit with these criteria, and it is highly likely that future successful wearable interfaces will encompass eyes-free design elements. Reflecting this match, we explore the design of a wearable motion input system in light of the principles identified above.

Bodily motions that take place in free space can be captured by sensors such as accelerometers and gyroscopes and have considerable potential for wearable computing systems. The sensors are stand alone (unlike motion trackers or camera based systems) and are small, low power and low cost. It is relatively easy to embed them in articles of clothing or simple accessories such as watches or shoes so that they remain unobtrusive. Motion is also a rich six degree of freedom input channel theoretically capable of supporting a wide range of interactions.

Researchers have examined motion input for mobile devices using paradigms such as gesture recognition [7], text entry [22] and menu selection [9], [14]. Indeed, several mobile handsets, such as the Samsung SCH-S310, incorporating motion sensors have appeared. The literature is scarcer in the domain of wearable computing. In eyes-free themed work, Brewster *et al.* [1] studied simple head gestures coupled with an audio interface for the selection of different radio channels. Several authors have also presented solutions for wearable computing based around a wrist-mounted sensor pack. Rekimoto [15] describes an elegantly simple gesture recognition system reliant on static pose information captured from a motion sensor in conjunction with information about tensions in the wrist. Cheok *et al.* [2] describe a motion sensing platform in a number of different configurations, including one in which it is mounted on the wrist, but provide few specifics. Cho *et al.* [3] describe a wrist mounted gesture recognition system based on a simple conditional gesture recognition engine. Witt *et al.* [24] describe the preliminary design of a motion sensing system mounted on the back of the hand and report that users can comfortably perform simple conditional gestures to navigate around a graphically presented menu or control a cursor. The goal of their work is to develop a system to enable maintenance workers to access a computer without removing cumbersome protective apparel.

4.1 Overview

WristMenu is a prototype interaction technique based on input from a wrist mounted motion sensor, coupled with output on a vibrotactile display. It is based on a simple form of conditional gesture input and currently relies on a graphical display to allow users to seamlessly learn the interface. It is intended as a simple control interface for a wearable device, allowing users to issue commands and access a range of functionality rapidly and discretely. The technique is designed to be domain agnostic, and suitable for common wearable computing scenarios such as maintenance [24].

4.2 Designing eyes-free input

The wrist is an appropriate body site for a wearable computing device; it is both easily accessible and socially acceptable. Wrist movement can include translations and rotations along and around all three spatial axes. However, compared to a device held in the hand, wrist-based motion input is impoverished; the hand itself is by far our most dexterous appendage. Furthermore, as the wrist is relatively distant from the elbow, the joint it rotates around, many of the motions it can make are relatively large in scale (although the just noticeable difference has been reported as low as 2 degrees [20]). For example, tilting a device held in the hand by 90 degrees is relatively simple in any axis, but subjecting a device mounted on the wrist to a similar experience will result in much more substantial, and potentially tiring and strenuous, motions.

Reflecting these concerns, our system focuses on one degree of freedom rotational motions made around the long axis of the forearm. These motions are relatively small scale, can be made quickly and have a comfortable range of around 90 degrees, from roughly palm down through until the palm is facing the body. Given the limited size and accuracy of the motions available, we split this area into 3 equally sized targets as shown in Figure 1. Each of these targets is situated in an easily distinguishable kinesthetic position: palm down, palm facing the body and in between these two states. Subsequently, the targets in these orientations are referred to as targets 1 (palm down), 2 (central) and 3 (palm facing body). This is shown in Figure 1.

Commands are composed of sequences of motions between the targets. Each command has three key points: the target it begins in, the target it ends in and optionally the target it turns in. This creates three classes of command, each of increasing complexity. In the first, the motion starts and ends in the same target without transitioning to another. In the second, it starts in a target, involves a motion to second target and then ends. In the third, it starts in one target, involves a motion to a second, a reversal of direction and an additional motion to a third target. These three classes can be seen in Figure 2. A total of 19 commands are available with this system.

4.3 Designing eyes-free output

The system incorporates vibrotactile output to support eyes-free interaction. Two effects are implemented. The first is a simple, brief, click-like sensation on the transition between targets intended to provide awareness of state-changes in the system. The second is a continuous, unobtrusive, low amplitude vibration present on only the central target, allowing it to be unambiguously identified by users. Both

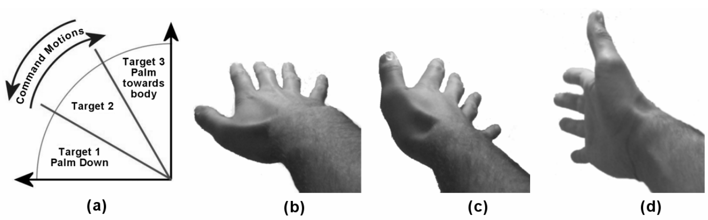

Fig 1. General control scheme for motions *(a)* and the three specific hand/forearm poses used in the system: selecting target 1 *(b)*, target 2 *(c)* and target 3 *(d)*.

vibrations are sinusoidal in form and have a frequency of 250 Hz. The click sensation has a curved amplitude envelope, gradually rising then returning to zero. This two-sample paradigm is adapted from that described by Poupyrev *et al*. [14]. It does not attempt to convey the content of the commands to users, instead focusing on providing rapid feedback which will increase user confidence about the system state.

4.4 Designing eyes-free command structure

The system supports three classes of command, each requiring motions of increasing complexity to reach. It is clearly advantageous to place the most commonly accessed functionality under the simplest commands. The majority of commands are also nested beyond others: a total of 6 commands commence with the wrist held palm down, another 6 start with the palm facing the body and the remaining 7 from the central orientation. Organizing the commands to take advantage of this hierarchical structure is also likely to provide benefits to users; such relationships may aid the learning process. For example, if the system were used to control a personal music player, a common operation like toggling play/stop could be placed on target 1 (palm down). A closely related operation, such as skip to next track, could be activated by the command involving a movement from target 1 to target 2 (central target) and a less frequent operation, such as skip to previous track, could involve a movement from target 1 to target 2 and back again. This is shown in Figure 2.

4.5 Designing graphical learning interface

As with marking menus, WristMenu relies on a graphical interface to enable users to learn its command set. This interface features a continually displayed three item menu bar, which shows the currently selected target and available commands. It is shown in Figure 3. As stroke origin is important, the basic concept relies on a continually displayed three item vertical icon bar. Highlighting indicates which icon is currently active. When a user engages the menu the display changes to show the currently available targets, one of which is already selected. Disengaging the menu immediately results in the activation of this highlighted command. The device can also be rotated until either of the other two commands is highlighted, and then disengaged to perform a selection. As the device is rotated, the icons in the menu change as different

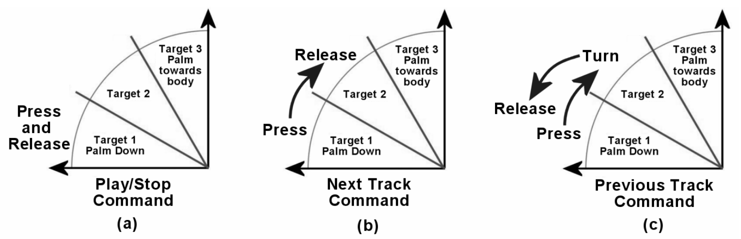

Fig 2. Three WristMenu commands arranged in a hierarchy of motions and intended to control a portable music player. *(a)* shows a command which involves no motions, *(b)* a command which involves a motion to a second target and *(c)* a command with two motions separated by a turn.

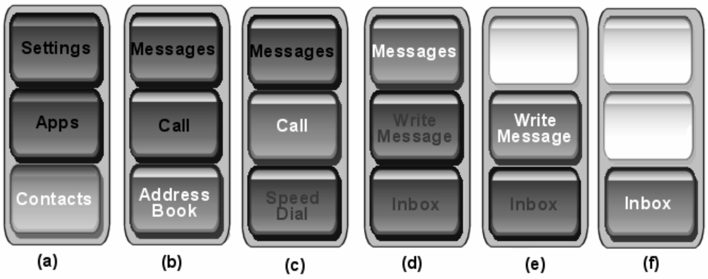

Fig 3. Graphical interface to motion input system. In *(a)* the wrist is held palm down, the "Contacts" command group is selected and the system is not activated. In *(b)* the system is activated and available commands are shown. The user rotates through the central target *(c)* until the palm is facing the body *(d)*, then back through the central target *(e)* until the palm returns to its original position *(f)*. The "Inbox" command can then be activated. Light shading at the top of each command icon shows when the menu is activated, white text the currently active target and blank boxes motions beyond the scope of the system.

commands become available. A user can reverse their direction to select one these newly available commands. We believe this strategy of continually presenting commands options (together with careful design of the command structure) will allow novices to quickly grow used to the system and move towards expert user status.

4.6 Prototype Implementation and Future Development

The WristMenu prototype was developed using an X-Sens MTi motion tracker [25], a matchbox sized sensor pack which includes three accelerometers that monitor lateral accelerations, including the constant 1G downwards due to gravity. By mounting this device on the wrist, and observing changes in the direction of gravity it is possible to infer the orientation of the wrist. WristMenu takes such measurements at 100Hz and uses a 5Hz low pass filter to eliminate sensor noise. A Tactaid VBW32 transducer [19] provides the vibrotactile cues. Both devices are currently attached to a desktop computer; the X-Sens provides its data through a USB connection and the Tactaid receives its signal from the audio out. The graphical interface is also presented on this computer, and commands are initiated and terminated by the press and release of a simple binary handheld switch. The sensor and transducer are shown in Figure 4.

Immediate practical developments to this system will address these deficiencies. Porting to a wireless motion sensing platform such as that described Williamson *et al*

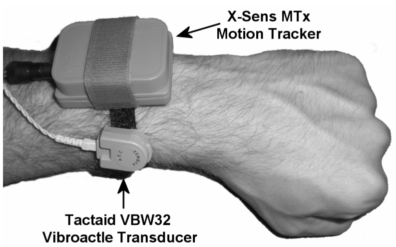

Fig 4. X-Sens MTx and Tactaid VWB32 used to produce WristMenu prototype

[23] (which has an integrated vibrotactile display), or by Cho *et al.* [3] (with an integrated screen) will add true mobility. Given the extreme angles of motion used, flexible displays, which could curve around the wrist affording a clear view of the learning interface irrespective of wrist orientation, are also relevant. Formal evaluations are also an important next step. We are planning a series of evaluations on not only the basic feasibility of the system, but also its learnability, how effectively it can be used eyes free and how it compares with other input techniques. Given the constrained nature of the sensory and attentional resources they must consume, a multi-faceted approach to the evaluation of eyes-free interfaces is imperative.

5 Conclusions

This paper reviews the literature on eyes-free interaction, reflecting first on its origins and scope. It surveys the modalities previously used to build eyes-free systems and the general issues that affect them. It then tenders a working definition for this emerging domain, and a set of design principles. It concludes with a detailed case study of the design of an eyes-free interface for a wearable computing system based on motion input and tactile output.

The spread of computational power to new niches continues apace. As devices diversify, we believe that eyes-free interaction design will become increasingly important. It may become commonplace for certain classes of device to have no visual display, or certain classes of task be performed when our eyes are otherwise engaged. Specialist domains such as wearable computing could already benefit from better eyes-free design. By distilling the available literature into a more palatable form, this paper hopes to move this process forward and provide a set of criteria against which future researchers and system designers can position their work.

Acknowledgements

This work was supported by the IT R&D program of the Korean Ministry of Information and Communications (MIC) and Institute for Information Technology Advancement (IITA) (2005-S-065-03, Development of Wearable Personal Station).

References

1. Brewster, S., Lumsden, J., Bell, M., Hall, M., and Tasker, S. 2003. Multimodal 'eyes-free' interaction techniques for wearable devices. In Proc. of CHI '03. ACM Press, New York, NY.
2. Cheok, A, D., Ganesh Kumar, K. and Prince, S. (2002) Micro-Accelerometer Based Hardware Interfaces for Wearable Computer Mixed Reality Applications. In proceedings of ISWC'2002, IEEE Press.
3. Cho, I., Sunwoo, J., Son, Y., Oh, M, Lee, C (2007). Development of a Single 3-axis Accelerometer Sensor Based Wearable Gesture Recognition Band. In Proceedings of Ubiquitous Intelligence and Computing. Hong Kong.

4. Crease, M. C. and Brewster, S. A. 1998. Making progress with sounds: The design and evaluation of an audio progress bar. In Proc. of ICAD 1998. Glasgow, UK.
5. Costanza, E., Inverso, S. A., Allen, R., and Maes, P. 2007. Intimate interfaces in action: assessing the usability and subtlety of emg-based motionless gestures. In Proc. of CHI '07. ACM Press, New York, NY.
6. Gaver W.W. Smith, R.B and O'Shea, T. Effective sounds in complex systems: the ARKOLA simulation. In Proc of CHI'91, ACM Press, New York, NY.
7. Kallio, S., Kela, J., Mäntyjärvi, J., and Plomp, J. 2006. Visualization of hand gestures for pervasive computing environments. In Proceedings of the Working Conference on Advanced Visual interfaces. AVI '06. ACM Press, New York, NY.
8. Kurtenbach, G., Sellen, A. and Buxton, W. An empirical evaluation of some articulatory and cognitive aspects of "marking menus." Human Computer Interaction, 8(1), (1993). 1--23.
9. Oakley, I. & O'Modhrain, S. Tilt to Scroll: Evaluating a Motion Based Vibrotactile Mobile Interface. In Proceedings of World Haptics'05, Pisa, Italy, IEEE Press.
10. Oakley, I. & Park, J., (2007) "The Effect of a Distracter Task on the Recognition of Tactile Icons" in the proceedings of WorldHaptics'07, Tsukuba, Japan, IEEE Press.
11. Oakley, I. and Park, J. 2007. A motion-based marking menu system. In Extended Abstracts of CHI '07. ACM Press, New York, NY.
12. Partridge, K., Chatterjee, S., Sazawal, V., Borriello, G. and Want, R. Tilt-Type: Accelerometer-Supported Text Entry for Very Small Devices. In Proc. of ACM UIST 2002.
13. Pirhonen, A. Brewster, S.A. & Holguin, C. Gestural and Audio Metaphors as a Means of Control for Mobile Devices. In Proceedings of CHI 2002, ACM Press (2002).
14. Poupyrev, I., Maruyama, S. and Rekimoto, J. Ambient touch: designing tactile interfaces for handheld devices. In Proc. of ACM UIST 2002, ACM Press (2002).
15. Rekimoto, J. Gesturewrist and gesturepad: Unobtrusive wearable interaction devices, In Proc of ISWC'01, 2001.
16. Roto, V. and Oulasvirta, A. 2005. Need for non-visual feedback with long response times in mobile HCI. In proceedings of WWW '05. ACM Press, New York, NY.
17. Smyth, T. N. and Kirkpatrick, A. E. 2006. A new approach to haptic augmentation of the GUI. In Proceedings of ICMI '06. ACM Press, New York, NY.
18. Sutcliffe, A. 2000. On the effective use and reuse of HCI knowledge. ACM Trans. Comput.-Hum. Interact. 7, 2 (Jun. 2000), 197-221.
19. Tactaid VBW32. www.tactaid.com/skinstimulator.html.
20. Tan, H.Z., Srinivasan, M.A., Eberman, B., and Cheng, B. Human factors for the design of force-reflecting haptic interfaces. In Proceedings of ASME Dynamic Systems and Control Division. 1994. Chicago, IL, ASME, pp. 353-359
21. Watson, M. and Sanderson, P. 2004. Sonification Supports Eyes-Free Respiratory Monitoring and Task Time-Sharing. Human Factors 46:3 pp 497-517.
22. Wigdor, D., & Balakrishnan, R. (2003). TiltText: Using tilt for text input to mobile phones. In Proc. of ACM UIST 2003, ACM Press (2003).
23. Williamson, J., Murray-Smith, R., and Hughes, S. 2007. Shoogle: excitatory multimodal interaction on mobile devices. In *Proceedings* CHI '07. ACM Press, New York
24. Witt, H., Nicolai, T. and Kenn, H. (2006). Designing a Wearable User Interface for Hands-free Interaction in Maintenance Applications. In Proceedings of IEEE International Conference on Pervasive Computing and Communications. IEEE Press.
25. Xsens Motion Technologies. www.xsens.com.
26. Yin, M. and Zhai, S. (2006). The benefits of augmenting telephone voice menu navigation with visual browsing and search. In Proc. of ACM CHI'06. ACM Press, New York, NY.
27. Zhao, S., Dragicevic, P., Chignell, M., Balakrishnan, R., and Baudisch, P. 2007. Earpod: eyes-free menu selection using touch input and reactive audio feedback. In Proceedings of CHI '07. ACM Press, New York, NY.