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Editors

Advances in Physiological Computing

Springer

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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

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Contents

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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.

We have arranged the collection to reflect a progression from pervasive areas to specific categories of application. Our opening contribution on meaningful interaction is an attempt to engage with one of the least-explored topics in this field—namely the process of inference that arises whenever a user interacts with a physiological computing interface. As stated earlier, there are a number of common concerns across physiological computing systems such as sensor design, signal processing, and classification. These fundamental issues are covered by Novak in the second chapter of this volume on engineering issues.

The next two chapters are both concerned with the use of physiological activity as a form of input control. The prominence of brain–computer interfaces (BCI) has perhaps overshadowed developments in the area of eye tracking as an alternative form of input control. The use of eye tracking as a form of human–computer interaction is an overlooked form of physiological computing and so the chapter by Majaranta and Bulling is a welcome addition to the current volume. These authors provide an introduction to the technologies, research, and issues for eye tracking in a naturalistic environment. The chapter by Zander and colleagues on BCI provides a novel perspective on this category of system. The traditional form of BCI is based upon recognition of an volitional intention (to move the cursor to the left or right) or a stimulus (letter or number) that the user wishes to select. By contrast, Zander and colleagues focus on passive BCI—a form of interaction where the wishes of the user are conveyed implicitly to the system without the need to actively formulate a volitional intention.

It is accurate to say that biofeedback is the grandparent of all physiological computing technology. It was the biofeedback approach that first used technology to create a closed-loop design to teach human participants the necessary skills for autonomic self-regulation. The connection between biofeedback and the biocybernetic loop at the heart of all physiological computing systems is discussed in detail by Pope and colleagues in their chapter. These authors provide an overview of biofeedback as a clinical intervention, which provides the basis for research into adaptive gaming technologies where the act of self-regulation is integrated directly into gameplay for both individuals and groups.

Monitoring brain activity for physiological computing has traditionally been achieved using EEG-based measurement, but there are other available alternatives. Peck and colleagues provide an overview of their work on functional near-infrared spectography (fNIRS) as a means of monitoring mental workload. fNIRS is a technology that is slowly making the transition from a laboratory-based method to an approach that can be used in the field. The monitoring of spontaneous changes in psychological states, such as increased mental workload or anxiety, can be used to inform the adaptation of technology. The net effect of this innovation is for software to adapt in a manner that is both timely and intuitive. This type of "intelligent" adaptation is particularly important for human–robot interaction as there is an increased requirement for robotic systems to demonstrate social awareness from the perspective of their human users. Bekele and Sarkar describe their research on the use of psychophysiological classification to enhance human–

robot interaction; their work includes an intriguing case study involving an interaction between a robot and individuals on the autistic spectrum.

Some of the pioneers of physiological computing performed their original research in the context of affective computing. The development of new application domains has shifted the emphasis from the detection of traditional emotional categories (e.g., happiness, fear, disgust) to those nuanced states that incorporate elements of both emotion and cognition. The chapter by Karran and Kreplin describes a program of research to investigate the detection of interest in the context of cultural heritage. This work is challenging in several respects, the psychological research underpinning the concept of interest is sparse, and the detection of psychophysiological change in response to media presentation creates a lot of noise and relatively little signal. This chapter captures the tension between a desire to explore new application domains and the real-world obstacles to system accuracy and usage. This theme is revisited by Westerlink and her colleagues at Philips Research Europe who describe the creation of a bracelet designed to measure anxiety. This chapter provides an industrial perspective on the development of a physiological computing device. The goal of this device is to provide the user with insight into one's own health and wellbeing and this therapeutic strand of physiological computing is the focus of the final chapter by Dobbins and her colleagues. Monitoring the physiology of an individual on a 24/7 basis will inevitably produce huge amount of data that may be adopted for the creation of digital memories. This is a form of life logging where the pervasiveness of physiological data is exploited and tagged in order to form memory cues, especially for those elderly users who are living with cognitive impairment.

One goal of this collection is to define the field of physiological computing with respect to the breadth of applications involving physiological data. Physiological computing is an exciting area for research because it provides a speculative vision of how we may interact with technology in the future. It also speaks of the increasing convergence between wearable sensors and wearable computing systems. But we have a long way to go, especially as those methods and measures developed under laboratory conditions must be transformed into robust and reliable data to inform working systems in the field. In that sense, this collection provides a perspective on the range and potential of physiological computing as a work-in-progress.

Liverpool, December 2013

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