InEar BioFeedController: A Headset For Hands-Free And Eyes-Free Interaction With Mobile Devices

Figure 1. The first "InEar BioFeedController" prototype has gold-plated physiological sensors attached to silicon pads.
The associated measuring unit is integrated into a black box with a microcontroller and 9V battery.
A micro-gyroscope is integrated into one of the in-ear cases.

Denys J.C. Matthies
Media Informatics Group
University of Munich (LMU)
Amalienstr. 17
80333 Munich
Germany
matthies@cip.ifi.lmu.de

CHI 2013 Extended Abstracts, April 27–May 2, 2013, Paris, France.
ACM 978-1-4503-1952-2/13/04

Abstract
Nowadays control of a mobile device usually requires the use of a touch screen. In everyday life, while engaged in real world tasks, it is sometimes impossible to control a device with one's hands.
Speech control is the most common solution to tackle this problem, but it is still error prone, uncomfortable and works poorly when ambient noise is present. Alternative control concepts must work in everyday surroundings with significant levels of noise and should not make use of the hands or require visual focus on the device itself. The prototype presented here is an attempt to provide a better solution to such situations: a headset that enables hands-free and eyes-free interaction for incoming phone calls as well as music player control. It enables safe control of the device in mobile situations as it neither requires the user to come to a standstill, nor does it distract his visual focus.

Author Keywords
Mobile devices; mobile computing; physiological interface; headset; touchless; non-contact; gesture & facial expressions; hands busy; eyes-free; hands-free.

ACM Classification Keywords
H.5.m User Interfaces: Input devices and strategies

"Human gestures and human speech are the most intuitive motions which humans use to communicate with each other" [5] p.2 - Recent Developments

This quote summarizes the reasons why there has been such a high amount of work dealing with these types of input: their intuitiveness. The most advertised touchless interaction for mobile devices is speech control, but this solution is not yet sufficient. Even if the method of speech recognition reaches a very high level of accuracy, it still requires a physical touch event and visual focus on the display in order to initialize.

However, there are a few other alternative control concepts for mobile devices. To classify the research prototype it is important to look at existing research, which has been divided into the following categories:

- Gesture Control
- Facial Expression Control
- Thought Control

Introduction

Technical devices such as mobile computers, tablets, smartphones etc. have thoroughly permeated our everyday lives and are the new mass computational platform [2]. These and many other new technologies have been produced to relieve our brains and simplify everyday tasks, but human-computer interfaces are not always comfortable to use. In many cases they only work well in special situations – when standing still, with finger-touchscreen interaction or by requiring heavy visual focus on the device's display.

Hands-busy and on the road situations are fields of application where control can still be described as a problem that is explained in more detail later in the "Use Cases" section. The use of mobile devices such as mobile computers, tablets and smartphones, which are designed to be usable while mobile, is often not feasible in these situations and especially on the road situations, where voice control works poorly or not at all. Alternative control concepts are needed to solve this problem. Regardless of the technology, new solutions for more efficient and easier control of technical devices, which take human factors into consideration, have to be found.

This paper aims to contribute to finding a viable alternative control for mobile devices, which matches the requirements of functionality in mobile situations. After giving an overview of previously completed work, this paper introduces a fully functional prototype called the "InEar BioFeedController," which overcomes the general problem of controlling mobile devices while walking and in hands-busy or hands-lazy situations. Furthermore, it gives an insight into the development of said prototype.

Related Work

Gesture Control refers to control by movement of the fingers, hands, arms or head. Currently, the most commonly used technology in this category is camera tracking. Recent and important publications are: "ShoeSense" from Bailly et al. [1], which enables the user to control frequently executed operations such as answering phone calls, increasing or decreasing volume and switching music tracks through triangle gestures and finger count gestures via a shoe implemented camera. Similar prototypes often use chest- body- and head-mounted cameras for control such as "Imaginary Interfaces" from Gustafson et al. [4], "Gesture Pendant" from Starner et al. [17], "PinchWatch" from Loclair et al. [9], and "SixthSense" from Mistry et al. [15]. For these setups the mobile device does not need to be touched to receive commands and can stay in the pocket, thus it does not require the full attention of the user. However, these projects require hand and arm gestures to be performed in front of the body. In every day usage situations, such as under poor light conditions, when bending over or performing other movements, the gesture recognition could potentially fail. Compared to these concepts, "WristCam" from Vardy at el. [19] enables one-handed control with a wrist-worn camera. Another important development for mobile device input is "FreeDigiter" from Metzger et al. [13] - which allows for the rapid entry of digits using finger gestures, which are read by an infrared proximity sensor attached to a headset that rests over the ear. For example, a music track is played by moving the appropriate number of fingers past the proximity sensor. The primary benefit of a control interface usable in everyday situations must be to create a fully hands-free interaction where the hands are available for other tasks. A logical solution to this problem would be to use facial expression control.

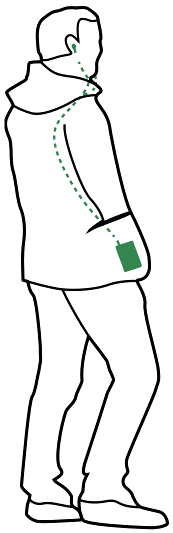

Figure 2. Standard situation when on the street: Wearing headphones (like the "InEar BioFeedController") that are connected to a Smartphone or an MP3 Player. Additional Input Interfaces often hinder the user from performing everyday tasks or are uncomfortable to wear.

Facial Expression Control interprets the movements of the eyes, eyebrows and mouth. Actual examples of this type of control are difficult to find for mobile devices. "Perspective Change" from Hemmert et al. [6] uses conscious eyewinks to switch between screen modes on a mobile computer by closing one eye. However, most interfaces record the movement of the pupil like in "EyePhone" from Miluzzo [14], which offers a partially hands-free interface system capable of driving mobile applications on a Nokia Smartphone by using the focus of the eye for selecting a function and an eyewink to execute them. In this design the device must be held at an appropriate position in front of the user, thus requiring the use of one hand. As it attracts his visual focus, it is also unsuitable for safe operation of the mobile device as a pedestrian involved in the flow of traffic. Other approaches use a head-mounted mobile eye tracker in the form of glasses as presented in "openEyes" from Li et al. [8]. The position of the pupil can also be measured by muscle-states with technology developed in the research field of neuroscience, such as electrooculography (EOG) [3]. These technologies could be used outside of the medical context and be integrated into the everyday lives of healthy people as well.

Thought Control is meant here as the theoretically ideal form of controlling technical devices, as it does not require activation of the human neuromuscular system. This is also called Brain Computer Interfaces (BCI) research. The most widely used technology in this research field is electroencephalography (EEG) [7] as it is inexpensive and does not require any invasive surgery; however, the physical setup takes considerable time. Experiments such as "how to play pinball with a non-invasive BCI" from Tangermann et al. [18] or "MusicMind" from Matthies et al. [12] show how complicated brain wave measurements by classic EEG technology function. This technology is still based upon making a decision between simple states. Additionally, long training phases and heavy classification algorithms are required. For now thought control is still at a laboratory level and far from being efficient to use in real practice. Emotiv[1] developed a new variant of a mobile EEG BCI called "EPOC" [10]. This headset has been used to conduct research on potential implementations such as dialing contacts with a P300 on an iPhone - "NeuroPhone" from Muckerjee [16] or controlling the Apple iOS music player on an iPad - "NeuroPad" from Matthies et al. [11]. These projects using "EPOC" read facial expressions and head gestures rather than thoughts for reasons of reliability in detection. "NeuroPad" shows the first suitable interaction possibility that decently addresses the problem of being operable in mobile situations without distracting the user from real-world tasks. Unfortunately, one large catch still remains: the "EPOC" is impractical due to its bulkiness, poor wear comfort and sensor maintenance. For everyday use, a more suitable interface is required - one that conveys the idea of such an interaction concept.

Prototype

Practical and safe control of a mobile device in mobile situations optimally requires a fully eyes-free and hands-free interaction. A theoretical and technically feasible solution to this problem was sought in related work. As the analysis has revealed, "NeuroPad" is a prototype that already solves most problems. The interaction concept was adapted, developed further and a new and very specific hardware interface was built, which is tailored exactly to the requirement that it must function well in mobile situations, i.e. on the road and without distracting the user from real world tasks.

[1] Emotiv: *http://www.emotiv.com* [accessed on: 23/11/12]

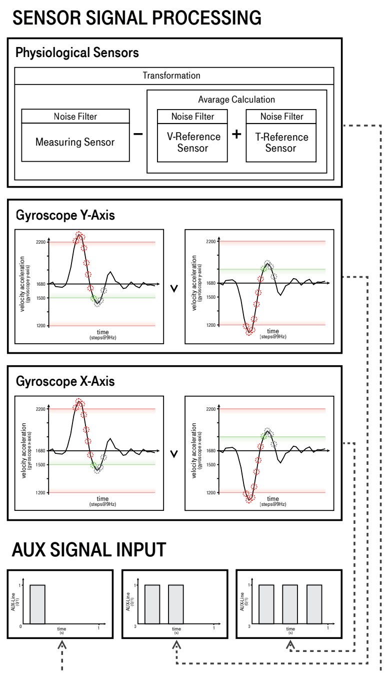

Figure 5. There are two reference sensors and one measuring unit. The raw signal is already noise filtered and preprocessed. A Fast Fourier Transform (FFT) is used, so "muscle artifacts" produced by ear wiggling or eye winking are easily identifiable. The head movement detection is accomplished with a double threshold analysis. If an action is successfully executed, a digital signal is passed through the AUX input to the mobile device (such as an iPhone), which interprets this control signal automatically.

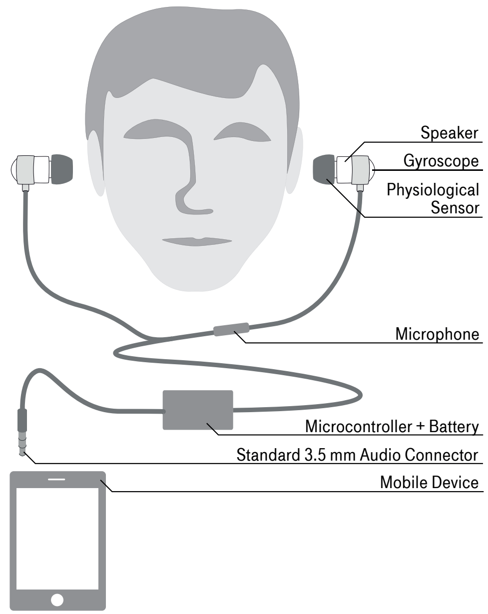

Figure 3. General construction of the InEar BioFeedController.

Implementation

The building of this prototype presented many different problems; it was a technical challenge combining several different technologies - mobile physiological sensors, a gyroscope sensor - and finding a way to make them functional for mobile devices. Head movement detection is accomplished with the gyroscope sensor, which is integrated into the in-ear headphones. This first prototype uses an SMD4 IC: ENC-03RC. The detection of facial muscle activity is accomplished with a physiological sensor, which is commonly used in biofeedback. To wink one's eyes or wiggle one's ears, facial muscles are activated, which in turn generate an electric current in micro-volt range, measurable in the ear canal. This first prototype uses EEG sensors from "NeuroSky[2]," which were originally designed for the measurement of brain waves. Gold-plated electrodes are attached to silicon pads and connected to the associated measuring unit, which is integrated into a black box with an "Arduino" microcontroller and a simple 9V battery, which delivers power for an hour. The output command for controlling functions on the mobile device is sent through a standard 3.5mm audio AUX line. This enables control of the music player and incoming phone calls by head gestures and facial expressions on any mobile device. The decision was made use intuitive head gestures like nodding for "YES" and head shaking for "NO." To avoid misinterpretation of normal movements, both gestures have to be executed in an exaggerated manner - with a weaker follow-up movement in the opposite direction. Rapid head shaking or nodding within a half-second and excessively slow movements over two seconds are ignored. Wiggling ears or winking eyes, allows users to "SKIP" queries. The controllable functionalities include switching music (on/off / next / previous) and answering incoming phone calls (accept / decline / mute).

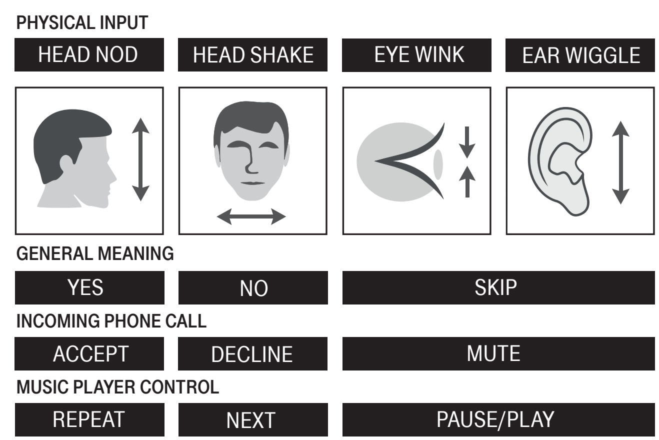

Figure 4. Function assignment.

[2] NeuroSky: *http://www.neurosky.com* [accessed on: 23/11/12]

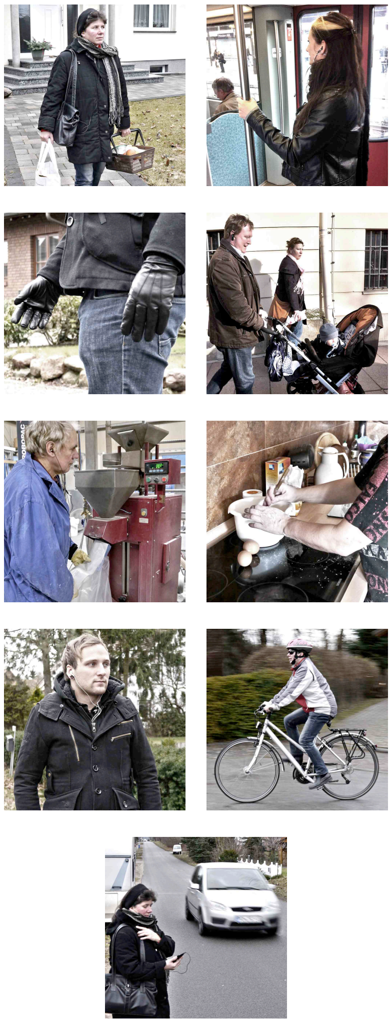

Figure 6. A collection of relevant use cases where the prototype would be beneficial.

Use Cases

The "InEar BioFeedController" can be useful in different scenarios, when operating a music player or smartphone with the hands is not possible: while carrying bags, hanging on in a bus or train, wearing gloves, holding a child's hand, pushing a pram, having full attention devoted to critical working tasks, having unclean hands, doing anything else with one's hands, or if the device is in an in inaccessible location such as a jacket pocket. When involved in traffic on a bike or as pedestrian, mobile devices may create dangerous situations by distracting visual focus. Therefore, having total control requires the user to come to a standstill and commands full attention of eyes and hands. The prototype introduced here is safe for use in traffic, because no tactile or visual contact is required, thus visual attention can remain on the road.

Music Player

The control of a music player, such as the iOS iPod Player, is made eyes- and hand-free through head gestures and facial expressions. Eye winks or ear wiggles play or pause songs, while head shaking skips the current song and a nod repeats it. It is also possible to eavesdrop on nearby conversations through pausing the music with an inconspicuous wink of the eye or an ear wiggle.

Phone Call

Incoming phone calls can be managed while wearing the "InEar BioFeedController." In inconvenient situations - e.g. during a quiet walk in the park or on the way home after a long day - calls can be rejected with a simple headshake. While performing a nodding gesture accepts an incoming phone call. By eye winking or ear wiggling the incoming call will be muted. The ability to identify the caller before answering a call could be obtained with a help of personalized ringtones.

Conclusion

Mobile devices have become an integral part of everyday life as they represent a great benefit to people; however, as mentioned, the control in mobile situations can still be described as a problem. The presented prototype demonstrates a possible solution with completely hands-free and eyes-free interaction. For controlling music or incoming phone calls the mobile device does not require physical touch and no visual focus, so the mobile device can stay in the pocket. This prototype allows free movement and comfortable control with natural head gestures and facial expressions rather than artistic performances. The interaction concept makes use of largely unnoticed operation, which does not disturb others. There is no significant maintenance except battery changes. The use of a gyroscope for detecting head movements is considered reliable, after the user learns the exaggerated nodding and shaking. Due to technical limitations rapid head shaking or nodding within a half-second and excessively slow movements over two seconds cannot be detected. Testing shows that it should be possible to identify mouth, nose, eyebrow movements, as well as ear wiggles and eye winks in the ear canal. Since this prototype does not use a very precise classification algorithm, only the strongest muscle movements are measured: conscious eye winks and ear wiggles. Since the sensors cannot move on their own in the ear canal, there are no ghost triggers, though sometimes the action is just not recognized. The electrical resistance seems to be different on how deep and closely the sensors are in the ear, which also depends on the shape and width of the user's ear canal. A more dynamic calculation and better sensors would remedy this. Due to the standard AUX control signal interpretation, the function assignment of an incoming call is, for now, not exactly as described; instead, to accept a phone call the user has to perform an eye wink or ear wiggle and may decline a call by nodding. Controlling a device in public with facial expressions and head gestures would not be more awkward then seeing people talking to thin air. Since the prototype is still in its early stages, large numbers of user tests have not yet been conducted to completely assess it. For major field studies an improved prototype with a more reliable physiological sensor, such as an electromyography (EMG) sensor, is needed in order to measure muscle movement more precisely.

References

[1] G. Bailly, J. Müller, M. Rohs, D. Wigdor, and S. Kratz. ShoeSense: A New Perspective on Hand Gestures and Wearable Applications. *CHI2012*, 2012.

[2] P. Baudisch. My New PC is a Mobile Phone Techniques and Technology for the New Smallness. *MobileHCI2010*, page 60558, 2010.

[3] A. Bulling, D. Roggen, and G. Troster. Wearable EOG Goggles: Eye- Based Interaction in Everyday Environments. *CHI2009*, pages 3259– 3264, 2009.

[4] S. Gustafson, D. Bierwirth, and P. Baudisch. Imaginary Interfaces: Spatial Interaction with Empty Hands and without Visual Feedback. *UIST'10*, 2010.

[5] T. Hahn. Future Human Computer Interaction with special focus on input and output techniques. *IEEE Trans. On Systems, man and cybernetics*, 2010.

[6] F. Hemmert, D. Djokic, and R. Wettach. Perspective Change: A System for Switching Between On-screen Views by Closing one Eye. *AVI'08*, 2008.

[7] B. J. Lance, S. E. Kerick, a. J. Ries, K. S. Oie, and K. McDowell. Brain- Computer Interface Technologies in the Coming Decades. *IEEE, 100(Special Centennial Issue):1585–1599*, May 2012.

[8] D. Li, J. Babcock, and D. J. Parkhurst. openEyes: a low-cost head- mounted eye-tracking solution. *ETRA 2006, 1(March):27–29*, 2006.

[9] C. Loclair, S. Gustafson, and P. Baudisch. PinchWatch: A Wearable Device for One ahnded Microinteractions. *MobileHCI2010*, 2010.

[10] E. S. P. L. Lori Ann Washbon. Electrode Headset. In Patent No.: US D565,735 S. Patent No.: US D565,735 S, Patent No.: US D565,735 S, 2008.

[11] D. J. C. Matthies, J.-N. Antons, F. Heidmann, R. Wettach, and R. Schleicher. NeuroPad: Use Cases For A Mobile Physiological Interface. *7th NordiCHI*, 2012.

[12] D. J. C. Matthies, M. Gärtner, W. Sengewald. MindArt: Visualizations of real EEG data. *Bernstein Conference BCCN2011 in Freiburg*, 2011.

[13] C. Metzger, M. Anderson, and T. Starner. FreeDigiter: A Contact–free Device for Gesture Control. *Eighth ISWC04*, 2004.

[14] E. Miluzzo, T. Wang, and A. T. Campbell. EyePhone: Activating Mobile Phones With Your Eyes. *MobiHeld2010*, pages 15–20, 2010.

[15] P. Mistry and P. Maes. SixthSense: A Wearable Gestural Interface. *SIGGRAPH Asia*, page 60558, 2009.

[16] M. K. Mukerjee. NeuroPhone: Brain-Mobile Phone Interface using a Wireless EEG Headset Dartmouth Computer Science Technical Report TR2010-666. *ACM SIGCOMM Workshop on Networking, Systems, and Applications on Mobile Handhelds (MobiHeld10)*, 2010.

[17] T. Starner, J. Auxier, D. Ashbrook, and M. Gandy. The gesture pendant: a self-illuminating, wearable, infrared computer vision system for home automation control and medical monitoring. *Digest of Papers. Fourth International Symposium on Wearable Computers*, pages 87–94, 2000.

[18] M. W. Tangermann, M. Krauledat, K. Grzeska, M. Sagebaum, C. Vidaurre, B. Blankertz, and K.-R. Müller. Playing Pinball with non-invasive BCI. *Advances in Neural Information Processing Systems Volume 21*, pp. 1641-1648, pages 1–8, 2009.

[19] A. Vardy, J. Robinson, and L. Cheng. The WristCam as Input Device. *IEEE ISWC '99*, 199-202, 1999.