Human–Computer Interaction Series

Stephen H. Fairclough
Kiel Gilleade *Editors*

# Advances in Physiological Computing

Springer

Human–Computer Interaction Series

Stephen H. Fairclough
Kiel Gilleade *Editors*

# Advances in Physiological Computing

Springer

# Human–Computer Interaction Series



For further volumes:
http://www.springer.com/series/6033

HCI is a multidisciplinary field focused on human aspects of the development of computer technology. As computer-based technology becomes increasingly pervasive—not just in developed countries, but worldwide—the need to take a human-centered approach in the design and development of this technology becomes ever more important. For roughly 30 years now, researchers and practitioners in computational and behavioral sciences have worked to identify theory and practice that influences the direction of these technologies, and this diverse work makes up the field of human–computer interaction. Broadly speaking it includes the study of what technology might be able to do for people and how people might interact with the technology. The HCI series publishes books that advance the science and technology of developing systems which are both effective and satisfying for people in a wide variety of contexts. Titles focus on theoretical perspectives (such as formal approaches drawn from a variety of behavioral sciences), practical approaches (such as the techniques for effectively integrating user needs in system development), and social issues (such as the determinants of utility, usability and acceptability).

Titles published within the Human–Computer Interaction Series are included in Thomson Reuters' Book Citation Index, The DBLP Computer Science Bibliography and The HCI Bibliography.

Stephen H. Fairclough · Kiel Gilleade
Editors

# Advances in Physiological Computing

Springer

*Editors*
Stephen H. Fairclough
Kiel Gilleade
School of Natural Sciences and Psychology
Liverpool John Moores University
Liverpool, Merseyside
UK

ISSN 1571-5035
ISBN 978-1-4471-6391-6 ISBN 978-1-4471-6392-3 (eBook)
DOI 10.1007/978-1-4471-6392-3
Springer London Heidelberg New York Dordrecht

Library of Congress Control Number: 2014934564



Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

# Foreword

> Teleman's physiological and biochemical status was monitored constantly during the mission through a specially tailored system of instruments blended together to form the Physiological Control and Monitoring System (PCMS). At the start of the mission, an intravenous catheter was inserted in the superior vena cava vein through a plug implanted surgically in his shoulder. A glass electrode was brought into intimate contact with his bloodstream at this nearest acceptable point to the heart. Through the electrode a series of minute pulses, set up by an electrochemical reaction with his blood, informed the computer continually of his body status. The computer was programmed to receive inputs directly from various parts of the aircraft's controlling instrumentation that, coupled with the *in vivo* status reports, determined the time and dosage of the drugs he received.
>
> From Joe Poyer's science fiction novel *North Cape* (p. 31).

This collection, "Advances in Physiological Computing," constitutes the most significant milestone thus far on an idea track that stretches back through the vision posed by Allanson and Fairclough's "A research agenda for physiological computing" (2004) and the body of work cited there to the genius of Wiener, Walter, and Ashby. My own leg of this relay was inspired by several whose work is little known, but whose contributions merit commending to present-day workers in this field.

Kenneth Gaarder was one of the three organizers of the 1969 Santa Monica meeting where the new technique of biofeedback was defined and named (Moss 1999), and coauthor of "Clinical biofeedback: A procedural manual" (1967), formatted in the style of Ashby's "Design for a Brain" (1954). Ken was an early mentor who urged this writer to apply control systems theory to the biofeedback enterprise, an entreaty that eventually found expression in empirical investigations of biocybernetic adaptation (Pope et al. 1995).

An important source of inspiration for the adaptive automation system described in the 1995 paper was John Reising's concept of a "symbionic" cockpit system that senses the physiological and mental state of the pilot and responds accordingly (Reising and Moss 1986), a concept that presaged the DARPA Augmented Cognition program. The resulting biocybernetic system at NASA Langley Research Center (LaRC) was the culmination of a series of developments that began with the publication of an agenda for research in pilot mental state assessment (Pope and Bowles 1982). A workshop was sponsored in 1987 (Comstock 1988) to assess the state of the art in "mental state estimation."

A paper (Reising and Moss 1986) published the previous year prior to the workshop had inspired planning at LaRC toward the design of a biocybernetic system applicable to the problem of mental disengagement in automated system operation. Itself inspired by a technology described in a 1969 science fiction novel by Poyer, the paper predicted the "symbionic" cockpit of 2010: "Nevertheless, it is certain that the pilot's 'plant dynamics' will be monitored in real time and that the data will be used to dynamically allocate tasks between the pilot and the electronic crewmember" (Reising and Moss 1986). This cockpit is yet to be realized; nevertheless, today's physiological computing researchers are creating science and technology that will one day enable symbiotic cyborg capabilities.

The immediate inspiration for the work reported in our 1995 paper was the work of a biofeedback research pioneer, Thomas Mulholland, on "Biofeedback as Scientific Method" (1977). Tom, too, imagined that the biofeedback process could be conceptualized with feedback control principles, and went further to show how biofeedback could be adapted to embody a scientific method. It continues to be an ambition of mine to extend Tom's ideas further, mapping more concepts from feedback control theory onto the biocybernetic loop.

One aspect of Tom's approach bears highlighting because it represents an instance of what appears to be a thread of creative shifts in perspective that appear in the physiological computing field. That aspect involved demonstrating that the temporal patterning of alpha activity, in the loop with light stimulation, exhibited the contrasting behavior expected for a feedback control system under positive (deviation amplifying) versus negative (deviation reducing) feedback conditions. This result was taken as evidence of a feedforward path (functional relationship) between light stimulation and alpha production (Mulholland 1977). What has been done here is to make profitable use of an otherwise unwanted phenomenon—system instability under positive feedback. In other words, turning a behavior usually to be avoided into a benefit. Similarly, Fairclough finds a use for "undesirable" positive feedback, suggesting interspersing positive feedback in games with negative feedback to provide periods of skill "stretching" among periods of skill consolidation (Fairclough 2008).

Fairclough argues also that brain–computer interfaces (BCI) are ideally suited to "extraordinary abilities" types of game mechanics because they are "limited in terms of degrees of control, less than 100 % accurate and require specific training"—again turning shortcomings into a "feature" (Fairclough 2008). Likewise, the problem of movement disruption of physiological sensing motivated a new method of modulating one player's game controller using the physiological signals of another, collaborating player who is physically inactive, thus enhancing the social interaction experience of electronic gameplay (Pope and Stephens 2012).

The physiologically modulated videogame concept has evolved from the failure of the closed loop biocybernetic method to achieve its intended purpose as an assessment procedure designed to determine the requirements for operator involvement that promote effective operator awareness states (Pope et al. 1995). Testing with the system revealed that, given enough practice, a subject may learn how to deliberately control automation to the level at which they prefer to work by regulating their EEG, thereby rendering the subject's responses unusable for the method's intended purpose. The assessment procedure then functions as a training protocol in that the subject is rewarded for producing the EEG pattern that reflects an increasing level of engagement by having the automated system share more of the work. If the original flight simulator is replaced with a video game, the system becomes a way to deliver biofeedback training that motivates trainees to participate in and adhere to the training process, transforming a failure into an idea for a new technology. As Gilleade et al. (2005) note, "…if through practice, the player becomes proficient in controlling their natural physiological responses; the awareness of volitional control makes the game become a biofeedback game once again."

The novel character of physiological computing seems to nurture the imagination and foster ingenuity in such ways. It is exhilarating to witness the inventiveness abundant in the physiological computing field and the meaningful application of analysis tools that are being brought to bear on the fascinating challenges of blending physiology with machines. Seeing that exploitation of tools is reminiscent of the experience of discovering in psychology graduate school what all those arcane engineering tools learned in college were actually good for. I expect to witness more examples of conceptual and technological innovation as this field advances, crystallized here by this timely volume. Its editors' writings have already helped me to get my bearings amid the concepts of cybernetics, biofeedback, and biocybernetic adaptation, orienting my perspective on even my own work. I look forward to furthering that educational process with the present volume.

Hampton, VA, December 2013 Alan Pope

## References

Ashby WR (1954) Design for a brain. Wiley, New York

Allanson J, Fairclough SH (2004) A research agenda for physiological computing, Interacting with Computers. 16:857–878

Comstock JR (1988) Mental State Estimation 1987. NASA Conference Publication 2504

Fairclough SH (2008) BCI and physiological computing: similarities, differences and intuitive control, Paper presented at the Workshop on BCI and Computer Games: CHI'08

Gaarder KR, Montgomery PS (1977) Clinical biofeedback: a procedural manual. Williams and Wilkins, Baltimore, pp. 177–191

Gilleade K, Dix A, Allanson J (2005) Affective videogames and modes of affective gaming: assist me, challenge me, emote me. In: Proceedings of Digital Games Research Association (DiGRA) Conference, Vancouver, Canada, June 2005, pp. 16–20

Moss D (ed) (1999) Humanistic and transpersonal psychology: a historical and biographical sourcebook. Greenwood Publishing, Westport, CT, 154–155

Mulholland T (1977) Biofeedback as scientific method. In Schwartz G, Beatty J (eds) Biofeedback: theory and research. Academic Press, New York, 9–28

Pope AT, Bowles RL (1982) A program for assessing pilot mental state in flight simulators. American institute of aeronautics and astronautics paper No. 82–0257, January 1982
Pope AT, Bogart EH, Bartolome DS (1995) Biocybernetic system validates index of operator engagement in automated task. Biol Psychol 40:187–195
Pope AT, Stephens CL (2012) Interpersonal biocybernetics: connecting through social psychophysiology, ICMI 2012, Santa Monica, California, 22–26 October, 2012
Poyer J (1969) North cape. Sphere Books Limited, London
Reising JM, Moss RW (1986) 2010: The symbionic cockpit. Aerospace and electronic systems magazine. IEEE 1(1) pp 24–27, Jan 1986

# Contents

# Contributors

**Daniel Afergan** Tufts University, Medford, MA, USA, e-mail: afergan@cs.tufts.edu

**Esubalew Bekele** Vanderbilt University, 518 Olin hall, 2400 Highland Ave, Nashville, TN 37212, USA, e-mail: bekele@vanderbilt.edu

**Jonas Brönstrup** Team PhyPA, Berlin Institute of Technology, MAR 3-2, 10587 Berlin, Germany, e-mail: jonas.broenstrup@gmail.com

**Andreas Bulling** Perceptual User Interfaces, Max Planck Institute for Informatics, Campus E1.4, 66123 Saarbrücken, Germany, e-mail: bulling@mpi-inf.mpg.de

**Elke Daemen** Philips Research Europe, Eindhoven, The Netherlands

**Gert-Jan de Vries** Philips Research Europe, Eindhoven, The Netherlands

**Chelsea Dobbins** School of Computing and Mathematical Sciences, Liverpool John Moores University, Byrom Street, Liverpool L3 3AF, UK, e-mail: C.M.Dobbins@ljmu.ac.uk

**Stephen H. Fairclough** School of Natural Sciences and Psychology, Liverpool John Moores University, Liverpool, UK, e-mail: s.h.fairclough@ljmu.ac.uk

**Paul Fergus** School of Computing and Mathematical Sciences, Liverpool John Moores University, Byrom Street, Liverpool L3 3AF, UK

**Kiel Gilleade** School of Natural Sciences and Psychology, Liverpool John Moores University, Liverpool, UK, e-mail: gilleade@gmail.com

**Robert J. K. Jacob** Tufts University, Medford, MA, USA, e-mail: jacob@cs.tufts.edu

**Joris Janssen** Philips Research Europe, Eindhoven, The Netherlands

**Alexander J. Karran** School of Natural Science and Psychology, Liverpool John Moores University, Liverpool, UK, e-mail: a.j.karran@ljmu.ac.uk

**Ute Kreplin** School of Natural Science and Psychology, Liverpool John Moores University, Liverpool, UK, e-mail: U.Kreplin@2011.ljmu.ac.uk

**Laurens R. Krol** Team PhyPA, Berlin Institute of Technology, MAR 3-2, 10587 Berlin, Germany, e-mail: lrkrol@mailbox.tu-berlin.de

**Francine Lalooses** Tufts University, Medford, MA, USA, e-mail: francine.lalooses@tufts.edu

**David Llewellyn-Jones** School of Computing and Mathematical Sciences, Liverpool John Moores University, Byrom Street, Liverpool L3 3AF, UK

**Romy Lorenz** Team PhyPA, Berlin Institute of Technology, MAR 3-2, 10587 Berlin, Germany, e-mail: lorenz.romy@googlemail.com

**Päivi Majaranta** School of Information Sciences, University of Tampere, 33014 Tampere, Finland, e-mail: paivi.majaranta@uta.fi

**Madjid Merabti** School of Computing and Mathematical Sciences, Liverpool John Moores University, Byrom Street, Liverpool L3 3AF, UK

**Domen Novak** Sensory-Motor Systems Lab, ETH Zurich, Tannenstrasse 1, 8092 Zurich, Switzerland, e-mail: domen.novak@hest.ethz.ch

**Martin Ouwerkerk** Philips Research Europe, Eindhoven, The Netherlands

**Evan M. Peck** Tufts University, Medford, MA, USA, e-mail: evan.peck@tufts.edu

**Alan T. Pope** NASA Langley Research Center, Hampton, VA 23681, USA, e-mail: alan.t.pope@nasa.gov

**Nilanjan Sarkar** Vanderbilt University, 518 Olin hall, 2400 Highland Ave, Nashville, TN 37212, USA

**Chad L. Stephens** NASA Langley Research Center, Hampton, VA 23681, USA, e-mail: chad.l.stephens@nasa.gov

**William van Beek** Philips Research Europe, Eindhoven, The Netherlands

**Joyce Westerink** Philips Research Europe, Eindhoven, The Netherlands

**Beste F. Yuksel** Tufts University, Medford, MA, USA, e-mail: beste.yuksel@tufts.edu

**Thorsten O. Zander** Team PhyPA, Berlin Institute of Technology, MAR 3-2, 10587 Berlin, Germany, e-mail: tzander@gmail.com

# Introduction

Physiological computing is the term used to describe any technological system where human physiology is directly monitored and transformed into a control input. It represents the logical endpoint of convergence between the human nervous system and its silicon-based counterparts. This category of technology endeavors to render input control as intuitive as a simple volitional act, such as raising one arm or moving forward. The capacity of sensor-based systems to monitor the brain and body yields a dynamic representation of the cognition, emotions, and motivations of the user. Tapping this implicit model of the user extends the adaptive repertoire of technology, creating a dialog between body and computer and shaping the interaction in a generative sense. The act of monitoring via sensor technology inevitably generates data that can be quantified, visualized, inspected, and shared. Users can acquaint themselves with a digital self that provides a quantified perspective on exercise, sleeping patterns, and changes in mood.

The current collection has been developed to provide a broad overview across this emerging area of research. The strong interdisciplinary character of physiological computing research encapsulates significant breadth of knowledge, from neuroscience to engineering. For those of us working in this field, particularly in multidisciplinary teams, one benefit of this research is the potential for psychologists to work alongside computer scientists and engineers on a common problem. But this interdisciplinary approach can create problems as research across the continuum of physiological computing systems, from brain-control interfaces to telemedicine, fractures into system-based communities working on very specific topics. To an extent, this development is both inevitable and necessary. However, research on physiological computing systems, whether the target system is concerned with input control, adaptation, or monitoring, has many more similarities than differences. All systems involve: sensor technology and the measurement of physiology in the field, biomedical signal processing, and classification. These areas are core to most categories in the current volume and almost every active researcher has engaged with this area in order to create new types of interactive experience. One focus of the current collection is to emphasize common ground between the range of physiological computing applications.