

Applications and Issues for Physiological Computing Systems: An Introduction to the Special Issue

STEPHEN FAIRCLOUGH^{1,*}, HUGO PLÁCIDO DA SILVA², HUGO GAMBOA³,
KIEL GILLEADE AND SERGI BERMÚDEZ I BADIA⁴

¹Liverpool John Moores University, Liverpool, UK

²IT – Instituto de Telecomunicações, University of Lisbon, Lisbon, Portugal

³LIBPHYS, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Lisbon, Portugal

⁴Madeira Interactive Technologies Institute, Universidade da Madeira, Funchal, Portugal

*Corresponding author: s.fairclough@ljmu.ac.uk

The prospect of connecting the brain and body to a technological device can elicit a broad range of responses from potential users. Early adopters are thrilled by the possibility of a device that can interface directly to the human nervous system. For the vast majority, interest is tempered by caution, as nascent varieties of physiological computing systems raise as many questions as answers about how we will interact with computers in the future.

It has been argued that physiological computing can enhance the quality of the user experience by creating a symmetrical form of human–computer interaction (Hettinger *et al.*, 2003) where a technological device can both create and access a dynamic representation of the psychological status of the user (Fairclough, 2009). This representation is based upon a biocybernetic loop (Pope *et al.*, 1995) where continuous monitoring of autonomic and neurophysiological signals enables the system to make inferences about the psychological state currently experienced by the user. This type of interaction is symmetrical because the ability of the user to interrogate the operational status of the device is mirrored by the capacity of the device to probe psychological responses from the individual.

The great asset of this technology is the potential to translate dynamic measurements of user context into intelligent forms of interaction where adaptation at the interface is both timely and intuitive from the perspective of the user. Early examples of physiological computing (Scerbo *et al.*, 2003) emphasized the capacity of intelligent adaptation to induce and sustain a desirable state of engagement in the operator during a safety-critical task. This approach has recently been extended to train specific states of attention via exposure to a biocybernetic loop (deBettencourt *et al.*, 2015; Mishra and Gazzaley, 2015). Because physiological data are associated with physical and psychological health, the same closed-loop logic can be applied to the mitigation of negative emotional states, such as

frustration (Kapoor *et al.*, 2007). Interaction with physiological computing systems provides implicit feedback about one's current psychological state via the types of adaptations that occur at the interface. This feedback can be used to inform self-knowledge and facilitate self-regulation, which may have therapeutic benefits for certain clinical groups (Lahiri *et al.*, 2015).

The potential benefits of physiological computing are clear, but at the time of writing, remain largely unrealized. This is understandable as the majority of current research focuses on fundamental issues related to sensor design, signal quality and methods for data analysis and classification (Silva *et al.*, 2014). This emphasis on the means to create physiological computing systems obscures sufficient consideration of the purpose of the technology and implications for user interaction. Like all emerging technologies, the extent to which physiological computing will be embraced by users and designers is a function of the actual (as opposed to potential) enhancement of interactive experience. We must also factor a number of other variables into this equation. Leaving aside the potential complication of peripheral devices, such as wearable sensors, there is the technical challenge of collecting accurate physiological data in the field, such as identifying noise in the signals and removing the influence of artefacts. The requirement of this technology to continuously monitor data from the brain and body also raises a number of issues around data ownership and privacy (Fairclough, 2014). A decision to

endorse physiological computing will represent a trade-off for the user between those benefits that are directly experienced and any potential drawbacks associated with sensor design, signal quality in the field and accuracy of inference, all of which determine the quality of intelligent adaptation at the interface.

Consideration of the user experience begs a number of questions about the utility of this emerging technology, for example: how will augmentation of existing technologies via a physiological computing enhance the user experience? Will the concrete benefits delivered by physiological computing be sufficient to persuade users to accept additional peripherals, such as headsets to monitor electroencephalograph (EEG) activity? Will the level of intelligent adaptation delivered at the interface provide sufficient utility that users will be completely comfortable in a new era of symmetrical human-computer interaction?

The current special issue includes five papers on the topic of physiological computing. Two are concerned with fundamental issues around signal processing and peripherals, while the remaining three describe potential applications. The paper by *Pimentel* and her colleagues describes how electromyography data can be collected to represent motor control and medical assessment. These authors describe an approach for capturing and analysing these data in real time, including the detection and removal of potential artefacts in the data. This work is an example of how techniques for data analysis must perform in real time and in the field in order to service physiological computing applications. In the field of Brain-Computer Interfaces, there are enormous benefits in terms of logistics for the measurement of EEG using dry electrodes and ambulatory headsets, but we know very little about the quality of data from these headsets compared with laboratory apparatus. The work presented by *Nijboer* and her colleagues compares detection of P300 evoked response between two dry electrode headsets compared with apparatus based that utilized traditional 'wet' electrodes. In addition, these authors explore user acceptance of each device and assess the relative merits of each system with respect to both signal quality and user satisfaction.

The original biocybernetic loop was created to ensure that operators remained in a state of engagement and alertness when using system automation. The need for this application has increased as system automation has advanced over the last 25 years. The shift in the role of human controller from operator to monitor creates a number of human factor problems, especially, when the user must suddenly transition from a long period of inactivity to an active control intervention. A study was conducted on this scenario by *Solovey* and her colleagues who measured task performance in conjunction with neurophysiological measures, specifically measures of neurovascular function obtained via functional near-infrared spectroscopy.

Physiological computing systems can also be used to quantify variables that relate to mental health, such as stress or

anxiety. This application was explored by *Tatarisco* and colleagues in the context of a virtual reality therapy that was designed to induce a degree of stress in the patient. These authors applied a fuzzy logic model to measures of autonomic activity to distinguish between different magnitudes of stress reactivity. Work on social interactions has traditionally emphasized overt responses, such as facial expression and body posture. The third application paper by *Chanel* and *Mühl* takes a psychophysiological approach to the measurement of social signals. These authors argue that physiological signals can be used to enhance an understanding of social interaction, both of the individual within the group and intra-group dynamics.

The range of papers appearing in this special issue demonstrates the breadth of research encompassed by physiological computing systems, from the design of hardware to enriching our understanding of social behaviour. Finally, we would like to thank the editorial team at *Interacting with Computers* who provided us with the opportunity to compile this special issue.

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REFERENCES

- deBettencourt, M.T., Cohen, J.D., Lee, R.F., Norman, K.A. and Turk-Browne, N.B. (2015) Closed-loop training of attention with real-time brain imaging. *Nat. Neurosci.*, 18, 470–475.
- Fairclough, S.H. (2009) Fundamentals of physiological computing. *Interact. Comput.*, 21, 133–145.
- Fairclough, S.H. (2014) Physiological data should remain confidential. *Nature*, 505, 263.
- Hettinger, L.J., Branco, P., Encarnaco, L.M. and Bonato, P. (2003) Neuroadaptive technologies: applying neuroergonomics to the design of advanced interfaces. *Theoret. Issues Erg. Sci.*, 4, 220–237.
- Kapoor, A., Burleson, W. and Picard, R.W. (2007) Automatic prediction of frustration. *Int. J. Hum.-Comput. Stud.*, 65, 724–736.
- Lahiri, U., Bekele, E., Dohrmann, E., Warren, Z. and Sarkar, N. (2015) A physiologically informed virtual reality based social communication system for individuals with autism. *J. Autism Dev. Disord.*, 45, 919–931.

- Mishra, J. and Gazzaley, A. (2015) Closed-loop cognition: the next frontier arrives. *Trends Cogn. Sci.*, 19, 242–243.
- Pope, A.T., Bogart, E.H. and Bartolome, D.S. (1995) Biocycbernetic system evaluates indices of operator engagement in automated task. *Biol. Psych.*, 40, 187–195.
- Scerbo, M.W., Freeman, F.G. and Mikulka, P.J. (2003) A brain-based system for adaptive automation. *Theor. Issues Ergon. Sci.*, 4, 200–219.
- Silva, H.P., Fred, A. and Martins, R. (2014) Biosignals for everyone. *Pervasive Comput.*, 13, 64–71.