Towards Thought Control of Next-Generation Wearable Computing Devices

Courtney Powell, Masaharu Munetomo, Martin Schlueter,
and Masataka Mizukoshi

Information Initiative Center, Hokkaido University, Sapporo, Japan
kotoni@ist.hokudai.ac.jp, munetomo@iic.hokudai.ac.jp,
schlueter@midaco-solver.com, m-mizukoshi@ec.hokudai.ac.jp

Abstract. A new wearable computing era featuring devices such as Google Glass, smartwatches, and digital contact lenses is almost upon us, bringing with it usability issues that conventional human computer interaction (HCI) modalities cannot resolve. Brain computer interface (BCI) technology is also rapidly advancing and is now at a point where noninvasive BCIs are being used in games and in healthcare. Thought control of wearable devices is an intriguing vision and would facilitate more intuitive HCI; however, to achieve even a modicum of control BCI currently requires massive processing power that is not available on mobile devices. Cloud computing is a maturing paradigm in which elastic computing power is provided on demand over networks. In this paper, we review the three technologies and take a look at possible ways cloud computing can be harnessed to provide the computational power needed to facilitate practical thought control of next-generation wearable computing devices.

Keywords: Thought controlled computing, Brain computer interface, Mobile cloud computing.

1 Introduction

Wearable computing devices are increasing in popularity due to their unobtrusiveness and their ability to connect to the ubiquitous Internet. A study reported in [1] found that 18 percent of the population of the United States and Britain are already using wearable devices. Thus, interest in wearable devices abounds, from head up displays (HUDs) such as Google Glass *(www.google.com/glass/)* to activity monitors, such as Nike+ FuelBand *(www.nike.com/us/en_us/c/nikeplus-fuelband)* and Fitbit Flex *(http://www.fitbit.com/flex),* to smartwatches such as Pebble *(http://getpebble.com/).*

It is not difficult to understand the popularity of wearable computing devices. The shift from stationary desktop PCs and mainframes to laptops, and eventually tablets and smartphones, enabled individuals to stay connected and work on the go. However, conventional mobile devices still force users to actively adjust their posture in order to utilize them. For example, people have to incline their heads downward in order to utilize laptops, tablets, and smartphones. Some wearable technologies, such as digital contact lenses and HUDs, aim to eliminate this. Further, they are more easily accessible

K. Imamura et al. (Eds.): BHI 2013, LNAI 8211, pp. 427–438, 2013.

than conventional mobile devices, and are already improving lives in a number of ways: improving health and fitness, boosting personal abilities, boosting self-confidence, facilitating self-reliance, providing infotainment, and even enhancing love lives [1]. Google Glass is even being utilized as a tool during surgical procedures [51].

The nature of next-generation wearable devices means that the usability issues faced by conventional devices will become acute. Inputting information into devices such as smartphones and tablets is difficult and time-consuming due to their small form factors. With devices such as Google Glass and smartwatches, manipulation is even more difficult. Furthermore, even voice commands will not suffice as concerns about the ability of the devices to act upon commands issued by nearby persons exist [3]. In addition, many people would rather not talk to their devices at all [4, 5]. Further, for voice commands, noisy areas pose a problem. Thus, another human computer interaction (HCI) challenge of wearable devices is physical interactivity in the face of social acceptance. The use of subtle expressions and micro-gestures [50] and related HCI devices such as Thalmic's Myo *(www.thalmic.com/)* is interesting. However, it is even being argued that gestural interaction is too unnatural [6].

With even more miniature devices, such as digital contact lenses [7] to come, compatible HCI modalities will become even more critical. Thus, thought control of wearable devices is inevitable, propelled by this need for convenient, compatible, and intuitive HCI modalities [8]. However, to be practical it requires vast amounts of computational power, which is not available on the devices themselves. In this paper, we give an overview of three technologies—wearable computing, thought controlled computing, and cloud computing—and look at the feasibility of synergistically combining them to achieve thought control of next-generation wearable devices.

The remainder of this paper is organized as follows. Section 2 looks at the next-generation wearable devices that will require the most complex input methods. Section 3 gives an overview of the brain computer interface (BCI) process, and presents three of the more popular noninvasive BCI devices. Section 4 presents three selected BCI case studies that demonstrate that thought control of devices is feasible. Section 5 looks at mobile cloud computing architectures that may be modified to facilitate real-time access and utilization of clouds. Section 6 discusses trends and developments that will accelerate realization of practical thought controlled computing. Finally, Section 7 concludes this paper.

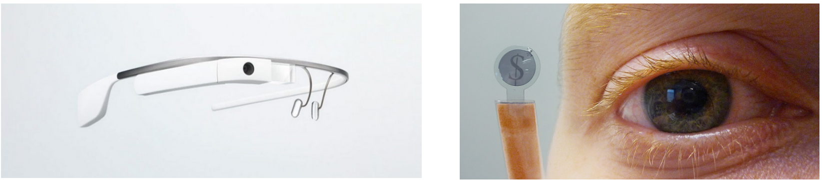
2 Next-Generation Wearable Technology

In this paper, our focus is on wearable technology such as HUDs, smartwatches, and digital contact lenses, which will require various commands to realize maximal utilization. Thus, in this section we look at Google Glass, smartwatches in general, and digital contact lenses.

Google Glass. Google Glass (Fig. 1(a)) is an augmented reality, Internet-connected computer comprising an optical head-mounted display, a camera, touchpad, battery, and microphone built into spectacle frames. It is designed to overlay useful information in the user's vision without obstructing his/her view, and facilitates the taking of pictures, recording of HD video, web search and browsing, and translation on the go [9]. Interaction with the device is accomplished by swiping a touchpad and issuing voice commands into a microphone on one arm of the frame.

Smartwatches. Intelligent watches have been around for a while, but continued miniaturization, advanced connectivity, and touchscreens have paved the way for watches that can compete with smartphones. Like smartphones, smartwatches provide live access to certain kinds of information and intelligent features; in addition, some are even app-based [10]. The same interaction modalities being used with smartphones and Google Glass (i.e., voice and gesture controls) is also being contemplated for smartwatches [11]. Oney et al. [12] have even proposed a diminutive QWERTY soft keyboard that uses iterative zooming to enter text on ultra-small devices, such as smartwatches, called ZoomBoard. However, the method is viewed as inferior to Morse code and graffiti by some people [13].

Digital Contact Lenses. Digital contact lenses are moving from the realm of Science Fiction to present-day reality. Parviz [14] has an advanced conceptual prototype and states that he has successfully tested a number of prototypes on animals. It has also been reported that a team from Washington University, USA have completed prototype trials in which by putting nanometer thin layers of metal along with light emitting diodes (LED) that measure one third of a millimeter across onto contacts, they could let a user read his or her emails, without the aid of a handheld device [7]. More recently, researchers at Ghent University Centre, Belgium developed a prototype lens with an embedded, spherical curved LCD that can show simple patterns (Fig. 1(b)) [15]. Further, the recent prototyping of a practical telescopic contact lens by Tremblay et al. [16] indicates that this type of technology is not a pipe dream. Thus, suitable means of interacting with it are essential.



(a) (b)

Fig. 1. (a) Google Glass, (b) Text message contact lens (Source: [15])

3 Brain Computer Interface (BCI) Technology

3.1 Stages in the Typical BCI Process

In this paper, we propose the use of thought as a means of interacting with the foregoing devices. Thoughts are accessed via brain computer interfaces (BCIs), which gather information from brain signals and translate it into tractable electrical signals. They are regarded as artificial intelligence systems as they can recognize a certain set of patterns in brain signals following five consecutive stages: signal acquisition, preprocessing or signal enhancement, feature extraction, classification, and control interfacing [17].

Signal Acquisition and Preprocessing. In this stage, brain signals are captured and noise reduction and artifact processing may be carried out. Most current BCIs obtain the relevant information from brain activity through electroencephalography (EEG), owing to its high temporal resolution, relative low cost, high portability, few risks to the users, and the fact that the signals are easily recorded in a noninvasive manner through electrodes placed on the scalp. However, the EEG signals in the electrodes are weak, hard to acquire, and of poor quality. This technique is moreover severely affected by background noise generated either inside the brain or externally over the scalp [18]. EEG comprises a set of signals that are classified according to their frequency bands as delta (δ), theta (θ), alpha (α), beta (β), and gamma (γ). In this paper, the frequency bands of interest are alpha, beta, and gamma.

Alpha rhythms lie within the 8 to 12 Hz range and primarily reflect visual processing in the brain. Their amplitude increases when the eyes close and the body relaxes, and attenuates when the eyes open and mental effort is made. Beta rhythms lie within the 12 to 30 Hz range and are associated with motor activities. They are desynchronized during real movement or motor imagery and are characterized by their symmetrical distribution when there is no motor activity. Gamma rhythms lie in the 30 to 100 Hz range, and are related to certain motor functions or perceptions. They may also be associated with motor activities during maximal muscle contraction [18].

Feature Extraction. In this stage, signal properties are analyzed and features of interest that encode user's intent isolated. BCIs extract features that reflect similarities to a certain class, as well as differences from the rest of the classes, from brain signals. This stage is challenging for the following reasons: 1) Brain signals are mixed with other signals coming from a finite set of brain activities that overlap in both time and space; 2) Signals are not usually stationary and may also be distorted by electromyography (EMG) and electrooculography (EOG) artifacts. The feature vector must also be of a low dimension, in order to reduce feature extraction stage complexity, but without relevant information being discarded [18].

Classification. The aim in this stage is to recognize a user's intentions on the basis of a feature vector that characterizes the brain activity provided by the feature step. Either regression or classification algorithms can be used to achieve this goal, but using classification algorithms is currently the most popular approach [24]. The classifier maps input signals to classes in which each class corresponds to a control command.

Control Interfacing. The control interfacing stage translates the classified signals into meaningful commands for any connected device. Among the brain signals that have been decoded such that people can consciously modulate them are visual evoked potentials *(VEPs),* slow cortical potentials *(SCPs)*, P300 evoked potentials, and sensorimotor rhythms [18].

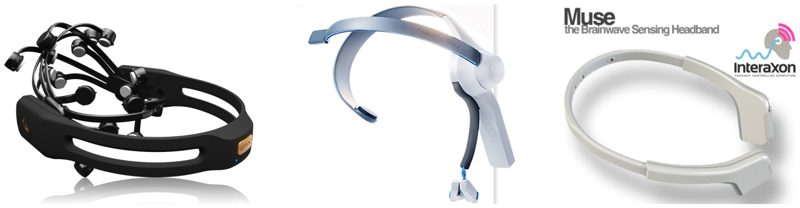
VEPs are modulations that occur after a visual stimulus is received, and are relatively easy to detect as they have large amplitudes. They are classified according to frequency as transient VEPs (TVEPs), which occur in reaction to visual stimuli frequencies below 6 Hz, or steady-state VEPs (SSVEPs), which occur in reaction to visual stimuli at higher frequencies. TVEPs are not typically used for BCIs. SSVEP-based BCIs allow users to select a target by focusing on it. When the user focuses on the target, the BCI identifies it through SSVEP features analysis. SCPs are slow voltage shifts below 1 Hz in the EEG that last a second to several seconds. They have been harnessed to move cursors and select targets presented on computer screens [19]. P300 evoked potentials are positive peaks in EEG due to infrequent auditory, visual, or somatosensory stimuli. Applications based on P300 evoked potentials can employ both visual and auditory stimuli [20, 21]. Sensorimotor rhythms are related to motor imagery without any actual movement [22]. It is possible to predict human voluntary movements before they occur based on the modulations in sensorimotor rhythms [23], even without the user making any movements at all [18].

Physiological artifacts such as EMG, which arise from electrical activity caused by muscle contractions, and usually have large amplitudes; and EOG, which are produced by blinking and other eye movements [25], can also be used for control in multi-modal systems.

3.2 Noninvasive BCI Consumer Devices

For consumer-oriented thought control of wearable technologies, we propose the use of noninvasive BCI devices. Among the most popular are the Emotive EPOC/EEG *(www.emotiv.com),* the NeuroSky MindWave *(www.neurosky.com),* and the Interaxon Muse *(http://interaxon.ca/muse/).* Another noninvasive BCI device that has great potential, the iBrain *(www.neurovigil.com/ibrain/),* is also being made ready for general consumer use.

Emotive EPOC and Emotiv EEG. The Emotiv EPOC/EEG (Fig. 2(a)) uses sensors to detect a user's thoughts, feelings, and expressions in real time. The Emotiv EPOC is a high resolution, multi-channel, wireless neuroheadset that uses a set of 14 sensors plus two references to tune in to the electric signals produced by the brain. It connects wirelessly to PCs running Windows, Linux, or MAC OS X. The Emotiv EEG has all the benefits of the Emotiv EPOC plus access to raw EEG. An improved, sleeker headset called the Emotiv Insight *(http://emotivinsight.com/),* which is said to be fully optimized to produce robust signals anytime and anywhere, is also being developed.



(a) (b) (c)

Fig. 2. (a) Emotiv EPOC, (b) NeuroSky MindWave, (c) Interaxon Muse

NeuroSky MindWave. The NeuroSky MindWave (Fig. 2(b)) is a lightweight, wireless, research grade EEG headset with passive sensors. It uses EEG from a single sensor to record brainwaves and outputs the data as proprietary algorithms (for focus and relaxation), power spectrum bands for alpha, beta, theta, delta, and gamma distribution, and the raw brainwave (including muscle movement such as blinks).

Interaxon Muse. The Interaxon Muse (Fig. 2(c)) is a lightweight, ergonomic, headband that contains four non-contact EEG sensors built into its loop. When properly worn, the EEG sensors on the front of the band make contact on the forehead, and the reference sensors on the arms rest on the backs of the wearer's ears, providing detailed measurements of specific brain signals and frequencies. Muse measures the wearer's brainwaves in real-time and can send them to a smartphone or tablet to show how well the brain is performing.

4 Selected BCI Case Studies

The potential of thought controlled computing is already being experienced via relatively simple novelties such as Orbit (toy helicopter) [26], subConch (mind control of sound) *(www.subconch.net/)*, Mico (brainwave music player) *(http://micobyneurowear.com/)* [27], and 3D object printing [28], to more serious projects such as BrainDriver *(www.autonomos-labs.de/),* and the "pass-thoughts" brainwave authentication study [29]. In this section, we look at three research efforts that demonstrate the feasibility of BCI for control and its inherent possibilities: Steering a tractor via EMG [30], NeuroPhone [31], and mind control helicopter [32, 33].

Gomez-Gil et al. [30] conducted a study in which they successfully steered a tractor via EMG. They used an Emotiv EPOC to acquire brain signals, which they then sent wirelessly to a laptop computer for processing. The commands interpreted from the signals were then sent to a specially designed controller box that used fuzzy logic technology to power a DC motor and thereby steer the tractor continuously. They used a combination of four muscle movements involving the eyes looking left and right with the mouth open and closed. They found that even though the steering accuracy using the BCI system was a bit lower than that of manual steering and GPS-controlled steering, the difference was not very significant. Consequently, they concluded that such a BCI system was feasible for practical use.

Campbell et al. created NeuroPhone [31], which operates by flashing a sequence of photos from the address book of a user's smartphone while the user observes. When the highlighted picture matches that of the person that the user wishes to dial, a P300 brain potential is elicited and wirelessly transmitted from the user's headset (Emotiv EEG) to the smartphone, which then automatically dials the person highlighted. Campbell et al. found that even though an EMG version of their application, in which they used a wink to trigger the dialing, was more reliable, the P300, or "think-triggered" dialer showed promise. One of the challenges they identified was that "real-time EEG signal processing and classification algorithms are designed for powerful machines, not resource limited mobile phones." For example, a weighted combination of various classifiers, such as that employed by Lotte et al. [24], which is not practical to run on resource-constrained machines, may have improved the accuracy of the system.

Pure mind control of a quadcopter was recently achieved by LaFleur et al. [32, 33]. They demonstrated that it is possible to control a quadcopter in 3D physical space using a noninvasive BCI device. Their control of the quadcopter was precise enough to enable it to navigate through a complex obstacle course (Fig. 3). The quadcopter was controlled by “motor imagination of the hands;” that is, simply by thinking about things like making a fist with the right hand, to move right; and thinking about making fists with both hands, to move up.

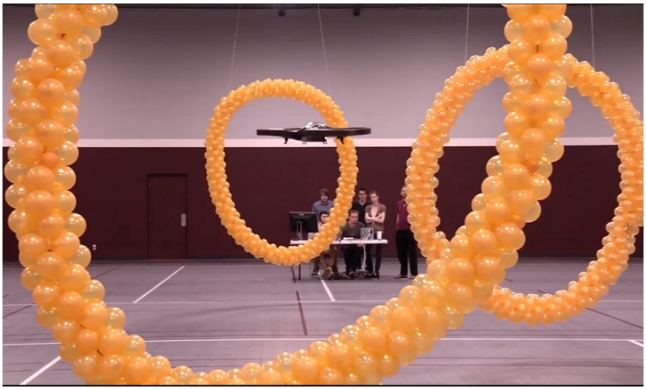


Fig. 3. Mind controlled quadcopter navigating its obstacle course (Source: YouTube screen capture [44])

5 Harnessing the Clouds

Cloud computing is a computing paradigm in which traditional computing power and services are provided over a network. We believe that the essential computational power required to obtain more precise BCI results [31, 36] can be achieved by harnessing the massive on-demand computational resources available via cloud computing. More precisely, we look to cloud-based mobile augmentation (CMA) to satisfy this need because wearable technologies are designed for use on the go. CMA is defined as the leveraging of cloud computing technologies and principles to increase, enhance and optimize the computing capabilities of mobile devices by executing resource-intensive mobile application components in resource-rich cloud-based resources [37]. Consequently, in this section, we look at architectures and models that may be modified to suit our need for real-time mobile cloud computational resources.

The cloudlet architecture proposed by Satyanarayanan et al. [38] is one such architecture. It calls for a “a trusted, resource-rich computer or cluster of computers that are well-connected to the Internet and available for use by nearby mobile devices.” In the architecture, dedicated virtual machines (VMs) are rapidly synthesized in nearby cloudlets for each mobile device, and these synthesized VMs provide access to the actual cloud services. This reduces latency associated with wide area network (WAN) utilization and facilitates real-time services resulting from the cloudlet's physical proximity and one-hop network latency. The architecture has been modified and utilized with promising results for augmented reality [39], and real-time language translation [40]. Further, the results of an analysis of cloudlets conducted by Fesehaye et al. [41] indicate that the cloudlet approach provides superior performance over simple cloud-based approaches for two or less cloudlet hops.

The cyber foraging model [42] may also be utilized. "In this model users can exploit various compute resources called surrogates, which can be used to run the server portion of the distributed applications. Using this model, the smartphone can offload tasks to a user's private compute resources such as laptops, desktops and home servers, or to public resources including clouds and compute clusters." It has been utilized by Kemp et al. in their eyeDentify system [43] for object recognition on a smartphone. They conducted feature extraction and matching on the system and found that it performed better than an identical standalone version. A similar model is employed for multi-party mobile video conferencing in the vSkyConf architecture [45], which is said to have reduced latency and provided a smooth mobile video conferencing experience [45].

Hybrid frameworks such as service-based arbitrated multi-tier infrastructure (SAMI) [48] and MOCHA [49], which aim to provide higher QoS and richer interaction experience to mobile users using a mixture of nearby resources and distant clouds may also be able to satisfy our need for on the go EEG processing. SAMI utilizes a compound three-level infrastructure comprising distant immobile clouds, nearby mobile network operators, and a closer cluster of mobile network operator authorized dealers, while MOCHA integrates nearby cloudlets with distant clouds.

6 Discussion

Although thought controlled computing is in relative infancy, it is advancing very rapidly. It is being assiduously researched by the US Army (which has historically driven technological advances, e.g., the Internet) for "synthetic telepathy," which will enable soldiers in battle to communicate silently [8, 47]. There has even been recent report of the first noninvasive brain-to-brain interface being achieved between a human and an animal [2]. In the arrangement, the human is able to control the movement of a rat's tail simply by thinking the appropriate thoughts. Breakthroughs such as this pave the way for the rapid realization of synthetic telepathy. Thought controlled HCI may in the interim be used as an adjunct to conventional HCI techniques, as postulated by Allison and Kasanoff [46], but it is inevitable. Consequently, it has attracted the attention of consumer electronics companies such as Samsung [52].

Perhaps the single most important event that will exponentially accelerate developments in thought controlled computing is the recently commissioned Brain Research through Advancing Innovative Neurotechnologies (BRAIN) initiative *(www.nih.gov/science/brain/)* in the USA. Launched April 2, 2013, the objective of the initiative is to map the activity of every neuron in the human brain within 10 years. Looking at this initiative through the prism of its precursor, the highly successful Human Genome Project [34], which resulted in profound understanding of genes and medical advances in the diagnosis and treatment of both common and rare diseases [35], a number of spinoffs can be expected within 10 years. We believe that these spinoffs will include clearer signals from the brain for thought control, exponential advances in thought control research, and more compact/smaller BCI devices (that may even be integrated into caps and eyewear [8]).

7 Conclusion

In this paper, we gave a selective review of wearable computing and thought controlled computing, and the challenges they face. We then discussed how a synergistic combination of these two areas with cloud computing can possibly overcome the challenges and enable practical thought control of next-generation wearable computing devices. With the achievements that have already been made using the current technologies and the developments that are underway, which will further exponentially advance BCI technology, we believe that the synergy proposed in this paper can enable practical thought control of next-generation wearable devices in the immediate future. We plan to actualize this synergy in future work.

Acknowledgements. This work is supported in part by the CSI fund, National Institute of Informatics, Japan and the Information Initiative Center, Hokkaido University, Sapporo, JAPAN.

References

1. RackSpace WhitePaper, The human cloud: Wearable technology from novelty to productivity (June 2013), `http://www.rackspace.co.uk/fileadmin/uploads/involve/user_all/The_Human_Cloud_-_June_2013.pdf`
2. Yoo, S.-S., Kim, H., Filandrianos, E., Taghados, S.J., Park, S.: Non-invasive brain-to-brain interface (BBI): Establishing functional links between two brains. PLoS ONE 8(4), e60410 (2013), doi:10.1371/journal.pone.0060410
3. Dickey, M.R.: Google Glass is awesome but no one's going to use it (May 2, 2013), `http://www.businessinsider.com/what-its-like-using-google-glass-2013-5#ixzz2SBoEe5mJ`
4. Stokes, O.: Wearable technology: A vision for the future (May 31, 2013), `http://www.telegraph.co.uk/technology/news/10091565/Wearable-technology-a-vision-for-the-future.html`
5. Blodget, H.: Sorry, Google, no one wants to talk to their glasses (May 6, 2013), `http://www.businessinsider.com/sorry-google-no-one-wants-to-talk-to-their-glasses-2013-5#ixzz2SfC3SEMF`
6. Pavlus, J.: Your body does not want to be an interface (April 24, 2013), `http://www.technologyreview.com/view/514136/your-body-does-not-want-to-be-an-interface/`

7. Wiegmann, P.: Digital contact lenses become reality! (November 23, 2011), `http://www.mymodernmet.com/profiles/blogs/digital-contact-lenses-become-reality`
8. Berleant, D.: The human race to the future: What could happen—and what to do, 1st edn. CreateSpace Independent Publishing Platform (April 28, 2013)
9. Rivington, J.: Google Glass: What you need to know (June 18, 2013), `http://www.techradar.com/news/video/google-glass-what-you-need-to-know-1078114`
10. Dachis, A.: What can I do with a smartwatch and should I get one? (June 24, 2013), `http://www.gizmodo.com.au/2013/06/what-can-i-do-with-a-smartwatch-and-should-i-get-one/`
11. Gayomali, C.: Five features every new smartwatch should have (March 22, 2013), `http://theweek.com/article/index/241794/5-features-every-newnbspsmartwatch-should-have`
12. Oney, S., Harrison, C., Ogan, A., Wiese, J.: ZoomBoard: A diminutive QWERTY soft keyboard using iterative zooming for ultra-small devices. In: Proc. 31st Annual SIGCHI Conference on Human Factors in Computing Systems, CHI 2013, Paris, France, April 27-May 2, pp. 2799–2802. ACM, New York (2013)
13. Coxworth, B.: ZoomBoard allows for easier typing on smartwatch screens (April 30, 2013), `http://www.gizmag.com/zoomboard-smartwatch-typing/27332/`
14. Parviz, B.A.: Augmented reality in a contact lens (September 01, 2009), `http://spectrum.ieee.org/biomedical/bionics/augmented-reality-in-a-contact-lens/`
15. Santos, A.: Researchers devise contact lens with built-in LCD (December 10, 2012), `http://www.engadget.com/2012/12/10/researchers-contact-lens-lcd-display/`
16. Tremblay, E.J., Stamenov, I., Beer, R.D., Arianpour, A., Ford, J.E.: Switchable telescopic contact lens. Optics Express 21(13), 15980–15986 (2013), `http://dx.doi.org/10.1364/OE.21.015980`
17. Khalid, M.B., Rao, N.I., Rizwan-i-Haque, I., Munir, S., Tahir, F.: Towards a brain computer interface using wavelet transform with averaged and time segmented adapted wavelets. In: Proc. IC4 2009, Karachi, Sindh, Pakistan, pp. 1–4 (2009)
18. Nicolas-Alonso, L.F., Gomez-Gil, J.: Brain computer interfaces, a review. Sensors 12, 1211–1279 (2012)
19. Hinterberger, T., Schmidt, S., Neumann, N., Mellinger, J., Blankertz, B., Curio, G., Birbaumer, N.: Brain-computer communication and slow cortical potentials. IEEE Trans. Biomed. Eng. 51, 1011–1018 (2004)
20. Furdea, A., Halder, S., Krusienski, D.J., Bross, D., Nijboer, F., Birbaumer, N., Kübler, A.: An auditory oddball (P300) spelling system for brain-computer interfaces. Psychophysiology 46, 617–625 (2009)
21. Mugler, E.M., Ruf, C.A., Halder, S., Bensch, M., Kubler, A.: Design and implementation of a P300-based brain-computer interface for controlling an internet browser. IEEE Trans. Neural Syst. Rehabil. Eng. 18, 599–609 (2010)
22. Pfurtscheller, G., Neuper, C., Flotzinger, D., Pregenzer, M.: EEG-based discrimination between imagination of right and left hand movement. Electroencephalogr. Clin. Neurophysiol. 103, 642–651 (1997)
23. Bai, O., Rathi, V., Lin, P., Huang, D., Battapady, H., Fei, D., Schneider, L., Houdayer, E., Chen, X., Hallett, M.: Prediction of human voluntary movement before it occurs. Clin. Neurophysiol. 122, 364–372 (2011)

24. Lotte, F., Congedo, M., Lécuyer, A., Lamarche, F., Arnaldi, B.: A review of classification algorithms for EEG-based brain-computer interfaces. J. Neural Eng. 4, R1 (2007)
25. Fatourechi, M., Bashashati, A., Ward, R.K., Birch, G.E.: EMG and EOG artifacts in brain computer interface systems: A survey. Clin. Neurophysiol. 118, 480–494 (2007)
26. Webster, G.: Brain-controlled helicopter takes mental concentration to new heights (2012), `http://edition.cnn.com/2012/11/23/tech/orbit-brain-controlled-helicopter`
27. Ikeda, M.: A brainwave music player so nice, Japan made it twice (March 15, 2013), `http://www.startup-dating.com/2013/03/brainwave-music-player`
28. Teo: Chilean team announces first ever physical object created with the mind (May 17, 2013), `http://neurogadget.com/2013/05/17/chilean-team-announces-first-ever-physical-object-created-with-the-mind/7971`
29. Chuang, J., Nguyen, H., Wang, C., Johnson, B.: I think, therefore I am: Usability and security of authentication using brainwaves. In: Proc. Workshop on Usable Security, USEC, vol. 13 (2013)
30. Gomez-Gil, J., San-Jose-Gonzalez, I., Nicolas-Alonso, L.F., Alonso-Garcia, S.: Steering a tractor by means of an EMG-based human-machine interface. Sensors 11(7), 7110–7126 (2011)
31. Campbell, A., Choudhury, T., Hu, S., Lu, H., Mukerjee, M.K., Rabbi, M., Raizada, R.D.: NeuroPhone: Brain-mobile phone interface using a wireless EEG headset. In: Proc. 2nd ACM SIGCOMM Workshop on Networking, Systems, and Applications on Mobile Handhelds, pp. 3–8 (2010)
32. LaFleur, K., Cassady, K., Doud, A., Shades, K., Rogin, E., He, B.: Quadcopter control in three-dimensional space using a noninvasive motor imagery-based brain–computer interface. Journal of Neural Engineering 10(4) (2013)
33. Nordqvist, C.: Helicopter operated by pure mind control. Medical News Today (June 2013), `http://www.medicalnewstoday.com/articles/261528.php` (retrieved)
34. Human Genome Project, `http://www.ornl.gov/sci/techresources/Human_Genome/home.shtml`
35. Human Genome Project produces many benefits (November 17, 2011), `http://www.genome.gov/27549135`
36. Pour, P.A., Gulrez, T., AlZoubi, O., Gargiulo, G., Calvo, R.A.: Brain-computer interface: Next generation thought controlled distributed video game development platform. In: IEEE Symposium on Computational Intelligence and Games, pp. 251–257 (2008)
37. Abolfazli, S., Sanaei, Z., Ahmed, E., Gani, A., Buyya, R.: Cloud-based augmentation for mobile devices: Motivation, taxonomies, and open challenges. arXiv preprint arXiv:1306.4956 (2013)
38. Satyanarayanan, M., Bahl, P., Caceres, R., Davies, N.: The case for VM-based cloudlets in mobile computing. IEEE Pervasive Computing 8(4), 14–23 (2009)
39. Verbelen, T., Simoens, P., De Turck, F., Dhoedt, B.: Cloudlets: Bringing the cloud to the mobile user. In: Proc. 3rd ACM Workshop on Mobile Cloud Computing and Services, pp. 29–36 (2012)
40. Achanta, V.S., Sureshbabu, N.T., Thomas, V., Sahitya, M.L., Rao, S.: Cloudlet-based multi-lingual dictionaries. In: Proc. 3rd International Conference on Services in Emerging Markets, pp. 30–36 (2012)
41. Fesehaye, D., Gao, Y., Nahrstedt, K., Wang, G.: Impact of cloudlets on interactive mobile cloud applications. In: Proc. EDOC, pp. 123–132 (2012)

42. Satyanarayanan, M.: Pervasive computing: Vision and challenges. IEEE Personal Communications 8, 10–17 (2001)
43. Kemp, R., Palmer, N., Kielmann, T., Seinstra, F., Drost, N., Maassen, J., Bal, H.: eyeDentify: Multimedia cyber foraging from a smartphone. In: ISM 2009, pp. 392–399 (2009)
44. Mind Over Mechanics (2013), `http://www.youtube.com/watch?feature=player_embedded&v=rpHy-fUyXYk`
45. Wu, Y., Wu, C., Li, B., Lau, F.: vSkyConf: Cloud-assisted multi-party mobile video conferencing. CoRR abs/1303.6076 (2013)
46. Allison, B., Kasanoff, B.: What can you do with a BCI? (October 1, 2010), `http://nowpossible.com/2010/10/01/bci-applications/`
47. Piore, A.: The army's bold plan to turn soldiers into telepaths (July 20, 2011), `http://discovermagazine.com/2011/apr/15-armys-bold-plan-turn-soldiers-into-telepaths/#.Ud0frT5gZX_`
48. Sanaei, Z., Abolfazli, S., Gani, A., Shiraz, M.: SAMI: Service-based arbitrated multi-tier infrastructure for mobile cloud computing. In: Proc. 1st IEEE International Conference on Communications in China Workshops, ICCC, pp. 14–19 (2012)
49. Soyata, T., Muraleedharan, R., Funai, C., Kwon, M., Heinzelman, W.: Cloud-vision: Real-time face recognition using a mobile-cloudlet-cloud acceleration architecture. In: 2012 IEEE Symposium on Computers and Communications, ISCC, pp. 59–66 (2012)
50. Goodman, A., Righetto, M.: Why the human body will be the next computer interface (March 05, 2013), `http://www.fastcodesign.com/1671960/why-the-human-body-will-be-the-next-computer-interface`
51. Dolan, B.: Frothy times for Google Glass in healthcare (August 1, 2013), `http://mobihealthnews.com/24364/frothy-times-for-google-glass-in-healthcare/`
52. Young, S.: Samsung demos a tablet controlled by your brain (April 19, 2013), `http://www.technologyreview.com/news/513861/samsung-demos-a-tablet-controlled-by-your-brain/?goback=%2Egde_1103077_member_260074341`